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Economic and Ecological Restructuring of Land and  
Water Use in Uzbekistan/Khorezm:  
A Pilot Program in Development Research



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**No. 1**

**Economic Restructuring of Land and  
Water Use in the Region Khorezm  
(Uzbekistan)  
(Project Proposal for Phase I)**

by

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**Economic and Ecological Restructuring of Land- and Water Use in the Region Khorezm (Uzbekistan)**Table of Contents

1	Overview	4
2	Project Setting, Structure and the Approach to Interdisciplinarity	6
2.1	Setting of the Project within the Regional Development Context	6
2.2	Dealing with Complex Problems: The Project Strategy	7
2.2.1	The Project Structure	7
2.2.2	Project Progression: The Long-term Strategy	8
3	State of the Art and Research Questions	10
3.1	Overview	10
3.2	The Aral Sea Crisis	10
3.3	Research Cluster: Ecological Landscape Restructuring	12
3.3.1	Land Use Systems (Module A)	12
3.3.1.1	Desertification	12
3.3.1.2	The Landscape Approach	14
3.3.1.2.1	Afforestation Options	15
3.3.1.2.2	Shelterbelts	16
3.3.1.3	Agricultural Production Systems	17
3.3.1.3.1	Crop Production Efficiency	17
3.3.1.3.2	Agriculture in Uzbekistan	17
3.3.1.3.3	The Dominant Role of Cotton	18
3.3.1.3.4	Wheat and Rice	19
3.3.1.3.5	No-Tillage Methods and Mulching	20
3.3.1.3.6	Aquaculture	20
3.3.1.4	Research Demand in Module A	21
3.3.2	Natural Resource Management (Module B)	21
3.3.2.1	Water Management	21
3.3.2.1.1	Water Resources	21
3.3.2.1.2	Irrigation	22
3.3.2.1.3	Groundwater Management	23
3.3.2.1.4	Water Use Efficiency	23
3.3.2.1.5	Conveyance Losses	24
3.3.2.1.6	Farm Water Cycle Modeling	25
3.3.2.2	Reversing Soil Degradation	26
3.3.2.2.1	Soil Degradation	26
3.3.2.2.2	Soil Organic Matter (SOM) and Fertilizers	27
3.3.2.3	Research Demand in Module B	27
3.3.3	Environmental Stress and Drinking Water Supply (Module C)	28
3.3.3.1	Environmental Pollutants and their Mitigation	28
3.3.3.1.1	Salinity	28
3.3.3.1.2	Airborne Salt and Dust Transport from the Aral Sea Bottom	29
3.3.3.1.3	Pesticides	29
3.3.3.2	Drinking Water Supply	30
3.3.3.3	Research Demand in Module C	31
3.3.4	Resource Inventory, GIS and Remote Sensing (Module D)	32
3.3.4.1	Research Demand in Module D	32

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3.4	Research Cluster: Economic Analysis	33
3.4.1	Market and Farm Level Analyses (Module E)	35
3.4.1.1	Economic Research on Transition	35
3.4.1.2	Agriculture in Transition	35
3.4.1.3	Research Demand in Module E	36
3.4.2	Resource Management and Water Pricing (Module F)	36
3.4.2.1	Economics of Water Scarcity	36
3.4.2.2	Economics of Water Problems in Uzbekistan	37
3.4.2.3	Research Demand in Module F	37
3.4.3	Health Economics (Module G)	38
3.4.3.1	Research Demand in Module G	38
3.5	Research Cluster: Legal-Administrative Studies	38
3.5.1	Land Tenancy and Land Use (Module H)	40
3.5.1.1	Land Tenure in Transition	40
3.5.1.2	Research Demand in Module H	41
3.5.2	Water Administration, Distribution and Use (Module I)	41
3.5.2.1	Water Administration in Uzbekistan	41
3.5.2.2	Reform Options in Water Management	42
3.5.2.3	Research Demands in Module I	43
3.5.3	Sales and Profits of Agricultural Products (Module K)	43
3.5.3.1	Research Demand in Module K	43
4	Human Capacity Building	45
5	Scientific Cooperation	46
5.1	The German Remote Sensing Data Center	47
5.2	The Fraunhofer Institute for Atmospheric Research (IFU)	48
5.3	Space Needs	48
6	Time Plan (Schedule of Activities)	49
7	Costs	49
8	Literature	51
9	Tables	62
10	Figures	69

## 1 Overview

The Aral Sea basin has been declared an “ecological disaster area” by international development agencies. The water level of the Aral Sea has fallen by over 18 m since the 1960s, and only 20% of the water volume of this, once the fourth largest lake of the world, remain. This has occurred because river water has been increasingly diverted for use in irrigation. The problems of the Aral Sea region are obvious to date. As the central Asian region experienced a tripling in population over the past 50 years, the central government banked on irrigation-based agriculture to pull the region out of its poverty. The consequences have been an ill-conceived construction spree of poorly built irrigation systems with policies and incentives that encouraged poorly adapted cropping systems and enormous inefficiencies in irrigation water and fertilizer use.

In the former Soviet Union, the region served as the main supplier of cotton, and agriculture in Uzbekistan was therefore almost totally dedicated to cotton production. To accomplish this in a country that is mainly covered by desert, the area under irrigation in the Aral Sea Basin was increased from 2.0 to 7.2 million ha between 1925 and 1985. The losses of river water in the ill-designed and inefficient irrigation systems along the Amu Darya and the Syr Darya, the major tributaries of the Aral Sea, are estimated to cost 40 km<sup>3</sup>/year of the water flow, enough to stabilize the Aral Sea at its present level. Water use per hectare is estimated at 16- 18000 m<sup>3</sup>/ha, double the amount used in other regions on similar crops. In Uzbekistan 0.7 million ha of the cultivated areas under irrigation have soils so sandy that they are actually unsuitable for conventional irrigation. If irrigation were to be withdrawn from that area, about 10-15 km<sup>3</sup> of water could be saved.

Yields of the principal crops (cotton, rice and wheat) are reportedly one-third of what is produced elsewhere with half the amount of water. The irrigation system practiced in the region – ditch/flood irrigation - has drastically increased soil salinity, requiring large amounts of water for soil leaching to ensure crop establishment. This and the long-time monoculture cropping of cotton have led to an exhaustion of soils. The government has tried to counterbalance the consequent reduction in crop productivity with ever-higher inputs of fertilizers and pesticides. With much of the forest gone, frequent heavy storms in the dry Aral Sea bottom – the newly formed Aralkum desert – carry thousands of tons of dusts and salts far away, unobstructed by trees, affecting air quality in the Basin. Pesticides, dusts, and salts accumulating in air and groundwater (from which drinking water is drawn) affect human health severely.

The production system and the administration of land and water have aggravated the problem. The centralized system of the Soviet era still dominates the pattern of land and water use and remains one of the major constraints to environmental improvement. Administrative rigidity hampers an efficient and sustainable use of the natural resources of the region. Measures such as the introduction of incentives to save water or the privatization of small farms are slow to take root in a widely unchallenged, planned economy with fixed quotas for crop production and centrally assigned water. Water is freely provided by the state’s distribution agencies, and the introduction of a water price would be a basic economic measure to improve the situation. Transfer of land from former state owned farms to private users –required by a new Uzbek law - is not compatible with the fact that the state is imposing fixed quotas for agricultural land under cotton cultivation. Legal uncertainty stemming, for example, from undefined exploitation rights and maintenance obligations (e.g. of the irrigation system), is impeding private initiative and investment in new areas of production.

The economic structure in Uzbekistan is also contributing to the impasse. The transition of the Uzbek economy from plan to market has merely started in the 1990s. Agricultural markets, which are of importance for the management of land and water resources throughout the country, are far from functioning efficiently. The large-scale production units, coinciding with the former kolkhozi and sovkhozi, still do not use the production factors land and water based on marginal cost considerations but on the basis of pre-determined production objectives. Because the “central planner” is unable to evaluate the social costs of land and water appropriately, these large-scale production units over-exploit the resources and create diseconomies of scale. Inter-generational considerations are not part of economic decision-making.

Today, international and domestic agencies acknowledge that land and water use patterns must again become sustainable. Only a drastic restructuring of agricultural production in the region would save the 35-42 km<sup>3</sup> of water<sup>per</sup>

year needed to stabilize the Aral Sea surface. Whether this goal can be achieved at all is to be seriously doubted and would at best take decades to accomplish. Therefore recent efforts to develop the region have shifted from saving the Aral Sea at all costs to the urgently needed amelioration of the health, wealth and livelihood of the people living in the Aral Sea Basin (“Water related vision for the Aral Sea basin for 2025”, released by UNESCO in 2000). The identification of alternative land and water use strategies that meet this objective provides the motivation and is the challenge of this inter-disciplinary research project proposed by ZEF.

Effective and sustainable land and water use can only be achieved with the economic and administrative reorganization necessary to carry out the required changes in natural resource management. The aim of the present project is to establish a research program that integrates landscape restructuring in the province of Khorezm, with suggestions for an economic and legal-administrative reorganization, in order to seek optimum human and natural resource efficiencies. The province of Khorezm was chosen because it is an area that has received relatively little international attention in the past. Yet the Khorezm region plays a central role in the water budget of the Amu Darya delta, and it is typical of the agricultural production systems in Uzbekistan, being based mainly on cotton production on irrigated land. **The central idea of the project is to set aside land for ecological purposes while compensating agricultural production loss through more efficient land and water use, based on the introduction of modern and profitable farming enterprise systems and more efficient institutional and legal designs for resource allocation.** The investment to improve the ecological condition of the region should be recovered through the improved quality of water and other health benefits.

During several reconnaissance trips made by ZEF and UNESCO scientists and during a workshop held at ZEF in September 2000, it became clear that in spite of extensive data collections undertaken by Uzbek scientific institutes, the existing databases do not suffice to embark on a pilot project for land restructuring. Data for the region is still widely scattered, unreliable and contradictory, or not easily and publicly available. Therefore, the aim of the present project phase will be to establish, in an “inventory”, a sound basis for the design of the land restructuring concept.

The program, with a projected lifetime of 10 years, is primarily a research project with research results expected to feed into development projects being planned and implemented by the World Bank, ADB and bi-lateral donors. As part of the technology transfer strategy, a close cooperation with the administration of Khorezm oblast is intended. For a partnership on scientific and educational exchange we entered into an agreement with the State University of Urgench (SUU) - the main regional institute for higher education based in the capital of Khorezm. The project infrastructure is to be set up in Urgench, largely on the SUU campus, including the GIS and other laboratories that will serve the project. A computerized database will be established based on existing data as well as on data to be elaborated for the specific purposes of the project. Ecological information related to water and land use will be gathered from experimental plots, set up on the university campus or in selected farms/kolkhoses. Information on economic and legal-administrative issues will also be gathered from field research, based on inventories and interviews. The database will provide the basis for the development of a concept for an effective and sustainable restructuring of the landscape in the Khorezm province, and to outline suggestions for the necessary administrative and legal-administrative reorganization. A stakeholder approach will be used for the design of the pilot project after the first phase (inventory) with farmers and government officials participating in the development of the pilot-farm project activities

Besides the main cooperative link between ZEF and the SUU, close relations with a university (TIAME) and several leading research institutes in Tashkent (e.g. an irrigation institute, a forestry research institute, and a soil institute) have been developed. The University of Nukus, which has much experience in regional GIS & remote sensing activities in cooperation with the DLR (German Space Agency) in Germany, will support the regional GIS center in Urgench. Within Germany, the DLR (GIS), the Fraunhofer Institute for Atmospheric Environmental Research (pesticides and salinity), and several institutes at the University of Bonn (remote sensing, irrigation, and health issues) will participate. An important outcome of this research project will be the education of young local and German M. SC. and Ph.D. students. To that end, a close cooperation between ZEF’s Ph.D. program, the State University Urgench, TIAME and other research institutes in Tashkent has been established. Finally, UNESCO will be a major partner in this project, supporting the capacity building activities and the technical and administrative aspects of the project.

## 2 Project Setting, Structure and the Approach to Interdisciplinarity

### 2.1 Setting of the Project within the Regional Development Context

The present proposal is a re-orientation from (of) the former UNESCO-BMBF Aral Sea Project (“Transform”) and builds on the previous NATO-DLR activities during which a GIS for the Amu Darya delta was developed (Ressl 1999). The Transform project aimed to halt the regional “brain drain” following the collapse of the Soviet Union by providing research funds to scientists working on the Aral Sea problem. The present proposal will not directly address the brain drain issue or the Aral Sea problem. Our approach is rather to provide the ecological, economic and legal-administrative basis for a restructuring of the economic and ecological landscape along the tributaries of the Aral Sea with a strong emphasis on natural resource conservation, human welfare, and human capacity building in the mentioned areas.

The Aral Sea problem gained worldwide attention in the 1990s, when the crisis became public after the initiation of the democratization process in the Soviet Union. Since then, the five Central Asian Republics that take part in the Aral Sea Basin have started to cooperate on the problem, e.g. by the foundation of the Interstate Coordinated Water Commission (ICWC) under the auspices of the International Fund for Saving the Aral Sea (IFAS). The ICWC consists of several organs, among which the Scientific Information Center in Tashkent and the Basin Water Management Authority (BVO) for the Amu Darya in Urgench are the most important for the present proposal (Micklin 1998) (a similar BVO also exists for the Syr Darya, based in Tashkent). IFAS funds regional environmental research programs. Other regional initiatives in which the central Asian states cooperate are the Commission of Sustainable Development (CSD) that is also related to the IFAS, and the Central Asian Economic Community (CAEC) that fosters the economic cooperation between the five central Asian states (Schlüter 1999).

A good overview of the international, supra-regional, bilateral, and national institutions and efforts is given by Schlüter (1999). The international actors are ten different UN organizations, several financial institutions (dominated by World Bank and ADB), and the EU. The latter runs several programs, among which TACIS (Technical Assistance for the Community of Independent States), and supports large projects related to environment and water management in its WARMAP program (Water resources Management and Agricultural production in the Central Asian republics) (AHT (WARMAP) 1999, Micklin 1998, Schlüter 1999). One important international NGO working in the health area is Médecins sans Frontières which maintains offices in Nukus and Muynak. NATO has also been involved in scientific activities in the Aral Sea region since 1993 (Micklin 1998) and has recently approved a proposal to improve the GIS lab at the University of Nukus. Bilateral Activities are maintained by the USA, the Netherlands, and Germany (GTZ, KfW, Konrad-Adenauer-Foundation, Friedrich-Ebert-Foundation, Naturschutzbund, and BMBF).

The Gozkompriroda GRID-Arendal project lists seven Uzbek Programs for Environmental Protection ([www.grida.no/enrin/htmls/uzbek/report/english/m.htm](http://www.grida.no/enrin/htmls/uzbek/report/english/m.htm)), which include programs on climate change, ozone layer protection, biodiversity, combating desertification, Aral Sea, and environmental protection (which includes health issues; access to natural resources; protection of ecosystems). A new Global Environment Facility (GEF) program on biodiversity has also been set up in 2000 ([www.undp.org/gef/portf/bioeur.htm](http://www.undp.org/gef/portf/bioeur.htm)). The GTZ maintains three experimental farms; however, the GTZ activities are mainly related to seed quality improvement and wheat production on the dry Aral Sea bottom. The Asian Development Bank also plays a central role in the development of agriculture, environment, infrastructure, industry and the energy sector in Uzbekistan (ADB 1996, 1997a, b, 1998a, b, 1999).

As late as 1987, the soviet State Commission on the Aral Sea Problem listed the improvement of land and water use in the catchment as a top priority, whereas the increase of the water inflow into the Aral Sea had been given the lowest priority. Concerns about the stabilization of the Aral Sea itself gained in priority as a result of a World Bank study in 1993 (Micklin 1998). This aspect has been dominating the public discussion since. Only in the recently launched “Water related vision for the Aral Sea Basin for the year 2025”, UNESCO has down-graded the goal of stabilizing the Aral Sea water level in favor of the -probably more realistic- goal of improvement of the livelihood for people living in the Aral Sea Basin (UNESCO 2000 a). The vision includes the goals of health improvement, food security, security from environmental disaster (floods and droughts, mudflows, earthquakes), environmental

protection, and economic wealth. The paper also addresses the trade-off between water use for irrigation (in summer) and hydropower generation for heating in winter. The paper proceeds to define target milestones for several ecological, economic and poverty indicators to be achieved by 2025.

The vision 2025 is complemented by a document from the NGO Médecins sans Frontières (MSF 2000) which addresses aspects not enclosed by the vision document, namely the water salinity (and drinking water quality aspects), the regional climate change, air quality (salts and dusts raised from the dry Aral Sea bottom by storms). In view of the sheer size of the problems, the MSF paper advocates a “Marshall plan” for the Aral Sea area. It also addresses the question of scientific exodus from the region, due to scarce funding for scientists.

An efficient land and water use in the “oases”, the combating of salinization of the Aral Sea region, and approaches to agro-phytomelioration are among the declared priorities for the combating of desertification in the Central Asian region in a report of the GTZ liaison office to the UN Secretariat for the Convention to Combat Desertification (UNCCD) (cf. GTZ-CCD 2000).

Very recently, the German government has suggested several topics for cooperation with Central Asian states within the framework of a sub-regional action plan for combating desertification (Ministry for Technical Cooperation on occasion of the UNCCD-COP4 in Bonn; Martius conference notes 14.12.2000), among which an improvement of agricultural water use and a sustainable regional water supply, the control of erosion and salinity, a harmonization of policy and legislation and scientific cooperation ranked first. The project proposed here fully meets these requirements.

Relating to the “Vision 2025”, the present proposal addresses the topics of environmental stability and sustainability, food security, health, and economic growth.

ZEF will address these problems by focusing on the ecological restructuring of the region (oblast) of Khorezm (increasing the areas covered by protective forest, and improving agricultural water use based on crop water demand);

- Including research modules on water salinity and air quality;
- Using a stakeholder approach that will be used for the implementation of project results; after the first phase (inventory) farmers will participate in the design of the on-farm project activities;
- Providing funds for scientific research within the framework of the project, as contract research to Uzbek partner institutions.
- A strong capacity building component in the project, in which the scientific background of the candidates will be improved through exchange (e.g. Doctoral Program at ZEF).

## 2.2 Dealing with Complex Problems: The Project Strategy

### 2.2.1 The Project Structure

In the design phase of this project (2000-2001), all participating researchers had to first obtain a general understanding of the overall problem. Several familiarization visits to Uzbekistan were undertaken. It rapidly emerged that the poverty-degradation nexus of rural areas along the Amu Darya was complex and could not be solved by re-structuring the landscape without adjustments in the economic and administrative spheres. No one element alone, but the whole water and land use system (consisting of the state, the farmers, the condition of resources) inhibits the development of sustainable practices in land and water use. Since “the whole is more than the sum of its parts”, it will not suffice to study one element at a time. During a workshop that brought together both German and Uzbek specialists in many fields, areas of common concern between several involved disciplines were identified. With the identification of the main tasks as well as the areas of common concerns, it was possible to inter-link the different aspects and develop the tasks in relation to the project as a whole. Problem statements were formulated, and the further course of the project was agreed upon.

The project activities are thus divided into 3 research clusters (ecology, economy, and legal-administrative issues, corresponding to the three departments at ZEF), subdivided further into the following ten modules (cf. also Figure 1):

Ecological Landscape Restructuring	Module A: Land Use Systems
	Module B: Natural Resource Management
	Module C: Environmental Stress and Mitigation
	Module D: Resource inventory, GIS & Remote Sensing
Economic Analysis	Module E: Market and Farm Level Analyses
	Module F: Resource Management and Water Pricing
	Module G: Health Economics
Legal Administrative Studies	Module H: Land Tenancy and Land Use
	Module I: Water Administration, Distribution and Use
	Module K: Sales and Profits of Agricultural Products

GIS/remote sensing is located in the first cluster but serves as a service component for the whole program, taking care of the data integration of the whole project.

In order to visualize the interdisciplinary aspect of the project, we arranged the modules into a matrix (Table 1). Within each of the modules, work units or “tasks” were identified that can be carried out as a Ph.D. project, a M.Sc. study, or contract research sub-contracted to Uzbek partner institutes. Some tasks are discipline-immanent, but many tasks can be found at the intersection of two modules in the matrix, reflecting the interdisciplinary nature of the project as a whole. For example, at the intersection A-E we find the tasks that involve the investigations in vegetation science (module A) and the economic market analysis (module E). It may be necessary to add other tasks in the course of the development of this proposal. The matrix was a crucial element in defining the most important interactions between the project modules.

The approach developed at ZEF flexibly integrates multidisciplinary work into an interdisciplinary approach. Intensive disciplinary and interdisciplinary work units with the aim of furthering the state-of-the-art are complemented with workshops, conferences and congresses. The strategy at the same time allows for intensive work in specialized fields and the development of synergy through the frequent exchange of ideas. Multidisciplinary round-table meetings are designed not only to strengthen the feedback from other disciplines, but also to develop new ideas building on synergy effects. Individual members of the project team will then develop these ideas further.

### 2.2.2 Project Progression: The Long-Term Strategy

The proposed project will be implemented in three main phases:

#### **Phase 1: Inventory Phase: Analysis of the Situation and Concept Development**

In the first phase the present situation in Khorezm will be analyzed in depth before elaborating possible restructuring solutions. The constraints to change must be studied in each sector of the society. Each disciplinary group will analyze the important aspects of the problem and the institutional, economic and ecological drivers of the system. Data will be gathered from existing databases, reports and studies, many of them only available as “grey” literature and made available in electronic form to all project participants. Also, where data for the region is lacking, new data sets must be generated tailored to the specific needs of the project by conducting experiments, surveys and interviewing campaigns. Information and databases from other parts of the world will be searched for relevant information as well. The data collected will provide the basis for the development of the pilot-project phase. Scientific results will be published.

Annually, workshops will be held to allow for inter-disciplinary information exchange and adjustment of further activities. At a final conference after 2.5 years, the gathered information as well as newly developed ideas will be evaluated and discussed and the concept for the pilot phase will be elaborated. The first phase is to be accomplished within 3 years (2001-2004).

#### **Phase 2: Re-structuring pilot project**

The individual project clusters will now implement their concepts experimentally on a pilot scale in order to allow for an in-depth analysis of the consequences of their remedial strategies. For the ecology cluster this implies

extensive field research in a pilot scheme implementing restructured land and water use in Khorezm. In the economic and legal-administrative clusters of research, testing will involve the implementation of alternative marketing, administrative and legal schemes on a pilot scale (a kolkhoz, a village or a region) that include the regions studied by the ecological group. Again regular workshops will evaluate the merits and shortcomings of the proposed schemes, identify key problems and suggest adjustments to the proposed strategies. Expected duration: 4 years (2004-2007).

**Phase 3: Implementation**

The results from phase 2 will be compiled into jointly crafted reports and presented in an adequate manner addressing different target groups (e.g., scientists will be approached by the means of an international scientific congress; policy-makers will be presented with reports and asked to participate in hearings, and stake-holders will be offered training and extension services). The modified land use systems will be studied for another 3 years in order to detect flaws and allow for adjustments. The project will identify some development schemes to be supported by multi-lateral or bi-lateral donor agencies where the principle tenets of the project can be implemented on a larger scale, and work with these agencies in transferring the technology developed in the project. Expected duration: 3 years (2007-2009).

### 3 State of the Art and Research Questions

#### 3.1 Overview

The goal of this project is to establish the basis needed for the demonstration of an effective and sustainable restructuring of the landscape in the district of Khorezm, and to outline suggestions for the necessary administrative and legal-administrative re-organization. In the following chapters, the scientific tasks lying ahead are outlined on the basis of our findings and the literature. Background information is given in Chapter 3, State of the Art.

We will first discuss the actual situation of the Aral Sea basin (Figure 2), characterized by the predominance of cotton in agriculture, which has led to the drastic increase of irrigated land in the last century, with the ensuing problems of water waste and shortage, desertification, land and soil degradation and salinization, and environmental degradation. We will then outline the development policy. Based on this analysis, we will identify the technical questions to be addressed in this project, namely, the improvement of the agricultural production systems (Module A: the introduction of protective forest stands and shelterbelts, the introduction of water-saving and soil-protecting cropping systems, and the diversification of the agricultural production system with aquaculture), an improvement of natural resource use (Module B: mainly irrigation water and soil), and studies on the situation of environmental pollution (Module C: salts, dusts and pesticides in soil, water, and air). Besides field studies, the GIS and remote sensing activities (Module D) serve to inventory the natural resource base, but will also help to access the vast data base that will be established.

A solely technical approach to development problems without addressing economic, socio-cultural and legal-administrative questions has produced major setbacks in past international development efforts and may also be a reason for the slow progress made in the Aral Sea Basin. The present proposal, therefore, sets out from the start to evaluate the past and present economic conditions that shape the actual environmental situation in the Aral Sea basin (Modules E, F, and G). A similar effort will be made to address the inconsistencies in administrative regulations and obstacles to their implementation that actually impede durable improvements (Modules H, I, and K).

#### 3.2 The Aral Sea Crisis

The shrinking of the Aral Sea surface - as the most visible and best-known sign of the Aral Sea Crisis - 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 the course of the past 40 years the Aral, formerly the world's fourth largest inland water body with a size of some 68.000 km<sup>2</sup> in 1960 (Micklin & Williams 1996; Ivanov et al. 1996; Table 2) has lost a dramatic 80% of its original water volume and 60% of its surface area (DLR homepage).

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 in 1997; the Aral being a typical example for environmental damage as a result of poorly managed or unsuccessful large-scale projects. Glantz (1998) has defined the Aral Sea problem as a typical example of a "creeping environmental problem" (CEP), i.e. a slow-onset, low-grade, long-term, cumulative environmental change, that evolves slowly, almost imperceptibly, which makes the perception and the onset of counterbalancing action 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").

This catastrophic environmental situation has been brought about by a gigantic irrigation system set up by the former USSR to cultivate monocultures- mainly cotton- and by a disregard for environmental protection needs and the extent of desertification in the sub region. Irrigation has been a traditional feature of agriculture in the Aral Basin, but water withdrawals from the inflowing rivers remained at fairly low levels until the 1960s. The water level and salinity level of the lake remained relatively stable. Then, the irrigated area in Central Asia was increased from 4.5 million ha in 1960 to about 7.0 million ha in 1980 (FAO 1997). It has attained 7.9 million ha in the year 2000 (Matyakubov 2000) and will be further increased. The Government of Kyrgyzstan alone is planning to almost double the present irrigation area to 2.5 million ha (Duyunov 1996); in Turkmenistan there are more than 5 million hectares

of fertile virgin lands considered as suitable for ploughing (Kirsta 1988); and in the region of Khorezm, about 5000 ha are annually added to the irrigated land (Chapter Irrigation; cf. also Figure 3). It is likely that the water demand in Afghanistan and Tajikistan will also increase after a stabilization of the political situation in these countries. These trends will persist because the population in the area is expected to grow from 55 million people now to 72 million in 2025 (WRI 1998).

Without intervention the Aral Sea will drastically decrease in size over the next 15 years (Table 2), and the level of salinity, now at about  $46 \text{ g l}^{-1}$  (DLR homepage), will be about  $100 \text{ g l}^{-1}$ , comparable to that of the Dead Sea in Israel. In 25 years, only some scattered water bodies will remain of the Aral Sea (GEF- Documentation 1998).

The shrinking of the Aral Sea has several drastic consequences for the environment and for the local population (BMBF-funded UNESCO Aral Sea Project, Final reports 1998, Report 2000 b; UNESCO 2000 a; GTZ 2000, Schlüter 1999; IMF- report 1998, EBRD-report 1997, World Bank project documentations 1996, 1998, Libert 1995, Kobori & Glantz 1998; Ressler 1999; Bos 1996; Giese 1998, Micklin 1991, 1998, Micklin & Williams 1996, Létolle & Mainguet 1996; O'Hara et al. 2000, Breckle et al. 2000):

- The dry Aral Sea bed has turned into a 3 million ha area of sandy-loamy sand and salt desert (Aralkum). This has become the chief source for salt drifts and deposits in the region.
- Strong winds or storms (300 out of 365 days) bring sand and salt particles to the Aral Sea basin. Air pollution with annually 100-140 million t dust containing salt and pesticides leads to respiratory and dermatological problems. Anaemic symptoms are shown by 71.5% of fertile women in Khorezm (Eshchanov & Bisalyev 1999). The percentage of health-affected children, over 72%, is also alarming (Karimov et al. 1999). Cases of acute respiratory infections, diarrhea diseases, and tuberculosis abound (MSF homepage).
- More than 30 large salt-dust clouds up to 450 km in diameter were discovered in the Aral basin by satellite photographs in 1975. The impact of salt fallout on agricultural production, however, has to be assessed against a high background level of water borne salinity.
- The whole of Central Asia suffers from erosion of biodiversity. Water resources are wasted through seepage and evaporation, the soils have become halomorphic and the rivers salty, and the rate of salinization and chemical pollution of watercourses in irrigated land is very high. More than 60% of the irrigated areas in Central Asia are salt-affected and have a groundwater level which is above the critical limit of 2 m. Nearly 50% of the salts in soils under these conditions originate from shallow groundwater levels.
- The desiccation of the Aral Sea has led to noticeable changes in the climatic conditions of adjacent areas. The Amu Darya delta belongs to the continental (C2) of the arid climate type in the classification by Lauer & Frankenberg (1988). Due to the shrinking of the Aral Sea the average temperature in July in Muynak increased from  $25.7 \text{ }^{\circ}\text{C}$  to  $28.3 \text{ }^{\circ}\text{C}$  between 1960 and 1985 (Maturatov 1989), and the frost-free period shortened to 170 days in the delta area (Kotlyakov 1991). Nowadays, the first frost sets in 10-12 days earlier compared to the situation before 1960. In the past, the Aral Sea was considered a regulator mitigating cold winds from Siberia and reducing the summer heat. However, it is not sufficiently clear how the changes in the regional climate affect the middle stretch of the Amu Darya River, where the Khorezm is located.
- Large areas of fertile land have been excluded from agricultural use, and now are covered with a thin crust of salt. In the coastal zone, the climatic and hydro geological conditions have deteriorated, and the ecosystems of the deltas formed by the Amu Darya and Syr Darya Rivers have been destroyed.
- The formerly very strong fishery industry has virtually disappeared: In 1960, a total of 43.340 metric tons of fish were caught in the sea, compared to 17.400 t in 1970, and no fish production at all since 1980. The view of fish trawlers lying in the sand has become a well-known visual metaphor of the Aral Sea catastrophe. The situation is aggravated by the poverty generated by the economic transformation process (Bauer et al. 1997, 1998).
- The difficulties in the supply of good quality drinking water will increase. Most people in Khorezm draw their drinking water from wells equipped with hand-pumps, sources that produce water with a very high salt content and a poor bacteriological profile. 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 (Karimov et al. 1999).

Several million rural inhabitants depend on irrigated land today. The primary goal of any development effort must be the improved livelihood of the inhabitants that suffer under the status quo. In the following, we discuss the possibilities for improvement in each of the problem areas outlined above, ending up with specific research questions in every field and topic.

The project will focus on one region to exemplify the problems of the Aral Sea basin. Project activities will be set up in Khorezm, a region located in the Amu Darya delta. The delta, which covers 28.000 km<sup>2</sup>, is located south of the Lake of Aral. Khorezm province, with the capital of Urgench, is located at the lower Amu Darya River and comprises an area of 455.000 ha, of which 173.000 are irrigated. Khorezm province is one of the areas most intensively used for agriculture. The Khorezm oasis is geographically located between 60°- 61° longitude and 41°-42° latitude, at 113-138 m above sea level. The border to the Northeast is formed by the Amu Darya, to the South and Southeast by the Karakum desert (meaning “black sands”), to the East by the desert Kyzylkum (“red sands”), to the West by the alluvial plain at the Tashauz oblast of the Republic of Turkmenistan and to the North by the autonomous Republic of Karakalpakstan that belongs to Uzbekistan. Agriculture around the Khorezm Oasis has been practiced for thousands of years. The surrounding deserts provide new land for irrigation. The Kyzylkum alone has a potential of 1.5 million ha that can be transformed into irrigated agricultural land (Khamraev et al. 1993). In 1993, the population density was 180 inhabitants/ km<sup>2</sup> (Akhmedov & Saidaminova 1995).

The deliberate regional restriction in this project will facilitate a comprehensive description of the agronomic, environmental and socio-economic setting. It is understood that conditions in other areas may deviate to some extent, but similarities within the Aral Sea basin are large enough for being able to draw universally valid conclusions from the project findings.

### 3.3 Research Cluster: Ecological Landscape Restructuring

#### 3.3.1 Land Use Systems (Module A)

The first research module (A) deals with land use. Changes in agricultural land use can be identified as the single most important factor of environmental change in the Aral Sea basin, with all other effects (water and soil degradation and waste, environmental problems) being a consequence of land use change. Research will focus on the possibilities of (re-) introducing trees and forest patches (protective forest stands) in the area, and the improvement of the crop production efficiency using traditional crops of the region (cotton, wheat, rice). These changes in land use and management are intended in the first place to improve the soil conditions and water balance. For a proper assessment of such improvements, the current situation of these natural resources must be assessed. Both aspects will be studied within Module B, Natural Resource Management. Module C covers all aspects related to environmental damage, i.e. the study of dusts, salts and pesticides in air, soil and water. Lastly Module D represents the central axis of the project, the GIS and remote sensing activities, where spectral information and other data are integrated.

##### 3.3.1.1 Desertification

The concept of land degradation in drylands (desertification) has been recently reviewed by Katyal & Vlek (2000). Land degradation sets in (1) when the potential productivity associated with a land use system becomes non-sustainable or (2) when the land fails to perform its environmental self-regulatory function. Therefore, land degradation is mainly anthropogenically induced, e.g. when the carrying capacity is persistently exceeded (Pascual in press), or when improper land use does not match the constraints given by the land's attributes. Land degradation must be considered a social problem (Blaikie & Brookfield 1987). Restorative measures and management can reverse the negative effects of over-exploitation and/or land misuse, but without the capability or authority to invest in such measures, farmers are doomed to exploit their limited resources further (Syers et al. 1996). In Khorezm (as in Uzbekistan as a whole), the small farmers are unable to invest, partly due to economic constraints and partly due to administrative problems (cf. Module G). Land is a public good in Uzbekistan, and its conservation is a declared governmental concern, but solutions must be found to tackle the inefficient approaches in view of Uzbekistan's limited financial resources. Scientific research is needed to be able to provide these solutions.

Degradation manifests itself when soil, water, and biota (vegetation and fauna) – the basic elements of land – are damaged in one or several ways: (1) Soil loses life-sustaining topsoil and some essential nutrients, accumulates

harmful chemicals, or develops physical deformities; (2) water accumulates close to or above the soil surface, leading to salinity; (3) vegetation loses productivity of useful plants due to systematic deforestation or overgrazing, resulting in loss of biodiversity; (4) wildlife and beneficial soil organisms decrease in diversity, biomass or both, resulting in less resilient communities. Of these processes, soil erosion is worldwide the most important (Oldeman et al. 1991). In drylands, erosion accounts for 87% of global soil degradation (900 M ha). Wind erosion is most common in semiarid and arid environments where it accounts for 42% of the erosion (Middleton & Thomas 1997). In the Khorezm, wind erosion predominates, because the land is flat and windbreaks, although present, are rudimentary and are still to be developed in order to become effective. High priority should be accorded to the control of wind erosion in the context of efforts to halt desertification.

Vegetation loss takes place primarily due to overgrazing, deforestation, and unregulated fires, or combinations thereof (Dregne & Chou 1993). Loss of vegetation initiates land degradation, which in turn leads to further deterioration of an area's vegetative cover (cf. Chapter Trees). Among the strategies to combating desertification listed by Katyal & Vlek (2000), the encouragement of afforestation is on the top of the list.

Irrigation-based agriculture in drylands is highly unstable. Kassas (1987) labeled irrigation of drylands "one of the seven paths to desertification". According to Hillel (1982), mismanagement and misuse of irrigation schemes all too often make them self-destructive. The world is losing 1.0 - 1.3 million ha of irrigated lands annually due to the salinization mainly of drylands (Ayoub 1998). UNEP (1991) reported degradation of some 43 million ha of irrigated lands, representing 30% of the 145 million ha of irrigated land in the world's drylands, which are prone to salinity related problems. The Central Asian Republics are a clear example of these phenomena. Preventive steps must be taken soon, otherwise the irrigation-induced rise of salinity in Khorezm will make agriculture increasingly difficult to sustain. Today, as much as 90 % of the land in Khorezm is affected by salinity.

Structured landscapes with varied land uses that provide sustained economic productivity, ecological stability, optimal use of resources, and an overall quality of life should form the core of any strategy to combat desertification (Katyal & Vlek 2000). Integration of arable crops with trees provides an opportunity to harness the potential of the crop while the trees compensate for the reduction in cropped area or yield through products that fulfill the varied needs of the farmers and ecosystem functions. The presence of trees imparts stability to the system and spreads the risk among the annual and perennial components. Even under severe circumstances, trees may survive and provide fodder and fuel (Katyal et al. 1994). Not least, they make the environment more hospitable, providing shadow for men and cattle, pleasing the eye. Measurably, trees make use of off-season rains, can draw down the water table and recycle nutrients from deeper soil layers, and suppress weeds because of their large canopy.

### 3.3.1.2 The Landscape Approach

The natural state of the Khorezm area is that of a semi-desert to desert environment. Were it not for the Amu Darya River, the landscape would have the face of the surrounding Kyzylkum and Karakum deserts. The river, however, which annually floods the surrounding land, has allowed the development and existence of a special floodplain vegetation cover, the Tugai forest (cf. below). By diverting river water into an irrigation system, the early inhabitants of the region managed to turn the landscape into an oasis, a stable, anthropogenic environment based on irrigation. The region has been inhabited for several thousand years ([www.britannica.com](http://www.britannica.com)). Apparently, the historic people managed to avoid the fate experienced by other early civilizations based on ditch/flood irrigation, the heavy siltation and salinization (Hillel 1991) that ultimately led to the decline of Sumer, Babylon, and other historic civilizations. Possibly, the large mineral freight of the Amu Darya (cf. Chapter Soils), continually supplying fresh nutrients, helped to avoid this downward spiral of soil degradation during the first 5000 years of Khorezm's agricultural exploitation.

The land restructuring that took place after the region was chosen to become the principal cotton provider within the Soviet Union was immense. The large extension of irrigated land, the withdrawal of almost all river water for irrigation have ignored the natural limits to exploitation by transforming vast tracts of land into a uniform, monotonous landscape, mainly a cotton monoculture.

In the last decade, ecosystem restoration and management (e.g. Samson & Knopf 1996, Rana 1998, Peine 1999) and the restoration of ecosystem "health" in the temperate ecosystems of the developed world have become objects of scientific study. Functional ecosystems provide benefits which otherwise have to be obtained at a considerable cost. They include protection against wind and water erosion, input of organic residue for the build-up of soil organic matter, retention and filtration of water, and salinity reduction. Designing structurally diverse agroecosystems can provide the same „ecological services“. Forests are an important strategy against desertification (see below; UNEP & GLAVGIDROMET 1999), and preventive efforts are becoming more important in view of future global warming rates that will disproportionately affect the central Asian states (Mitchell & Hulme 2000).

The question thus raised is: How can the Khorezm landscape be re-designed in order to become ecologically sustainable again, allow an efficient use of the limited water and land resources to produce enough for the livelihood of its inhabitants? In our view, an ecological restructuring of the landscape to ensure proper (agro-) ecosystem functioning is urgently needed to halt further desertification. **Thus, the specific objective of this section is to develop concepts for an ecological restructuring of the Khorezm oasis in order to sustain effective agricultural production, diversify the landscape, increase biodiversity and provide a harmonious and healthy environment to live in.**

We will follow two lines of thought, the (re-)introduction of trees into the landscape, which we expect to exert widespread ecological functions, and the sustainable intensification of agricultural production systems, because agriculture is the main land use. This poses two questions:

(1) To what extent can the tree or bush component be brought back into the landscape, and what role can it play in the restoration of the basic ecosystem functions (discussed below) that were lost in the transition to mono-crop agriculture? Our studies will focus on possibilities to enhance tree presence in the landscape: The setting-aside of marginal land (in the sense of agriculturally unproductive) for forestry (establishment of forest islands), and the inclusion of hedgerows and shelterbelts in the agricultural landscape, amidst and around the fields.

(2) How can an intensification and increase of resource use efficiency in agricultural production be achieved? An ecological restructuring could never be imposed on the farmers at the cost of agricultural production in this landscape. Cotton is produced in Khorezm at high level of external inputs, e.g. water, fertilizers and pesticides. However, these costs are not totally accounted for, as for example water is provided free by the state. Irrigation water use per hectare is double the amount used in other regions, e.g. in Turkey where similar edaphic and climatic conditions exist, yet at the same time, the yields of these crops (principally cotton and wheat) are reported to be one-third of what is produced elsewhere. Thus, efficient use of irrigation water in crop production, crop intensification, and fertilizer use efficiency (including organic mulching) are research topics addressed in this part of the project. Minimum tillage (cf. Machado & Silva 2001), and bio-drainage with Alfalfa strips will be studied as contract

research components. Equally, a study of aquaculture in irrigation canal systems will be undertaken. Aquaculture is a way of intensifying the productivity of the irrigated systems while at the same time providing fish as a high-protein food, additional income, and keeping the irrigation channels free of weeds.

#### 3.3.1.2.1 Afforestation Options

In the context of this project, afforestation means that some of Khorezm's agricultural land will be converted into forest. It is understood that taking land out of agriculture will meet resistance on the part of the government as well as the collective farms. However, 90% of irrigated land in Khorezm is affected by salinity, and around 30% are medium and strongly saline soils. Thus, a substantial fraction of land shows only marginal productivity and poor efficiency of other production factors such as water, fertilizer and labor. These resources might be better directed toward the better-endowed land. Afforestation (creation of forest patches) would thus be carried out on the 10 – 20% of the land that is the least productive, restricting tree planting to marginal areas or to field or waterway edges. At the same time, the benefits of the forest functions both ecologically and in terms of health should be made clear to the residents and farmers. Also, the impact on income due to an eventual production loss must be properly compensated, and adequate schemes must be developed together with the Cluster Economy (Module E). Finally, the potential to enhance productivity of the better-endowed land must be demonstrated (Task Crop Intensification).

Shelterbelts will normally be established on fertile, productive land rather than on marginal soils. Thus, other species than those used for afforestation may be used in shelterbelts. The production reduction due to land set aside for the shelterbelts (trees and bushes, planted in strips of up to 5 m wide and which will take some time to become effective) is likely to be compensated for by the crop yield increase attributed to shelterbelts (Onyewotu et al. 1998, PFRA Shelterbelt Centre 1999), but again, this has to be demonstrated for Khorezm.

We expect to be able to demonstrate that the efficiency of the remaining land, water and other inputs can be improved substantially. The land can be used more intensively by inserting a catch crop (a nutrient-conserving crop) between the traditional cotton-wheat rotations. The introduction of minimum tillage and mulching techniques will help to conserve nutrients in the soil and preserve/re-introduce soil life, and prevent soil loss to wind erosion. Further, with a water use efficiency in Khorezm that is somewhere around half the efficiency reached in other countries in comparable climatic regions, considerable savings are to be realized by a more rational use of irrigation water. This, and the water eventually saved by not cultivating the marginal areas can be used for flushing salts from some of the most salt affected soils (and, eventually, to feed the Aral sea). The overall reduction in water use would also reduce the high water table. More intensive land use and more efficient use of inputs should also lead to higher productivity, making farming more profitable and afforestation affordable.

Agroforestry and arid zone forestry have been widely promoted in the last decade. Agroforestry landscapes represent complex systems that alter the ecological conditions of a whole region, improving microclimate and hydrological regulation and increasing soil formation processes (Pawłowski 1988). The manifold benefits of trees in landscape ecology include ecological functions related to their effects on wind, water, and soils. Forest systems contribute to landscape biodiversity. They have effects on adjacent land, e.g. field surrounded by forest patches or strips, where they improve microclimate, provide an input of plant residues (organic matter), and increase crop yield (Manyong et al. 2000). Large-scale changes in vegetation cover can have considerable effects on regional climate. Not least, forest products can yield an important additional income to rural population (Arnold & Townson 1998). They provide shade to humans and to cattle, and improve livelihood and the quality of life. All these effects are well documented (Huxley 1999, Young 1997, Baumer 1990, Raussen 1990, FAO 1989, Keswani & Ndunguru 1982). Structured landscapes with varied land uses that provide sustained economic productivity, ecological stability, optimal use of resources, and an overall quality of life should form the core of any strategy to combat desertification (Katyal & Vlek 2000).

In semi-arid and arid regions, forests occur only under two circumstances: (1), naturally, in floodplains along riverbeds, and (2), in irrigated landscapes. Natural floodplain forests in the lower Amu Darya River are the Tugai forests (Treshkin et al. 1998) that, in different formations, cover 120.000 ha in all Central Asia (a similar areas to the floodplain forests of Amazonia). They consist of tree species tolerant of high soil moisture and salinity and able to live under the low air humidity conditions of the desert (Treshkin et al. 1998). Typical plants include floodplain tree

species such as *Populus* and *Salix*, but also salt-tolerant grasses (that have the potential to be used for phytomeliorative purposes (Bachiev, Treshkin & Kuzmina 1994). Tugai forests cannot survive without being flooded once every one or two years. With the absence of such natural floods due to the reduced water flow in the Amu Darya, the area of these forests has drastically diminished from over 350.000 ha in the beginning of the century to 22.000 ha in the 1990s, and all the remaining forest patches apparently have been degraded, as the tree productivity decreased by about 25% from 1960 to 1995 (Treshkin et al. 1998).

All forest stands in the irrigated areas are planted; they are thought to occupy not more than 3% of the landscape in Khorezm. Poplar (*Populus ariana*) and, occasionally, Pine (*Pinus* sp). are planted for the production of wood for construction and handicraft purposes. Khorezm is additionally characterized by many hedgerows that have only recently been planted among the fields, mainly as windbreaks, but also for other purposes (e.g. mulberry trees for silk production). However, these plantings are not based on a scientifically sound planning (Botman pers. comm.).

Although some tree species such as poplar have been grown for centuries in Khorezm, the establishment of forests is a relatively new experience in Khorezm. The region lacks a forestry research program. For species to be established, growth, survival and production conditions must be first determined, i.e. a thorough screening of suitable local and imported species must be undertaken, in order to be able to recommend species adapted to every site (soil, water conditions) and predominant purpose e.g. (bio-drainage, windbreak, forest products or other) and adapted to the harsh environment. The benefits of different approaches must also be comparatively assessed.

One particular constraint to the evaluation of different options is uncertainty as to the legal situation. Some information from Uzbekistan suggests that no more than 3% of all irrigated, agricultural land can be planted to forest by law. However, it will be essential to analyze the relevant provisions, in order to discover where regulatory, administrative and judicial competence is situated. This includes clarification whether the pertinent norms are national legislation or administrative decrees, whether they apply regionally or nationally, and what sanctions the law stipulates in case of infringement. The intended increase of forests on up to 20% of the land, based on the apparently weak productivity of these marginal soils, will conflict with this and a legal solution must be sought (link to Module H).

A third aspect to be covered is the question of the utilization rights of forests and their products. The land is actually common good but is becoming increasingly privately owned. The trees and forests on it can belong to either the owner of the land or the person that planted the trees (for a similar problem in China in the fifties cf. Wu & Shepherd 2000).

#### 3.3.1.2.2 Shelterbelts

The ameliorative effects of forest shelterbelts have been extensively studied (Kayimov 1993). The average increases in crop yield on the adjacent agricultural land of 10% given by Dolgilevitch (1983) and Moshaev (1988) can reach 20% under optimal structure and after the shelterbelt trees have reached their final height (Vinogradov 1988). A woody biomass of 20-60t ha<sup>-1</sup> was determined by Kayimov (1993), but annual tree production varies widely. In the Fergana valley, 25-26 year old poplar trees reach a total biomass of 1.0-1.3 t per tree ; elm 0.5-0.8 t per tree ; and for ash and maple 0.2 t per tree, values that can be used to calculate annual stand production (Kayimov 1993). Grasses and understorey wood annually produce 0.15-2.5 t ha<sup>-1</sup> in such shelterbelts (Chawronin et al. 1986). Architecture, structure and species composition of the forest shelterbelts in the region are extensively discussed in Kayimov (1986, 1987), Kayimov et al. (1990), Moltshanova (1982), and Moltshanova & Kayimov (1985).

For different areas of the USSR, so-called "effective norms" for an optimal share of forest shelterbelts as windbreaks have been established (Table 3). For Uzbekistan, based on wind speed and frequency, an effective percentage of forests in the range of 0.5-3.0% was established by Moltshanova & Bojko (1968). It is likely, however, that optimizing the ecological functions mentioned under "Afforestation" will require higher proportions of forest in the landscape. We assume that the forest landscape in Khorezm can be increased to 8-10% without a loss in agricultural production, because the reduced cropping area will be balanced by a higher production on the remaining area (due to side effects of shelterbelts, but also due to an intensification of the agricultural production; cf. Module A).

A reforestation program is already being run in the neighboring province, Karakalpakstan, by the State Forestry Committee of the Republic of Karakalpakstan, Nukus, in three circumstances: In the dried Aral Sea bottom (North of Muynak), in the desert, and in irrigated areas. However, the plantation on the dried Aral Sea bottom has only been successful on former "beach" areas near the shoreline where salinity is low (Wucherer pers. comm. 2000). One successful example of reforestation is the establishment of a shelterbelt of 100 ha of forest (UNDP project) to protect the city of Nukus from desert sands coming with the wind. During a visit in 2000, the three-year-old trees were about 4 m high (Ganiev, Martius, pers. comm.). Experience may also be drawn from large afforestation programs that have been undertaken in China since the Fifties, considering mainly the functions of sand-/windbreaks, intercropping, farmland shelterbelts, and diversification (Wu & Shepherd 2000).

To resume, almost nothing is known about the present situation and the potential for forestry in Khorezm. However, initial efforts to reforestation are being observed in the region. Therefore, scientific research programs accompanying these attempts are urgently needed, in order to assess the constraints and improve the overall system performance with special regard to water saving.

### 3.3.1.3 Agricultural Production Systems

#### 3.3.1.3.1 Crop Production Efficiency

Food security is mainly a concern in Sub-Saharan Africa and South East Asia, but other developing countries will also face a decrease in per capita food availability (Pinstrup-Andersen et al. 1999). The transformation economies of the Central Asian countries will likewise be affected by the global trends of growing food insecurity, further aggravated by the threat of extreme climatic changes, and the present scenario of extremely low resource use efficiencies in currently used crop production systems (UNESCO 2000 a). In Uzbekistan, agriculture is a major part of the economy, accounting for 30% of gross domestic product, 44% of employment, and 60% of export earnings (ADB 1999). By far the most important crop is cotton, and basic food requirements still depend largely on grain imports, although increasing areas, withdrawn from cotton production, are planted to grain crops (ADB 1996, 1998, 1999).

To achieve a sustainable intensification of agriculture, Reeves (2000) outlined a "new" research paradigm based on an integration of the four scientific realms: environment, crop genotype, management, and human sciences. Crop breeding and/or the testing of new varieties will not be part of the present project, as this area is well covered by scientific institutes in Uzbekistan and a GTZ project. A surge in cereal yields was experienced worldwide over the past 30 years, particularly on irrigated land as a unique conjunction of agronomic and plant breeding advances (Evans 1998). In contrast, the addition of new farmland has played a secondary role in keeping up with population increases. In Khorezm, however, production increases still are mainly achieved by adding new desert land to the system under irrigation, at a current rate of annually 5000 ha (Chapter Irrigation).

#### 3.3.1.3.2 Agriculture in Uzbekistan

Uzbekistan covers an area of 447.4 thousand km<sup>3</sup>, of which 4.2 million ha are irrigated arable land. With a population of 23.7 million in 1997 only 0.17 ha arable land are available per capita (the same as in China). The growing population rate in the Aral Basin during the last century was strongly correlated with the enormous increase of the irrigated area in this region (Figure 3).

During the Soviet Union period, Uzbekistan's primary agricultural role was to produce cotton, fruits and vegetables largely for export to other Soviet republics. Agriculture is the key sector of the Uzbek economy with a share in GDP of over 30 percent (IMF 1994, 1998, World Bank 1993). As part of the Government's policy to achieve national food-sufficiency, wheat production was drastically increased during the past 5 years. Now, cotton and wheat account for about 70 percent of the area under cultivation. According to official data, approximately 3.5 million persons are employed in agriculture, equivalent to about 40 percent of the total number of all employees in the economy.

### 3.3.1.3.3 The Dominant Role of Cotton

Cotton is the world's most important natural fiber (Munro 1994). In Uzbekistan, cotton, as an exported arable crop, has a high significance for the national budget. In 1970, 70% of the irrigated land was used for cotton, declining to 56% in 1990. The annual yield today amounts to around 1 million t raw fiber, of which 800.000 t are exported and 200.000 t are processed within Uzbekistan. World market prices for cotton have continuously decreased over the past years and amount to around 1000\$ per t ex farm at present. The cotton fiber export price F.O.B. Uzbek border in the past was 1.600, 1.755, 1.593, and 1.583 US\$/ton in 1994, 1995, 1996, and 1997, respectively (Source: Ministry of Macroeconomics and Statistics). Cotton trading is strictly state-controlled. Farms are forcedly selling their cotton to the State and are paid in the local currency (Sum), which has a fixed conversion rate to the USD. The cotton price is fixed in before, meaning that cotton farms receive about 50% of the world market price, if calculated at the official/auction exchange rate (IMF 1998). No reliable data material is available for management analyses (costs, labor input, profits, prices ex farm) that are urgently required as a basis for the intended alterations in the existing cropping system.

Via cotton, the government finances an ambitious industrial investment program, subsidizes consumers, especially in urban areas, and an expensive social security program. The authorities have taxed the cotton (and wheat) sub-sectors through a variety of implicit and explicit mechanisms, including the foreign exchange system, the state order system, low producer prices, and control over farms, as well as marketing and processing organizations. This non-transparent system of direct and indirect controls, of taxes and subsidies has led to severe distortions in relative prices, disincentives to agricultural producers, and an inefficient allocation of resources both across sectors and within agriculture.

With an average annual precipitation of only 92 mm (varying between 40 and 160 mm yr<sup>-1</sup>), all agriculture in Khorezm needs irrigation. The extremely arid summer with an average precipitation of less than 5 mm explains the high water consumption for the cultivation of cotton (Tables 4 and 5). According to Micklin (1991) the potential evapotranspiration (PET) amounts to 2000 mm per year. Borisov (1965) indicated a PET of 1500 mm per year, and Tursunov (1981) 1300-1700 mm per year. Cotton has an annual water demand of 700-800 mm. Ressler (1999) calculated a water consumption rate of 1190 mm for cotton in the delta of the Amu Darya using ET<sub>0</sub> and ET<sub>crop</sub> data according to Doorenbos & Kassam (1979). According to Sarybaev (1991), water consumption in Khorezm is increasing to 1500-3500 mm due to high infiltration losses in the deteriorated and dysfunctional canals during water inflow.

With a medium evapotranspiration rate of 6 mm day<sup>-1</sup> during the main vegetative phase it is necessary to irrigate in intervals of 8–10 days. Yields can start to decline at 50% available soil moisture. The actually practiced flood irrigation does not allow application rates below 100mm. That shows clearly that an irrigation schedule according to the plant water demand with this application method leads to water losses in the process of percolation of up to approximately 50%. In soils with high salt concentration this water will seep away and is lost for irrigation. Reclamation of highly saline soils may require further leaching and thus, initially high amounts of water will be used for ponding (Hillel 2000, Abdel-Dayem et al. 2000). Future irrigation schemes should be based on plant water demand, replacing the current flooding practice with a much lower water application, leading to a lowered groundwater table and thus keeping soil salinity low.

According to data from the cotton trading company "Reinhart" (Winterthur, Switzerland), the quality of Uzbekistan cotton has decreased over the recent years. This is mainly due to the increasing use of early maturing species. The cultivation of such varieties gains importance because the number of frost-free days has decreased to 170 days in recent years, and because the water availability is more ensured at the onset of the vegetation period than at later stages. Cotton, which is very frost-sensitive, needs a growth period of around 150-200 days between sowing and harvesting.

However, the high quality standard of cotton produced in Khorezm and Karakalpakstan has been maintained, which is the main reason why the national government is maintaining the present quota regulations in these areas.

The ongoing degradation of agricultural land has also contributed to a continuing decrease in cotton yields. In Karakalpakstan, cotton yields have decreased from average 32.2 dt/ha in 1980 to 22.2 dt/ha in 1998, and they are

slowly but steadily decreasing in Khorezm as well (Figures 4 and 5). The main reason is soil salinization. The average salt affected soils decrease cotton yields by 30-40% (Kabulov & Orel 1999). Shirokova (2000) found yield losses between 20-30% at a salinity level of  $EC_e = 6 \text{ dS m}^{-1}$ . The salinity-driven decrease in cotton yield has been estimated to about 1 million tons annually of raw material for Uzbekistan (Kabulov & Orel 1999). The yield decrease in Khorezm, however, has been relatively low, from 33dt/ha in the early eighties to 29dt/ha in the period 1994-1999 (Matyakubov 2000). Due to the salinization, only an average number of 70 000 plants/ha is obtained, far below the optimum number of 100 000 plants/ha.

Farmers have tried to contain the yield decline by applying higher fertilizer doses (Figure 4). According to Giese (1998), in the Central Asian Republics around 480-600kg per ha fertilizers are applied, among this 34 kg of toxic chemicals. Finding means of meeting the governments production goals while conserving natural resources and using inputs efficiently, sustaining agricultural production and meeting the farmers need for diversified sources of income will be a major goal of the first phase of the project.

#### 3.3.1.3.4 Wheat and Rice

Before independence, wheat was only cultivated in non-irrigated areas of Uzbekistan, with yields lower than 18dt/ha, providing only 20% of the country's wheat demand (AHT, feasibility study 1999). It is estimated that Uzbekistan needs to produce at least 4.2 million tons of grains to meet domestic requirements. Since 1991, cultivation patterns have changed significantly. In 1999, cereals were cultivated on 1.720 million ha; 80% of this (1.36 million ha) being under irrigation. Dominant is winter wheat, cultivated on 1.42 million ha (=83%). Wheat cultivation takes place mainly at the expense of alfalfa. Other important crops to be found are rice (164 000 ha), barley (59 000 ha), and maize (57 000 ha) (Mc. Quiston et al. 2000).

In 1997/1998, 16 100 ha of wheat were cultivated in Khorezm with an average yield of 5.03 t/ha (Ministry of Macroeconomics and Statistics cit. in Mc. Quiston et al. 2000). For the same year, average yields in Karakalpakstan are quoted as 1.53 t/ha. Major constraints for wheat yields are salt stress and deficient irrigation in relation to time and quantity. Wheat is more sensitive to salt than cotton. A high ground water level in connection with salt accumulation affects the growth of the roots and the nutrient uptake. Salt in the upper soil layers affects germination and emergence of the seeds, and this, in turn, impedes the achievement of an optimal stocking density.

According to international experience, under these conditions cultivation in beds is recommended for wheat and cotton (shaped beds of 0.90 m width and 25 cm height). Water supply is provided through trenches alongside the beds. This method leads to yield increases of between 20-40% and saves water up to 50%. Winter wheat requires 400-600 mm of water in four to six additional applications during the vegetation period.

The optimal sowing time for a seed quantity range between 160- 250 kg/ha is between October 5<sup>th</sup> and 15<sup>th</sup>. When wheat follows cotton in the rotation, multiple picking of cotton may delay removal of cotton stalks; therefore, 60% of the wheat in irrigated areas seeded into standing cotton to allow sowing at the optimum date. For various agronomic reasons the extension of summer wheat cultivation is recommended. With similar yields and a different water demand, both wheat species can be grown in different vegetation periods to the farmers' benefit. Cultivation of durum, well known in Uzbekistan in former times, should be taken up again. At present, Uzbekistan is importing 500 000 t per year. Given the high world market prices, it would be reasonable to export durum and import low-cost consumption habits.

"Pilov" made from specific rice varieties is the most popular dish in Uzbekistan, where around 500 000 t/year of this staple food are cultivated. The cultivation of upland rice is not common in the region. Initial cultivation tests, however, are being carried out at present (Rau et al. 1998). Wetland rice is mainly cultivated on heavy and water impermeable soils. Rice is the only suitable arable crop for the strongly salinized soils in the Syr Darya delta. The method of leaching the salts by application of an extremely high water input during the growth period allows cultivation.

In Khorezm, rice is produced with very high yields per ha and an extremely high irrigation input, at least if the last available data from 1986 still hold true (Table 5a). The biological water demand of paddy rice, calculated from pot

experiments, amounts to only 500-700 mm (Saiceva, quoted from Baraev 1989:558). Considering evaporation losses from the water surface, the effective demand for water is supposed to amount to 1200-1500 mm. Ressler (1999) calculated consumption figures of 1415 mm for the delta area. The easily permeable sandy soils in Khorezm are not suitable for paddy rice cultivation because daily filtration losses amount to 5.1-5.4 mm (Baraev (1989).

#### 3.3.1.3.5 No-Tillage Methods and Mulching

No-tillage or minimal tillage is a land preparation technique increasingly applied in tropical and subtropical countries (Unger 1984, Machado & Silva 2001). It conserves fuel, soil moisture and soil organic matter, reduces soil erosion and improves crop productivity. Experiments on no-tillage meet with the expectations of scientists from Uzbekistan as expressed during the workshop held at ZEF in October 2000. Organic mulching is applied in farming systems where conservation of organic matter is an issue; the mulch cover increases soil fertility, protects the soil against erosion losses and extreme temperatures, it increases soil moisture, replenishes secondary nutrients, conserves soil organic matter, and provides a substrate for soil organisms to live in and to feed upon (FAO 1975, Sanchez 1976, Kamara 1986). Soil preservation through mulching and no-tillage is a nutrient conservation strategy, allowing the reduction of fertilizer use (Gruhn et al. 2000). Although the availability of organic matter might be a problem in Khorezm, tests will be carried out to assess the beneficial effects of this technique.

#### 3.3.1.3.6 Aquaculture

For Uzbekistan, fish consumption recommendations for a balanced nutrition of the population have been determined as 12 kg per person per year. In Soviet times, those amounts were provided from two sources: 1) 60 000-80 000 tons of marine fish per year from other regions of the former USSR; 2) 25 000-30 000 tons from local aquaculture (50-70% common carp, 30-50% silver carp and bighead). Today, the Uzbek market is provided with just 9 000 tons mainly from aquaculture. This represents less than 1 kg per person and consists mainly of supplies in the cheapest fish (silver carp). An increase of the fish production is therefore an important factor for maintaining population health.

Aquaculture is an ideal agribusiness for Uzbekistan. Due to the favorable natural conditions the freshwater fish production here will be more economical than in other republics of the former USSR, including Russia. Many of these countries produce marine fish and have an interest in importing freshwater fish. Even under the harsh actual economic conditions in Uzbekistan fish production is very profitable: The production costs amount to about 50-80 Uzbek sum, whereas the market price is about 200-500 sum per kg fish (data from 2000).

In Uzbekistan, local agro- and aquacultural technologies were developed based on the conditions of a planned economy with financing from the state budget. The aquaculture technology used in Uzbekistan is very extensive. The current productivity is only 1-1.5 t ha<sup>-1</sup> (in the past, with artificial food and fertilizers, it was 3 t ha<sup>-1</sup> on average). Fattening ponds are large - 100 ha and more. Aquaculture was developed mainly in special fish farms run by the Ministry of Fisheries. Recently, those farms have come to include the 'Uzriba' Corporation. Only one aquaculture enterprise exists in Khorezm district, named "Viloyat", a fish farm with more than 1 000 ha of ponds. Table 6 shows the production statistics.

The market economy will favor aquaculture in small fattening ponds - about 1 ha. Such ponds can be distributed in all places including irrigation or drainage canals. The aim of the project is to demonstrate this possibility as a valuable resource. Fish production using canals will increase the water use efficiency, improve agricultural diversification (less dependence on single crops) and provide farmer with a high-protein product and a highly valued product to sell. Fish can also help keep irrigation and drainage canals free from weeds.

Factors that limit the fish production in canals include water losses, salinization and sedimentation. In addition, the canal environment creates problems for fish capturing, related to fluctuating water flow, canal drainage, the use of biocides and fertilizers. Water in canals may originate from reservoirs, rivers, lakes, etc., which have influence on the natural flora and fauna including the fish varieties. Nevertheless, irrigation canals are able to support various levels of fish production. For evaluating possibilities for aquaculture, direct links will be built to the legal-

administrative part of the project (Task H1), because rights of use and obligations of maintenance of irrigation canals have to be clarified.

#### 3.3.1.4 Research Demand in Module A

Specific objective: Develop concepts for the introduction of protective forest and intensive and sustainable agricultural production systems as a component of ecological restructuring of the Oasis in order to diversify the landscape, sustain effective agricultural production, protect natural resources, increase biodiversity and provide a harmonious and healthy environment to live in.

Research demand

- **How can forest stands on marginal lands be developed?**
- **How can shelterbelts be established on favorable land?**
- **How can land use be intensified in a sustainable way, while at the same time meliorating land attributes?**

Research questions

- What indigenous or exogenous trees can be used for reforestation on marginal lands?
- What difficulties will be encountered in producing seedlings and establishing stands under saline conditions?
- What has been the experience of shelterbelt establishments in Khorezm?
- To what extent can crop intensification lead to a better use of land and increase crop productivity?
- Can modern crop growing technologies lead to substantial water savings and improve water quality?
- Can fertilizer saving technologies help raise production and make farms more profitable?
- Are there other modern technologies (no-till, mulching) that can improve the efficiency of agriculture and the environment of Khorezm?
- Can aquaculture help diversify the agricultural production systems to the benefit of the farmers and ecology?

### 3.3.2 Natural Resource Management (Module B)

#### 3.3.2.1 Water Management

##### 3.3.2.1.1 Water Resources

Located in the heart of Central Asia, the Aral Sea Basin has a gross area of 91.2 million hectares, of which about 45.0 million hectares are situated in the Amu Darya Basin. All rivers originate in snowmelt and rainfall in the up to 7 500 m high Pamir Mountains and in the Central Tien Shan mountain range, east and south of the basin. The rivers run approximately 2 500 km through the mountainous upstream countries of Afghanistan, Tajikistan and the Kyrgyz Republic and then flow through the plains of the downstream countries of Uzbekistan, Turkmenistan and Kazakhstan before they reach the Aral Sea. The Amu Darya and Syr Darya basins have over 20 storage reservoirs while 60 irrigation canals of varying size have been constructed (Bos 1996, Figure 2). Overall annual run-off is between 125-130 km<sup>3</sup> (average annual discharge rate is 78.5 km<sup>3</sup> in the Amu Darya and 37.2 km<sup>3</sup> in the Syr Darya (AHT (WARMAP) 1999) but slightly different data are given by Ivanov et al. 1996; cf. Table 7).

Water is a critical element in Central Asia. Water from the Amu Darya River, the sole supply for the Khorezm region is maximally used, and reliance on external water resources through river diversion cannot be seriously taken into consideration. Of the total amount of water carried by the Amu Darya river of around 76 km<sup>3</sup>, as much as 88% is diverted, 70% before it reaches the Khorezm province (ADB 1997). The Khorezm oblast uses slightly over 5 km<sup>3</sup> yr<sup>-1</sup>; 95% of it for agriculture (ADB 1997). The water entering Uzbekistan contains <0.5 g/l of salt. The river recovers 20 - 30% of the water diverted for irrigation, enhancing the salt load of the river by the time it reaches Khorezm to an average of 1-1.5 g/l. These levels may vary from 3g/l in the spring to 0.5 g/l in the late summer (pers. comm. by

workshop participants at ZEF, October 2000). These salt levels may eventually be reduced with the completion of the drainage diversion that will by-pass the Khorezm region. Given the poor overall quality of the water, measures are needed to reduce the dependency on the river, which has to be realized by an improvement in efficiencies within the existing hydrological system. Thus, increasing the efficiency of water use is the precondition for an improvement of the present-day situation of the agricultural production system, an ecological landscape restructuring, and the supply of clean drinking water, all essential to the people of the region.

### 3.3.2.1.2 Irrigation

The role of irrigated agriculture in food production is significant; although only 17 % of global cropland is irrigated, these lands provide 40 % of the world food production (FAO 2000). As all easily available water resources are already used to a high degree, only an improvement of irrigation efficiencies can allow increased crop production from irrigated land. Many cultures developed technologies and means to move water to people and irrigate their land. The rapid expansion of the irrigation in the first half of this century has often taken short-cuts in an effort to save money, and failed to install the necessary drainage systems. As the analyses of the World Bank show, the impacts caused by deficits related to planning, operation and maintenance became obvious already in the eighties. Rajagopalan (1988) estimated approximately 40 million hectares of irrigated land to be affected by salinity (14% of the 220 million hectares being irrigated world-wide at this time). Expansion of irrigated land has virtually come to a halt, as today irrigation systems are increasingly costly to build and maintain. Retrofitting drainage systems is often prohibitively expensive, so that low-application irrigation techniques might be the more suitable remedy to salinization and the rising water tables. Substantial increases in water use efficiency can be realized by such methods (Hillel 1991). The savings in water will be increasingly important in the region.

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. The irrigated area is annually increased by about 5000 ha (Figure 6). 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 net has declined from 33m/ha to 29m/ha between 1982 and 1999 (Matyakubov 2000). Moreover, the inflexibility of the legal-administrative framework stops farmers from mitigating the accumulation of salts or from lowering the water table through an effective use of water. The consequences are high losses of irrigation water, soil salinization, rising groundwater table and critical loading of salts, pesticides and fertilizers in the groundwater (cf. Chapter Groundwater). Farmers attempt to counterbalance the build-up of salinization by increasing the water quantities used in soil flushing; flushing water use has risen from an average of 385 mm in 1991 to 430 mm in 1999 (O'Hara 1997). Apart from the waste of scarce water resources, these effects limit agricultural yields and adversely affect the quality of agricultural products by bringing pollutants into the food chain.

Salinization of irrigated land has assumed alarming proportions. Currently, about 30 million out of a total of 260 million hectares of irrigated land are severely damaged by the build up of salts. Another 80 million hectares are affected to some degree and 1.5 million hectares are estimated to be lost from production every year (FAO 2000). Doppler (1985) estimated the worldwide loss of agricultural production due to salinization and water logging at approximately 20 billion (thousand millions) US \$ (prices from 1979). Especially under high evaporation potential conditions, salinization of irrigated soils with inadequate drainage poses a serious threat. Combined with inefficient agricultural practices irrigated agriculture can cause environmental damage to both surface and groundwater quality. Excessive irrigation water drives the leaching of chemicals, like  $\text{NO}_3\text{-N}$  and pesticide residues, into the groundwater (Kanwar & Baker 1993, Watts et al. 1993).

Overall water use efficiency in Khorezm is said to be less than 50% (ADB 1997). However, such values should be handled with care, because they depend on the assessment method used which can be influenced by site-specific factors. Nevertheless, some projects using surface irrigation techniques in developing countries are operated with much higher overall efficiencies. Plusquellec (1990) reports that the overall efficiency in the Gezira Scheme in Sudan amounts to 65 –70 %, a very high value that might be favored by low infiltration of the soils. Almost all (99%) of the Khorezm area is supplied by furrow irrigation with an on-farm efficiency claimed to be 65% in the ADB (1997) report, however, we estimate that this value is set much too high and requires verification. Ninety-two percent of the land is drained. 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 (ADB 1997).

#### 3.3.2.1.3 Groundwater Management

Uzbekistan possesses an estimated 20 million m<sup>3</sup>/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. 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. Salinity is one of the major problems in irrigated agriculture in Khorezm and leads to crop yield losses of up to 50%.

A prerequisite for ameliorating the risen groundwater is the implementation of a monitoring network of sufficient density consisting of different network orders (continuous measurement by recording instruments; observation wells that enable sampling; temporal measurement by portable equipment). Using the measured data and an existing ground-water model would enable the development of strategies to reduce the ground water level by changes in irrigation management and other means such as re-use of drainage water or bio-drainage (subprogram A3). The model can quantitatively simulate consequences of measures to improve water management on a farm area. The specific aim of lowering the ground water table on the farm down to at least 2 m from the soil surface may require supplemental rehabilitation of the drainage network.

Research results obtained in the Punjab province of Pakistan may illustrate the suitability of groundwater and surface water modeling for reducing the problems caused by high groundwater levels. In some parts of the Indus basin rising groundwater tables limit the crop production by salinization of the soil and water logging problems. At the same time water is a scarce resource in many irrigation schemes located in the area. Therefore the conjunctive use of surface water and groundwater is considered to be a promising approach towards the solution of both problems. Using GIS-tools to combine groundwater and surface water modeling, Sarwar (1999) developed strategies to lower groundwater tables and to raise the water use efficiency by conjunctive use approaches. As the rising groundwater table is caused mainly by inefficient irrigation performance, improving the operation of the irrigation systems and integrating the groundwater use are the key-steps of intervention. Simulated strategies show that it is possible to keep the groundwater level below critical depth by increasing the use of groundwater for irrigation purposes. Moreover the strategy enabled the enhancement of cropping intensity by 30 %.

Due to high concentrations of salt in the drainage water of the Khorezm area, the re-use of drainage water needs to be considered with care. Choosing periods with lower salt content in drainage water and crops with higher salt tolerance, or applying drainage water during phases of lower crop sensitivity to salinity (Ayers & Westcot 1985) and mixing of water may facilitate the introduction of water re-use, at least temporarily. Besides the re-use of subsurface water, the re-use of surface runoff from furrow irrigation should be considered (if surface runoff cannot be avoided with acceptable expenditure by cutoff or surge flow techniques of furrow irrigation). Walker & Skogerboe (1987) developed design procedures for re-use systems by re-integrating runoff from furrows, which is collected by a tailwater channel, stored in a small reservoir and recycled by pumping back into the irrigation system. The strategy enables a further improvement of efficiency and provides water of higher quality for re-use compared to the re-use of subsurface water.

#### 3.3.2.1.4 Water Use Efficiency

Improving water application efficiency can substantially reduce the consumptive water use and the hazard of salinization as well as the cost of drainage (Addink et al. 1980, Bresler 1991, Bresler & Laufer 1988, Hillel 2000, Howell 1988, Teckle & Yitayew 1990). The efficiency of irrigation water by surface irrigation methods lies at 30-50%, of pressurized sprinkler irrigation systems at 70-80% and of drip irrigation at 90%. Sprinkler and drip systems apply water more uniformly than the traditional surface irrigation. This higher uniformity improves the control of soil moisture during the irrigation season, often connected with increased yields (Duyunov 1996). Efficient irrigation methods greatly reduce the drainage water volume. The proper choice of irrigation for a given infrastructure, however, is a compromise between investment opportunities, technical and administrative abilities, and awareness of the growing problem. However, even with limited investment opportunities, Khorezm appears to have substantial

scope for improvement. After all, water use efficiencies (WUE) reported for Khorezm are less than 30% (participants in workshop at ZEF, October 2000) and thus appear to reach only 1/3 to 1/2 of those obtained in Turkey, a country of similar infra-structure and climate.

A comparison with a worldwide study on irrigation water use of the International Commission on Irrigation and Drainage allows assessment of this figure. 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. We conclude that Khorezm has a large potential for water saving by improving water use efficiencies; however, to what extent remains to be formally scientifically assessed.

Therefore, in the present proposal we do not suggest the introduction of drip and sprinkler irrigation. Although these methods would provide the highest water savings, they are costly and cannot be economically applied to as large an area as Khorezm in its entirety. However, the savings that would be possible by improving the current practice of ditch and flooding irrigation are immense.

#### 3.3.2.1.5 Conveyance Losses

Water losses due to poor transport systems are estimated to amount to 40 km<sup>3</sup> of water per year - saving this amount alone would be enough to stabilize the Aral Sea at its present level. According to Baraev (1999) 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 m<sup>3</sup> per ha, whereas only 5 500 m<sup>3</sup> per ha arrive at the field.

As well as losses in the distribution network, irrigation water is also lost on the farm-level especially during field application. Losses in open channel systems are principally caused by seepage, evaporation from the canal water surface and operational wastes (Labye et al. 1988). Evaporation losses usually are considered to be small in comparison to seepage losses. Operational losses strongly depend on site-specific factors, such as technical infrastructure, capacity to operate the system adequately and the organizational framework. At least 2 % of the design discharge should be tolerated (considered?) as operational wastes. Seepage losses must be estimated separately for lined and unlined canals. In case of unlined canals seepage losses depend to a high degree upon the infiltration rate, which is usually correlated with the soil type. Besides the mode of operation (continuous flow or rotational flow) the degree of seepage loss is determined by geometrical characteristics of the network, such as wetted perimeter and length of the canal reaches. Numerical values vary within a wide range of 1 (lined canals) to 20 in case of unlined canals on sandy soils.

In order to improve the current operation of conveyance and distribution networks in the region under consideration, the canal reaches with high losses should be identified using geometric information and knowledge on lining respectively on the soil type (in the case of unlined canals). Supplemental measurements (water level measurement applying the ponding method to canal reaches; comparison of inflow and outflow of water) will help to locate weak points in the networks. A second step may consider operational approaches towards an improvement (better coordination of hydraulic operation; realization of even discharges as far as possible). Scheduling models (Radermacher et al. 1992) and computer simulation of canal hydraulic (Manz 1989) provide the starting point of operational approaches in the context of the overall system (including the field level). The optimization of canal operation needs to be based on hydraulic modeling of the site-specific canal network regarding each canal reach and using the operational parameters (discharge, water level) in order to minimize losses under existing constraints. As the overall efficiency has to be improved, optimization procedures of the network should be linked to the irrigation performance on farm and field level. Further steps may consider the lining of canals, the change of geometric parameters or taking areas which are fed by canals with non-acceptable amount of losses (length; material; soil) out of irrigation. These areas could be considered potential candidates for reforestation (Module A).

### 3.3.2.1.6 Farm Water Cycle Modeling

Water mismanagement and poor on-farm drainage are major causes of unproductive water losses. To improve this situation it is necessary to monitor the present practices, to analyze the main weak points and to start rehabilitation work using knowledge of the complete farm water cycle.

Approaches towards the improvement need to integrate any relevant aspect of irrigation water use. The overall-solution should be built up by the following sub-approaches: (1) crop water demand, regarding the influence of soil moisture level on agricultural yield; (2) leaching requirements, considering the impact of soil salinity on crop yield; (3) water balance of the irrigation field (integrating effective rainfall and capillary rise into the balance, if relevant in the considered situation); (4) process of water application to the field with special consideration of application efficiency depending on irrigation method, field geometry, soil characteristics and irrigation depth (using the relationships towards optimization of efficiency under existing constraints); (5) distribution and conveyance of irrigation water in the irrigation network (modeling of hydraulics in order to derive the parameters to handle the system and towards the overall optimization of the scheme); (6) integration of drainage quantity as well as quality in order to assess and improve the leaching efficiency and to consider the optional re-use of drainage water. Several models cover one or more of the mentioned aspects. Surveys on available software using internet-based sources were compiled by FAO Land and Water Division (2000), Stein (1996), Mead (1997). The research to be carried out may start with the critical review of available models regarding the specific situation as well as the objectives. In case of application, calibration and modification must be realized.

A first step towards the assessment of existing deficits as well as the conception of improving strategies is the reliable estimation of the crop water demand. In order to derive this knowledge, a combined approach of measurements by lysimeters (Roth et al. 1994) and calculation procedures seems to be suitable. The Food and Agricultural Organization of the United Nations makes calculation procedures (Allen et al. 1998) and software (Smith 1992) related to evapotranspiration available.

Research carried out in Sumatra considers the use of water-yield functions and aims at water saving during vegetation phases with minor sensitivity of agricultural yield.

On the base of data derived from an irrigation scheme in southern Sumatra, the simulation shows that it is possible to save 40 % of irrigation water without a significant decrease of yield by the introduction of intermittent irrigation on field level reducing the irrigation during phases when rice yield shows lower sensitivity to lack of water. When applied in combination with the optimization of the system operation, a cropping intensity index of 70 % can be improved up to 100 %.

Experience gained from irrigation experiments in the Egyptian El Nahda project may be helpful. In order to facilitate mechanized agriculture, the irrigation fields in parts of the scheme are too large for the available field application discharge (Tischbein 1997). Furthermore fixed timing as well as defined amounts of irrigation make it impossible to meet temporal requirements of the crops (meteorological parameters; vegetation phases; growth of roots). Therefore the application efficiency derived from the measurement of irrigation water input and soil moisture is in the order of just 16 %. The introduction of flexible irrigation timing considering the time-depending requirements of the crops has led to an improvement of up to 24 %. As this level is still not reasonable a hydrodynamic model available from the FAO (Walker 1989) was used to simulate measures towards further improvement. Calibrated to the situation of the considered fields, a better adaptation between application discharge, field size, soil parameters, infiltration characteristics and irrigation depth was simulated (Tischbein 1997). As a result, the doubling of application discharge enables an increase of the application efficiency to 51%. Because the hydraulic capacity of the existing system limits the available application discharge, this effect can be practically realized by halving the field size. Assuming a fourfold increase in the initial application discharge, the simulated improvement of the application efficiency comes up to 65 %.

Moreover the handling of the problem is complicated by the limited availability and the uncertain reliability of data concerning soil, water resources and irrigation practices of the region under consideration. This fact makes it necessary to undertake an intensive phase of secondary data analysis for the Khorezm region, supplementary data collection and data processing in order to locate areas appropriate to carry out the detailed experiments. The

knowledge thus gained will allow up-scaling of experimental results, and will make it easier and more efficient to apply the improved strategies to a larger area.

### 3.3.2.2 Reversing Soil Degradation

Soils are a central compartment of ecosystems; they represent the interface between underlying minerals, vegetation cover, water and the atmosphere. Studies of the behavior of the soils under changed land use systems are imperative, because the irrigation by flooding technique practiced in the region leads to waterlogging of soils, and this, in turn, to an accumulation of salt in the soils. In Karakalpakstan, the neighboring province, 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. The intensively managed cotton monocultures over decades also have required large inputs of fertilizers and pesticides. This has exhausted soils and has led to soil degradation in terms of loss of soil organic matter and nutrients, while pesticide use has left soils highly contaminated (Bogdasarov et al. 1998).

The soils of Khorezm are mainly composed of sandy and loamy alluvial deposits that differ in age. They are strongly influenced by river flooding and long-time agricultural practice. The thickness of the sediments varies between 35 and 140 m, the upper 12-15 m presumably dating from the Holocene period (Létolle & Mainguet 1996). The medium specific amount of suspended sediments in the Amu Darya River is  $3.5 \text{ kg m}^{-3}$  water. Except for the Yellow River in China, it is the river with the highest ratio of suspended sediments worldwide. For thousands of years, the Amu Darya River has transported suspended sediment into the delta region that now amounts to millions of cubic meters.

The soils in the oasis which have developed from riverbed deposits are mainly composed of sand and loamy sand. The soils of the original low-lying areas along the riverbed contain a high percentage of loam. Tursunov & Fathy (1984) have shown the wide heterogeneity of the texture of the soils in the area of the old irrigated oasis (Table 8). Tursunov (1981) has also excellently described the very complex soil characteristics of the Khorezm oasis. The fertile soils made highly intensive agricultural production possible. But soil deterioration is evident from the drastic decline of the amount of water stable macro-aggregates ( $d > 25 \text{ mm}$ ) from 10-15% in 1965 to 1-2% in 1984 (Tursunov 1985). Investigations of the effects of landscape management on soil characteristics will have to consider the different soil types in order to be relevant to the full area of Khorezm.

#### 3.3.2.2.1 Soil Degradation

In the seventies, two thirds of the irrigated soils in Khorezm (about 160.000 ha) were classified as “meadow soil”, corresponding to Xerosols and anthropogenic Fluvisols. They were characterized by a humus content of 1.2-1.6%, a  $\text{P}_2\text{O}_5$  content of  $>60 \text{ mg/kg}$  soils and  $150\text{-}200 \text{ mg kg}^{-1}$  soil  $\text{K}_2\text{O}$  in the top layer (0-20cm) (Tursunov 1981). This anthropogenically transformed oasis soil (Russian: Anthrozem) has a fairly good agricultural potential. Soils have been degraded during the last decades and today correspond more closely to so-called Meadow-Takyr and Takyr soils (in Russian terminology). The comparable units in the Soil Map of the World (SMW, Buringh 1979) are (takyric) Yermosols as a sub-unit of Aridisols. An accurate soil map of the region, reflecting the anthropogenic changes that have occurred over the past decades is essential for the success of the project.

The ongoing process of desertification has resulted in far-reaching changes in soil formation as a result of salinization, dehumification, compaction and anthropogenic pollution. Soil productivity is to a large extent determined by its fertility, which in turn is dependent on rootable soil depth and nutrients stored in its mineral and organic constituents. The humus content in the sandy Zerozem (gray desert soils of Xerosol type) and Takyr soils is very low (0.3-0.7 %) (Spaar & Schuhmann 2000). Continuing soil degradation (desertification) would lead to a further loss of soil organic matter and, thus, soil fertility. This process can be stopped and reversed only if sustainable cropping systems are introduced based on the conservation or enhancement of soil organic matter. Such systems could take advantage of diversification in space (intercropping: hedgerows, shelterbelts and forest patches) and time (crop rotation systems).

Making better use of the “ecosystem services” provided by the of the agroecosystem, including the preservation and management of the soil biota that produce and maintain organic matter (Martius et al. 2001) is one important element in the conservation strategies to be adopted. The negative effects of intensive irrigated agriculture on wildlife diversity are well- documented (e.g.; Lemly et al. 2000); less well documented are the effects on beneficial soil organisms that eventually can become much more devastating for the maintenance of central ecosystem functions than the -lamentable- loss of bird and mammal diversity (e.g. Reddy 1995, Höfer et al. 2000). Soil organisms are increasingly seen as ecosystem engineers, important if not central to ecological functioning (Lavelle et al. 1997, Jones et al. 1994), e.g. for soil fertility (Stork & Eggleton 1992, TSBF 1999), and their management has recently been studied intensively (Lavelle et al. 1999: Earthworms).

#### 3.3.2.2.2 Soil Organic Matter (SOM) and Fertilizers

The productivity of semi-arid croplands is influenced by the salt load and by soil organic matter (SOM) content (Badía 2000). Salinity is dealt with in Module C. Here we concentrate on SOM. The loss of soil organic matter leads to a reduction in soil fertility and a decline in soil structure, the water holding capacity and the biological activity of a soil. SOM is readily lost when organic matter inputs are reduced upon cultivation (Jenkinson & Ayanaba 1977). The percentage loss of SOM as a result of cultivation can be as high as 70% of C for the most fragile environments (Jenny & Raychaudhuri 1960, The Dang & Klinnert 2001). Organic nitrogen follows a similar trend. Little research has been done in the region on means and strategies to enhance or even protect SOM.

The introduction of intensive agriculture with its reliance on NPK fertilizers has placed added demands on the soil to provide the remaining essential nutrients. Moreover, in many countries fertilizer use favors nitrogen disproportionately to the crop demands (Bumb 1995). As a result, the long-term use of chemical fertilizers may disturb soil nutrient balances or cause soil acidification. Thus, intensive agriculture may have amplified the magnitude and increased the rate of the age-old problem of soil degradation (Hillel 1991).

Human intervention may overcome most soil constraints, but often only at a considerable, sometimes prohibitive cost. The production potential that can be realized and the requisite plant nutrients may vary not only in space but also in time. The costs associated with soil fertility improvement that are justifiable in a given environment is a function of the expected resulting outputs and varies from region to region. The differentials in these acceptable costs should lead to different strategies to satisfy plant nutrient demands. Moreover, an adjustment in strategy may be required over time to adjust to changes in market and production factors.

In fact, fertilizer use on cereals has seen a meteoric rise over the past 30 years (Figure 8), and is reflected directly in cereal production. In the early 1990s 7 million tons of N ( $100 \text{ kg N ha}^{-1}$ ) were applied on around 70 million ha of irrigated rice of South, East and Southeast Asia, with a mean yield of rice of  $5 \text{ tons ha}^{-1}$  (Cassman & Pingali 1995). However, with N: P : K ratios in the region of 1:0.15:0.1 (Bumb & Baanante 1996) actual application rates of P and K are below those recommended, approaching a mere 15 kg P and 10 kg K. Moreover, fertilizer N losses in rice are notoriously high, reaching 30-50% of the applied N (Vlek & Fillery 1984; Simpson & Freney 1988), negating possible N gains. Thus, at 5-ton yield levels, the major nutrient balances would be close to neutral. If biological N fixation were to be eliminated by the introduced nitrogen, the overall N balance would likely be negative. Indeed, steady yield declines in rice-rice cropping systems have been recently reported and appear to be related to declining N supply (Cassman & Pingali 1995). Other regions are, however, experiencing declines in yield associated with an exhaustion of sulphur or micronutrients such as Zn, which are increasingly found to be deficient (Vlek 1985). Little is known about the nutrient balances in the Khorezm region and such information is urgently needed.

#### 3.3.2.3 Research Demand in Module B

Specific objective: Before any sensible suggestions can be made regarding changes in the management of the natural resource base, the current status of these resources needs to be assessed. This information needs to be available to the project in an easily accessible way, preferably in a GIS-based database system. Based on this information and an on-site research program the project will aim to maintain and sustainably restore soil fertility and ecological functions (biota) of the soil and to develop sensible ways of delivering, commanding and applying water to better meet crop demands and alleviate the pressure on the resource base. In particular, a reduction in salinity and a permanent restoration of organic matter are aimed at.

## Research demand

- **To provide a status quo description and GIS database of water resources and the irrigation system**
- **To provide a status quo description and GIS database of soil resources**
- **To provide a hydrological analysis of the current irrigation system**
- **To develop strategies and models for more efficient use of soil and water resources**

## Research questions

- What is the status of the water resource base and water delivery system?
- What is the fate of irrigation water in the current system?
- What low-tech irrigation strategies will lead to water savings?
- To what degree are the soils of Khorezm degraded?
- Can the SOM level and biological activity of soils be enhanced?

## 3.3.3 Environmental Stress and Drinking Water Supply (Module C)

## 3.3.3.1 Environmental Pollutants and their Mitigation

## 3.3.3.1.1 Salinity

Vast amounts of salts are being produced and relocated in the Amu Darya and Syr Darya river basins. Between 1985 and 1990, the average discharge of salts per year from irrigated land into the two river basins was estimated to be 135 millions tons or about 18 tons ha<sup>-1</sup> of irrigated land. The annual salt load in the river water amounts to appr. 81 million tons, 56 million tons of this being mobilized from the subsoil. The annual economic losses due to salinization are huge. Rough calculations by various authors, based on the agricultural yield foregone and the costs for leaching and the disposal of salts point to annual losses of US \$ 400 - 1000 million at current economic prices (AHT 1999 [Feasibility study to the WAEMP-project (Water and Environmental Management Project)]). The non-agricultural losses are probably even higher. In order to reduce river salt loads in the region, irrigation has to be managed properly.

The high salt freight of the rivers, the so-called primary salinity, is one reason for a high level of salinity in the agricultural land. The current average mid- and downstream salinity level in the Amu Darya is 0.7-0.9 g l<sup>-1</sup>, but annually in the dry season (October to April) and during dry years the salinity can rise to 2.2-4.0 g l<sup>-1</sup> (AHT-study WARMAP 1999 and Baraev 2000 pers. comm.). This means that an annual quantity of 2000 mm of irrigation water carries an average salt input of 20 t per ha. Compared to these amounts, the level of air-borne salinity is low, approximately 500 kg ha<sup>-1</sup> (Razakov 1990, cit. in Giese 1998). Khorezm is one of the most salt-affected areas in Uzbekistan (Figure 9).

Irrigation in semi-arid regions is inextricably linked to salinization (Bridges and Oldeman 1999). While research on soil salinization in this region is limited to a number of case studies (Kust 1996, 1997, O'Hara 1997, Kuzmina & Treshkin 1997), conclusions on the nature and possible mitigation strategies of salinity problems may be derived from experiments in other semi-arid regions, i.e. Northwestern India and Pakistan (Singh et al. 1994), West Africa (Ceuppens & Wopereis 1999), Northern China (Wang and Cheng 1999), Chile (Donoso et al. 1999) etc. High evapotranspiration rates result in accumulation of water-borne salinity following two different pathways (Condom et al. 1999), i.e. neutral salinization and alkalization inducing a process of sodification. While saline land has gradually increased in the Aral Sea basin (O'Hara 1997), great variations in the irrigation water -- taken either from the canal or from the groundwater -- lead to wide range of chemical properties of soils.

A particular problem is the secondary salinity that results from the high groundwater table. Groundwater generally lies far above the soil depth of 2 m, which leads to the transport of water-soluble salts into the root zone of the plants and to the soil surface via evaporation and capillary effects. The maximum level reached by the groundwater is 0.3-0.85 m in April, and the minimum level is 2.1-2.5 m during September-December (The average amplitude amounts to 1.1-2.2 m). The degree of salinization in the groundwater in irrigated areas has increased from 1-3 g l<sup>-1</sup> to 10 g l<sup>-1</sup> and more; in non-irrigated areas it has increased from 20 g l<sup>-1</sup> to 50 g l<sup>-1</sup> (Faizullaev 1980).

The flow of water is the driving force for the movement of substances like salts, fertilizers and pesticides. The salt loads in drainage water of the Amu Darya is, on average, 5.5 times that of irrigation water. By the time the water enters the Aral Sea, it carries around a gram of salt per liter of water. Although the use of NPK decreased from 1.34 to 0.97 million tons and that of pesticides from 86 to 58 thousand tons between 1989 and 1993 for Uzbekistan as a whole (ADB 1997), the fate of these compounds or their residues remains unclear. The hydrological model of the farm water cycle would provide the base for modeling the transport of these substances. Transport models would make it possible to develop irrigation and drainage strategies in order to lower the stress on soil and groundwater posed by harmful substances. Such models further enable prediction of stress alleviation by modified irrigation strategies.

The salt content in the soil (chlorides and sulfates are predominant; Bogdasarov et al. 1998) varies widely (between 0.3 and 5 % or more), corresponding to stocks of 50-833 t salt ha<sup>-1</sup> in the upper 2 m of soil. About 50% of the arable land in Khorezm are affected by salt (15% of low, 20-25% of medium and 10-15% of strong salinity; the latter with a yield depression of >50%; Azimbaev 1999). Salt accumulation and salt migration depend on a multitude of different factors, among which the degree of mineralization of the irrigation water and the hydrological effects of high groundwater table are the most important.

The cotton crop is routinely sprayed with defoliant each fall to get rid of the leaves and ease harvesting. As a consequence, excessive use of agrochemicals has contaminated surface and groundwater supplies in the region. Furthermore, cities and villages in the region have minimal sewage treatment capacity, and municipal and industrial wastewater is released directly into the rivers.

#### 3.3.3.1.2 Airborne Salt and Dust Transport from the Aral Sea Bottom

The drying out of the Aral Sea has created a new desert, the "Aralkum". This solid salt marsh emits tremendous masses of salt and finely dispersed dust that is transported by a powerful air stream running from west to east (UNEP 2000). As a result of the aridity and the high summer temperature, low values of air pressure are recorded in the region, which leads to a constant inflow of air. The delta region is therefore annually attacked by about 25 heavy dust storms, which can turn into dry tornados (Burgaev 1957). In 60% of all cases these storms occur in the Aral region from NW and transport a high share of dust and salt from the former sea bottom (Ressl 1999). Some dry tornados can deposit 20-30 m<sup>3</sup> of dust per ha (Létolle & Mainguet 1996). The average yearly fallout of salt in the Aral Sea basin is estimated between 150 and 230 million tons (Chalidze 1992). These aerosols comprise sulfates, chlorides and even heavy metals. Typical Aral dust has been found in various parts of the globe, thousands of kilometers away from Central Asia (UNEP 2000).

Sandblasting and burial of young seedlings by blown sand can be an important production constraint, particularly for cotton production. In wind tunnel experiments, millet plants survived short-term sandblasting at any growth stage, but their growth was significantly reduced by strong sand deposition (Michels et al. 1995). At early growth, the plants were especially vulnerable to wind erosion events, whereas a combination of abrasion and burial by blown sand was responsible for damage at mature stages. Ridges can reduce soil losses (Biielders et al. 2000) and may also be suitable for mitigating agricultural impacts of burial sand.

#### 3.3.3.1.3 Pesticides

While pesticides have been excessively used during the Soviet area, pesticide use in Republic of Uzbekistan has plummeted (Figure 10) mostly due to economic difficulties. At the present time the danger of pesticide pollution is mainly due to waste water from production sites; polluted run-off from fields; air pollution through substantial dissemination of pesticides into the atmosphere; and direct application of chemicals to control algae and other organisms in water. Pesticide residues are very heterogeneously distributed and occur in 'hot spots' of contamination such as spray plane airfields and pesticide storage depots / dumps.

DDT, 1,1,1-trichloro-2,2-bis-(p-chlorophenyl) ethane, was one of the most widely used chemicals for controlling insect pests on agricultural crops and insect vectors of diseases such as malaria and typhus. DDT is very persistent

in the environment and as much as 50% can remain in the soil 10-15 years after application. The breakdown product DDE can even persist for decades. DDT is highly insoluble in water and is soluble in most organic solvents. It is semi-volatile and can be expected to partition into the atmosphere as a result. Some DDT may be degraded in air, but the compound may persist for a long time, bound to certain soils. A possible -- but slow -- degradation pathway of DDT in the soil is anaerobic de-halogenation leading to another toxic compound (DDD).

The movement of pesticides into groundwater is affected by plant uptake, volatilization (evaporation) to the atmosphere, chemical or microbial degradation (breakdown), adsorption by the soil, and transport by water. The widespread occurrence of pesticides in groundwater has caused concern over the potential for adverse health effects from chronic exposure via contaminated drinking water. Groundwater is the only source of drinking water in many rural areas of Uzbekistan. Significant contamination may occur because of the extensive use of agricultural chemicals and the shallow depths of aquifers. Mammals do not metabolize DDT very rapidly; instead, it is deposited and stored in the fatty tissues. The biological half-life of DDT is about eight years; i.e. it takes about eight years for an animal to metabolize half of the amount it assimilates.

Initial measurements by the Research Center for Water Management Ecology (RCE) revealed persistently high DDT concentrations in the Amu Darya basin. The study site in Khorezm district had maximum concentrations of 1.33 ppm (soil), 0.16 ppm (ground water) and 1.76 ppm (drainage water). DDT concentrations in the crop grown in this area routinely exceeded permissible standards, in some cases by several orders of magnitudes. Although the selected site was a former agricultural airfield and thus, may have higher DDT levels than average, these preliminary data clearly underscore the significance of the problem in the regional context.

#### 3.3.3.2 Drinking Water Supply

Few will argue that the Khorezm and Karakalpakstan regions are among the unhealthiest on earth (cf. Micklin & Williams 1996). The supply of safe drinking water is essential for public health. The WHO Protocol on Water and Health (UN/ECE and WHO/EURO 1999) defines access to drinking water and access to sanitation for everyone as the main targets. This contrasts substantially with the situation in Uzbekistan, where at least 11 % of the urban and 39 % of the rural population lack access to clean drinking water (NEHAP 1999).

Only half of the Uzbek towns have sewage systems. In these cities the sewage treatment rate amounted to 51.1 % in 1999. The Khorezm region has facilities to treat only 37.8 % of sewage produced (NEHAP 1999). From 1,860 rural households (Khorezm) which took part in a survey more than 91 % used latrines for sanitation. Children less than five years of age did not use latrines. They were free to urinate and defecate outside the house. Usually the evacuation of the latrines was done by family labor (in average every 10 months). The wastes from the latrines were mostly put directly onto the agricultural land. The surveyors (Bogdasarov et al. 1997) conclude that these practices pose a threat to the public health (Oldham et al. 1999). An additional extraordinary practice to get rid of the sewage entails sewage water from small factories, enterprises and also from most hospitals going directly to the drainage channels without passing settling sumps.

According to these facts problems concerning the quality of drinking water are various and tremendous. The chemical pollution of groundwater is caused by the use of huge amounts of pesticides and fertilizer, and the microbial pollution of groundwater is a consequence of the lack of sanitation. The groundwater is very close to the surface and washes up the latrines. Unsanitary groundwater is often used as drinking water. The use of chemical and polluted sewage for irrigation in the Khorezm region is likely.

Recent studies (Semenza et al. 1998, O'Hara et al. 2000) display the poor health status of people who live in regions affected by the Aral Sea problem. The Province of Khorezm has a morbidity rate of 72.3 %. This number exceeds all other regions in Uzbekistan (NEHAP 1999).

Investing in water supply and sanitation will produce benefits associated with health and environment. Support for public health investments can only be achieved by political decisions. An approach that considers political economy, disease ecology, social and economic changes on global and local scale is the *political ecology of disease* (Mayer 1996).

The burden of environmental pollution in Uzbekistan causes suffering and distress associated with disease as well as economic damage. Andrews<sup>1</sup> estimated the annual number of avoidable water related infectious cases of morbidity for Central Asia to be 3.45 Mio. The estimated benefits from reducing avoidable water related infectious disease comes to 24 Euro per capita. He also mentioned that the available information on water related diseases is extremely limited.

In 1999 the amount of drinking water samples that did not meet (local) health standards was 24.8 % concerning chemical indicators and 6.79 % regarding bacteriological indicators (NEHAP 1999). Within a study conducted by the CDC, seven wells were tested for coliform bacteria. Contamination of all wells was proved (Semenza et al. 1998). More than half of the participants of another study thought their drinking water to be healthy. They are not conscious of health threats which are posed by drinking water (Oldham et al. 1999).

Guidelines for drinking water quality recommend an annual sanitary assessment of small and remote water supplies. Monitoring for indicator bacteria is an appropriate method to assess health risks from fecal contamination (WHO 1996). The following statistical numbers can describe the health status of the population. The average life expectancy at birth decreased from 72.7 years in 1996 (WHO 1998) to 68.5 years in 1999 (WHO 2000). Differentiated for sex, the life expectancy at birth was 65.8 years for males and 71.2 years for females in 1999 (WHO 2000). The infant mortality rate was 24.2 per 1000 live births in 1996 (WHO 1998). Ten % of the children die during their first year of life (Micklin 1988). The main cause for infant mortality is diarrhea and related diseases.

Chemical pollution of the drinking water is claimed to cause chronic diseases like anemia and different types of cancers (lung, skin, esophageal, lymphatic and hematogenic organs). In the adjoining region of Karakalpakstan almost 80 % of pregnant women suffer from anemia. Uzbek health authorities have determined an alarming growth trend of the occurrence of cancers (NEHAP 1999).

### 3.3.3.3 Research Demand in Module C

Specific objective: Develop concepts for 1) protection against airborne pollutants comprising dust, salt and (possibly) pesticides brought to Khorezm from adjacent land as well as rather distant locations including the bottom of the Aral Sea, 2) mitigation of soil salinization processes and contamination with residual pesticides and 3) improvement of poor quality drinking water by reduction of its chemical and or bacteriological loads. For the three environmental problems the project aims at preventive rather remedial solutions.

#### Research demand

- **Provide background information and establish a GIS database for salts and pesticides in air**
- **Provide background information and establish a GIS database for salinity and pesticide contamination of soils**
- **Evaluate the quality of the drinking water supply in Khorezm**
- **Provide measures for the mitigation of these environmental stress factors**

#### Research questions

- What are the composition and freights of aerosols and what are the consequences for agriculture?
- What is the degree of soil salinization and contamination and how can soil quality be improved?
- What is the variability in quality of sources for drinking water and why?

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<sup>1</sup> These facts are based on the presentation of Kevin Andrews (Water Research Centre, UK) at the Conference on Global Change-Understanding the Earth System (1999 in Bonn), which was a summary of a study undertaken by him in support of the joint World Health Organisation/European Environment Agency Monograph on Water and Health in Europe (WHO/EEA 1999)

### 3.3.4 Resource Inventory, GIS and Remote Sensing (Module D)

Geographically referenced thematic information is a key element for the restructuring of land- and water-use in the Khorezm region. It is necessary that this information is provided in a reliable manner, easy to access and integrated in a GIS.

The current data situation, however, is extremely unsatisfying. The existence of data (maps, statistics, socio-economic data, etc.) is often not clear or contradictory data exist. The main problem is the dispersion of relevant data over different local institutions, often in different format and available only as “gray” literature; no homogeneous, easily accessible database exists. Furthermore, an exchange of data between institutions is not practiced. Much agricultural and ecological information needed as a basis for the specific questions in the present project is missing for the Khorezm region as well as for the entire Amu Darya delta.

In the framework of research work carried out at the German Remote Sensing Data Center (DFD) in the years 1993-99 in cooperation with international partners, a prototype GIS of the Amu Darya region has been developed (Dech 1993, Ressler 1995, Ressler 1996, Ressler 1999). The GIS integrates remote sensing data as well as other data sources; e.g. from digitized maps. Furthermore, multi-criteria analyses have been developed for the optimization of irrigated agricultural lands in the Amu Darya lower course and its delta area. The major goal was the reduction of the agricultural water demand through alternative land use models and the creation of a monitoring instrument for the ecological development of the region. In this framework, methods for information extraction from satellite data have been developed. The main part of this work was carried out in the framework of a Ph.D. thesis and in cooperation with international partners funded by the NATO Science for Peace Program or the SPOT Vegetation Program. An overview is given on the DFD web page [www.dfd.dlr.de/app/land/aralsee/index.html](http://www.dfd.dlr.de/app/land/aralsee/index.html)

These research activities concentrated on investigations covering the complete Amu Darya delta. The spatial resolution of the data used for the analyses is in the range of 1:200,000 to 1:1,000,000. This prototype GIS shall be used in the project as a basis. However, a completely new conceptual approach for the GIS is necessary in order to further develop the prototype system to a central project database. Moreover, data with higher resolution are necessary for the Khorezm region, which have to be acquired and integrated into the GIS. An example of how the data will be structurally linked to each other in the database and used for modeling is given in Figure 11.

Recently, a project "Sustainable development of ecology and land and water use through implementation of a GIS and remote sensing center in Karakalpakstan, Uzbekistan" has been approved, which is funded by NATO Science for Peace program (project leaders: Prof. Micklin, Dr. Ressler). This NATO funded project is focusing on Karakalpakstan, however, some of the data in this project cover the whole Aral Sea region and will be used in this project as well. Moreover, an exchange of scientific results is envisaged, which ensures that the synergy between both projects is used as much as possible.

#### 3.3.4.1 Research Demand in Module D

In particular the following problems are unsolved:

- No consistent data base on the region exists
- Some maps exist, however these are not area-wide, vary in quality and actuality, are of insufficient scale, etc.
- Up-to-date information is needed for several analyses
- No water use agreement exists between Khorezm and Karakalpakstan, unregulated water consumption causes water shortage
- Up to now no controlling system is available for water consumption regulation
- Khorezm and Karakalpakstan are the ecological most damaged areas of all areas along the Amu Darya, rehabilitation measures are most crucial
- In the last 20 years there has been a significant drop in agricultural productivity in Khorezm
- No irrigation adoption systems exist for high or low flow years of the Amu Darya

The GIS and remote sensing activities play an essential role within the project. All project activities concerned with the ecological restructuring of the landscape are based on analyses that are related to geographically referenced

thematic and cartographic information. Moreover, the economic and legal-administrative studies also rely on basic information provided by the GIS.

Therefore the establishment of a central project database is essential. This easy-to-access database will allow every project member access to all relevant data (digital raster and vector maps, tables, statistics, etc.) and avoid duplicate data acquisition.

The main activities of the GIS and remote sensing group will be

- To generate and operate the central Project Database,
- To establish a GIS center in Urgench,
- To develop methods for information extraction from remote sensing data,
- To acquire and integrate existing map information,
- To update old and generate new digital maps based on remote sensing technology, and
- To support the selection of the pilot farm by providing relevant thematic information layers.

In addition to the agricultural tasks the GIS and remote sensing activities will work on the ecological monitoring of defined crisis areas in the Aral Sea region and the Aral Sea itself.

### 3.4 Research Cluster: Economic Analysis

The transition of the Uzbek economy from plan to market has merely started in the 1990s. With regard to many economic indicators, Uzbekistan seems to be better off than neighboring countries (Alam & Banerji 2000).

In Uzbekistan, agricultural markets that are of utmost importance for the management of land and water resources throughout the country are far from functioning efficiently. The legacy of the Soviet system still dominates the pattern of land and water use and remains one of the major sources of environmental disaster. The large scale production units, kolkhozes and sovkhozes, did not use the production factors land and water due to marginal cost considerations but on the basis of pre-determined production objectives. Because the “central planner” proved unable to evaluate the social costs of land and water appropriately, these large-scale production units over-exploited resources and created diseconomies of scale. Inter-generational considerations were not part of economic decision-making. After a period of several decades during which the trend towards large-scale monoculture agricultural production units combined with large-scale irrigation schemes had persisted, the Aral Sea dilemma culminated on the eve of transition in a situation in which the environmental catastrophe was said to be irreversible. Instead, international and domestic agencies started to acknowledge that the question was now how to cope with the environmental stress factors such that the emerging land and water use patterns become sustainable again. However, related institutional market arrangements that allow for higher ecological sustainability of land and water use must also be achieved together with higher economic efficiency and be culturally acceptable to the local population. The identification of alternative land and water use patterns which meet this objective provides the motivation and is the challenge of this inter-disciplinary research project.

It is widely acknowledged that the environmental problems in Uzbekistan which are linked to land and water use practices are significant and that the underlying causes are very complex. Against this background the government of Uzbekistan has developed the “*National Environmental Action Plan*” in 1999 which allocates top priority to decision-making on integrated water, land and salinity management in order to achieve a more sustainable agricultural production system. The objectives of this Action Plan are the following (United Nations: 2):

1. Improving the health of the human environment,
2. Increasing the effectiveness of the use of natural resources and halving the economic damage caused by the exhaustion of natural resources,
3. Protecting the most vulnerable and valuable elements of Uzbekistan’s nature.

This Plan acknowledges the pivotal role of agricultural markets, agricultural policies and institutional reforms in an attempt to develop an effective and sustainable agricultural sector. Additionally, in a recent report by UNDP (2000: 40) the objectives of the *agricultural reform agenda* for Uzbekistan were summarized as follows:

- Improve farmers' incentives to eliminate massive price distortions in input and output markets
- Stimulate efficient use of water by gradually transferring the responsibility for the operation and maintenance of irrigation from government agencies to water users.

The economic analysis relates to the 2<sup>nd</sup> objective of this "National Action Plan" as well as to the two major objectives of the agricultural reform agenda. However, it is not clear what type of reform can best serve these objectives. The multitudes of market and policy distortions in Uzbekistan that are, to a large extent, due to the legacy of the Soviet era, prevent the identification of simple solutions. The "transition from plan to market" is not a linear process in which the major elements of market oriented reforms, namely liberalization, privatization, and macro-economic stabilization could be implemented in a technocratic way. Instead, it is necessary to analyze which opportunities the *transition process*, which has merely started in Uzbekistan, offers to reach a more sustainable and more efficient resource use.

The first major research question of the economic analysis is therefore:

- **Which changes to the agricultural production system, to agricultural policies, and to agricultural markets are essential to improve the economic efficiency and at the same time the environmental sustainability of land and water use in the Khorezm region?**

However, as the National Environmental Action Plan recognizes, any alternative solutions of land and water use must also have positive effects on the health of the human habitat. There is no doubt that the intensive use of toxic chemicals in large-scale agriculture and the salinization of drinking water is hazardous for human health. In the Aral Sea region pollution of the ecological system primarily affects woman and children. Over 75 percent of pregnant women and 78% of children suffer from anemia (Report on Women's Health and Access to Health Care, CER 2000). The extent of the problem is widely under-researched.

The second major research question of the economic analysis is therefore related to health issues:

- **What are the effects of current land and water use practices in Khorezm on the health of the local population and what are the economic implications of these health threats? Which type of land and water use restructuring would reduce the negative economic effects on human health of the local population?**

Hence, any proposed alternatives of land and water use will not only have to meet criteria of ecological sustainability and the concomitant economic efficiency but also of human health.

Human health aspects, besides being a matter of humanitarian concern, also have important economic dimensions as the local populations' health status affects the "human capital factor" which is, in addition to land, water, and capital the other most important production factor in agriculture. The negative effects of current agricultural production systems on human health are likely to also be costly for the Uzbek society.

In order to address these complex research questions the economic analysis will be split into three research modules. The first two research modules will deal with the first research question. The third research module will address the second set of research questions:

- **Farming systems and regional markets** for food and agricultural inputs: Economic analyses and studies (Module E)
- **Resource management and water pricing** (Module F)
- **Health economics:** links between land and water use and health of local population and related economic effects (Module G)

Tables 9 and 10 provide an overview of some socio-economic indicators that are illustrative for the development of agriculture, the economic situation in Uzbekistan and the health situation of the population. Figure 12 shows the output performance of gross domestic product (GDP) and gross agricultural output (GAO) of Uzbekistan in the

1990s in comparison with other economies in Central and Eastern European Countries (CEEC) as well as in countries of the Commonwealth of Independent States (CIS). The relatively moderate output decline of both, GDP and GAO, is not the result of a more successful transition from plan to market but rather an indication that the transition process has merely started. In fact, this development suggests that the state-dominated sector has been preserved or even extended while the informal economy, which has become such an important source of economic restructuring in other transition economies, is still relatively unimportant (IMF 1998). Estimates by Johnson et al. (1997) showed that the share of the unofficial economy in Uzbekistan was with 9.5% in 1994 and 6.5% in 1995, much lower than in most other economies of the Former Soviet Union.

There is no easy way to assess the degree of the negative environmental externalities on the health of the rural population and the specific causality between current land and water use practices and the human health status in the study region. Possible solutions to these problems range from administrative bans (e.g. of pesticides) to particular taxes (e.g. on fertilizer) or bargaining agreements with or without public intervention (e.g. on water use). What approach is taken is a question of public choice. The question is what kind of procedures are currently being used, what their effectiveness is, which kinds of impediments may be in place, and under which circumstances improvements may be feasible.

### 3.4.1 Market and Farm Level Analyses (Module E)

#### 3.4.1.1 Economic Research on Transition

The term '*transition*' refers to the *set of reforms and their timing and sequencing* with which a country realizes the *system switch from plan to market*. The *initial conditions* on the eve of transition (e.g. resource endowment) have shown to be one crucial factor influencing the economic results of this process. Furthermore, the country-specific *mixture of reforms* as well as the *timing and sequencing of reforms* are considered important for the economic results of the transition process. While Uzbekistan is rich in natural resources and is endowed with a well-educated population and a qualified labor force, the country has chosen a gradual transition strategy (World Bank 2000). In fact Uzbekistan's economic performance in the 1990s has been rather mixed (see Table 11).

Various cross-country studies have assessed to what extent the transition process has induced economic restructuring (e.g. World Bank 1996). Analysis of agricultural sector is an important component of such studies because of the relative importance of agriculture prior to the transition and because of the particularly strong output decline in many transition economies. A number of these studies proposed quantitative models for this analysis, often based on neo-classical theory, but extended by incorporating some of the peculiar characteristics of the transition process (e.g. Brockmeier et al. 1998, Häger et al. 2000, Wehrheim et al. 2000). The theoretical basis of such adapted models stems from what could be called a *theory of transition* (e.g. Blanchard 1998, Hagedorn 1998, Johnson 1998).

#### 3.4.1.2 Agriculture in Transition

Reform opportunities in the transition process also affect the agricultural sector that has been de-collectivized in the transition process only at the margin. While the former *kolkhozi* and *sovkhozi* continue to exist, the private subsidiary plots (LPH) have gained in importance. In fact, because of this phenomenon, agricultural production has assumed a dualistic structure with the large-scale former collectives as the centerpiece and the small-scale production units as ever more important complements. The related implications of these changes in Russia have been studied in detail by ZEF researchers (Wehrheim et al. 2000). The effects of the new agricultural production structure on household expenditures, incomes, and therefore also on poverty have been analyzed based on micro-economic surveys of households in various regions (i.e. oblasts) of the Russian Federation (e.g. von Braun et al. 2000, Tho Seeth et al. 1998). Also, institutional features of the transition process that have hindered the emergence efficient agricultural markets have been addressed (Wehrheim 1998). Regional policymaking plays a pivotal role for the question if agricultural producers are subsidized or taxed (Melyukhina et al. 1998). Macroeconomic developments such as the emergence of fiscal deficits or exchange rate misalignments have also had a substantial effect on the potential of agriculture in the transition process (Serova et al 1999, Wehrheim & Wiebelt 1998, Wehrheim 2000).

Market distortions similar to those identified in the Russian Federation are likely to prevail in Uzbekistan. Yet, some features of the Uzbek economy are characteristic for this country and its distinct cultural, historical and political background. It will be one of the tasks of the project to identify these economic characteristics and incorporate them into the economic analysis and models.

#### 3.4.1.3 Research Demand in Module E

- **Development of various economic models as decision support tools to assess implications of various land and water restructuring given the institutional constraints of the Uzbek society**
- **Support of farm level decisions in the areas of farm restructuring, alternative farming systems and landscape conservation measures**

Research questions

- What is the current economic situation of different types of agricultural producers in the Khorezm region?
- What are the economic incentives within different farm types with special emphasis on resource use?
- What is the economic viability and efficiency of alternative farming, irrigation and conservation practices?

#### 3.4.2 Resource Management and Water Pricing (Module F)

##### 3.4.2.1 Economics of Water Scarcity

The economics of water scarcity, institutional reform, and water pricing are the focus of an ever-increasing body of theoretical and empirical literature. Many country studies simply review the institutional conditions of water exploitation and explore the possibility of alternative arrangements (e.g. Ali 1999 for South Africa). Others are based on economic modeling approaches that often are not very precise on the ecological features of water use. Mukerjee (1996), for instance, developed a computable general equilibrium model for the Olifants River catchment in the Transvaal/South Africa. While such a model has great potential to look into the economy-wide effects of various water policies it can only analyze inter-sectoral (i.e. between different sectors in the economy) *but not* geographical distribution of water resources. Other authors provide decision support systems for water resource policies that are either based on optimization or on dynamic simulation techniques (e.g. Simonovic & Fahmy 1999). Ringler (1999, cf. also Ringler & Rosegrant 1999) developed such a model for the Mekong River basin. Her model indicates the complex trade-offs that arise when water resources are to be redistributed among various nations adjacent to such a huge river basin. The model has the potential to provide helpful, analytical insight into the economic effects of various scenarios of water resource distribution. Yet another type of water management model with an economic component was proposed by Rosegrant (1998) who developed a highly disaggregated world food and water model which allows comparison of various scenarios of water scarcity and effects on world food markets from a global perspective.

Water models will have to deal with the substantial trade-offs between economic, ecological, and policy demands on this resource. A relatively large number of water management models exist. The choice of model and the final decision on the focus of the model should be driven by the objectives of the research. A recent review of existing modeling approaches is provided for instance by McKinney et al (1999). The presented models can serve as *blueprints* for the development of a suitable water management model for the Khorezm region that will be tailored to the specific needs of the project.

##### 3.4.2.2 Economics of Water Problems in Uzbekistan

Various papers on land and water use practices provide a relatively detailed discussion of the economic inefficiencies of the irrigation system in Uzbek agriculture and, hence, the problems associated with water management (e.g. Thurman 1995; Lerman et al 1996). Only few water management models appear suitable to analyze the present state of water management for the Republic of Uzbekistan and can be used for a quantitative assessment of alternative policy scenarios.

GLOBESIGHT is a decision support system for the allocation of available water resources in the whole Aral Sea Basin rather than a specific water management model (Schlüter et al. 2000). This model deals with *population* on three levels of detail driven by population growth rate, crude birth and death rates, and fertility/mortality, respectively. The *economy* is represented in terms of four sectors: agriculture, energy, industry, and services. Growth of the sectors is driven by domestically generated investments and the portion of export earnings (energy, agriculture, etc.) allocated to different sectors. *Agriculture* is represented in terms of food and industrial crops. Production is specified in terms of land—irrigated and rain-fed—and yields. Feedback from the income per capita influences caloric demand per capita and, therefore, food demand. A feedback is provided to indicate the need for an increase in land and yield for food production in response to the increase in caloric demand. The *energy sector* is made to depend on foreign, in addition to domestic, investments. Anticipated earnings from the energy exports are allocated to industrial sectors, agriculture or services, in pursuit of reaching the vision.

The *water model* has supply (with recycling) and demand in terms of irrigation, industry and domestic use. Water irrigation demand is driven by land and assumed water use efficiency, while industrial and domestic uses are determined by industrial and population growth, respectively, modified by the respective efficiencies. Water flow to the Aral Sea, referred to as water balance, is the supply remaining after use (Schlüter et al. 2000: 5). The Aral Sea Basin model was used to analyze various development options for the basin. Whereas the model will be instructive for the specification of a water model for the Khorezm region it is rather crude and would not enable us to carry out the specific assessment of various land and water use strategies in this region.

A river basin model for the Amu Darya River in Uzbekistan has also been developed at DLR which is part of this research consortium (*Group D: GIS and Remote sensing*). Its focus was on agricultural cropping patterns and land use practices. The model could be a starting point for the model developed within this project. The important extension would be to add further economic components and endogenize the water price. If this could be achieved, the model could become a very valuable tool for quantifying allocative effects of different institutional arrangements in water use.

### 3.4.2.3 Research Demands in Module F

This review indicated that there is not a lack of water management models as such but instead a lack of truly interdisciplinary water management models which are detailed enough to allow for analyzing policy alternatives which will be acceptable for the various constituencies. In fact, no model explicitly takes into account the institutional and political constraints that prevent the implementation of available knowledge in more efficient water management strategies. We therefore envisage the following research demands:

- Provide decision support for the development of market-oriented irrigation systems to improve economic efficiency and environmental sustainability of land and water use practices in the lower Amu Darya River area, more specifically the Khorezm region.
- Develop an interdisciplinary water management model with a relatively high level of regional disaggregation. The modeling approach has to be chosen such as to provide sufficient details on economic, institutional, and ecological aspects of water use in Khorezm. Therefore the individual components have to be modeled individually but parallel to each other. In an early stage the components have to be linked with each other and then need to be enhanced consecutively in order to make their “interiors” more realistic. One of the major challenges will be to design the model in such a way that it will be able to reflect the institutional constraints that are responsible for the inefficiencies in the management of water resources in the region.

Research questions:

- How can various components (economic, hydrological, and institutional features) of water management models be linked to represent a complex water management problem – such as that of the Khorezm region in Uzbekistan - most realistically?
- What are the economic effects of alternative cropping and water management systems for agricultural producers and rural households?
- What are viable alternatives to current forms of water management?

- What alternatives have the potential to be beneficial with respect to three objectives: improved economic efficiency, enhanced ecological viability and high political acceptability?

### 3.4.3 Health Economics (Module G)

According to official sources Uzbekistan has achieved a relatively high health standard. The number of doctors per capita, the average life expectancy at birth, and the infant mortality rate give the impression that the health of the local population is in a relatively favorable condition, even on a regional level (Tables 12, 13). Various special programs of the government of the Republic of Uzbekistan indicate that high priority is given to the health status of woman. Since 62 percent of the country's population lives in rural areas substantial efforts are made to provide health care to women in rural areas (CER 2000).

However, even official reports acknowledge that the maintenance of these high standards has become ever more difficult in the course of the transition. Because of the economic output decline the country experienced in the early 90s, both the budgetary expenditures and the total expenditures for the health system declined substantially (UN 2000; Table 14). The picture becomes gloomier when looking at reports of some international agencies (e.g. Médecins Sans Frontières, MSF 1998). Herein it is claimed that: "The tragedy of Uzbekistan originates in a cotton monoculture forced on it by the former Soviet Union (FSU) and still practiced today. ... The Aral Sea region has the highest level of anemia in the world and infectious diseases are increasing. With one of the highest levels of TB prevalence in all of Europe and the FSU and at risk from cholera and typhoid epidemics that have broken out in neighboring regions, the country also faces alarming increases in cancer and kidney diseases." (MSF 1998: 1). Reports of the WHO also acknowledge the dramatic improvements in the number of hospitals and doctors but at the same time point out that the increasing incidence of serious diseases raises the question about the effectiveness of the health system and about the health status of the country's population given the severe environmental conditions (WHO 1996).

#### 3.4.3.1 Research Demand in Module G

The study of health issues in Khorezm regions will serve the following two major research needs:

- Identification of efficient policies to reduce negative externalities on the health of the local population of land and water use practices in the lower Amu Darya River area
- Socio-economic analysis of health effects with particular emphasis on alternative land and water use practices in the region

#### Research questions

- What are the effects of current land and water use practices in Khorezm region on the health of the local population?
- What are the links between economic and environmental factors that determine the health status of local population?
- What are the economic implications of the expected negative effects on human health?
- What are the costs of environmental stress for human health and human productivity?
- Which restructuring of land and water use in the Khorezm region has the potential to reduce the negative effects on human health and the associated economic costs?

### 3.5 Research Cluster: Legal-Administrative Studies

While the symptoms of the Aral Sea syndrome at first sight may have suggested a problem of purely agro-technical character, a closer look at the underlying reasons clearly showed the problem's complex nature. Problems of agricultural production closely relate to – and often derive from - the **legal-administrative situation** and the **institutional system**. Measures such as the introduction of incentives to save water or the privatization of small farms are being stifled by a still widely unchallenged planned economy with fixed quotas for crop production. The

state is legalizing transfer of land from former state owned farms to private users on the one hand, but on the other hand – and inconsistently – is maintaining a fixed overall area under cultivation for cotton. Water is centrally assigned and inefficiently administered. Undefined user rights and maintenance obligations create legal uncertainty – impeding private initiative and investment in new areas of production, etc.

This has been repeatedly stated by international development organizations including the IMF (IMF Staff Country Reports 96/73, 97/98, 98/116), by the Uzbekistan government (Karimov, Uzbekistan along the road of deepening economic reform, 1995) and the international research community (Eckert & Elwert 2000, Renger 1998).

Uzbekistan is facing the challenges of transformation on several fronts – among them building the legal-institutional foundations for a new administrative system and creating efficient and competent institutions that regulate the allocation of agricultural resources in accordance with the law. The government of Uzbekistan still seems to be tolerating a large gap between the adoption of policies and laws and their actual enforcement. Many reforms exist only on paper or are implemented selectively (Nunn / Rubin / Lubin 1999).

With the project's overall goal in view - **improving the economic effectiveness and ecological sustainability of water- and land-use practices** – the subproject on institutional structure and regulatory reform will concentrate on **the question of which modifications of the legal framework, institutional organization, the attitude and behavior of actors involved are necessary to implement sustainable, efficient agro-systems.**

Land allocation and agricultural use of land, distribution of water and marketing of products all imply **decision-making on different levels** (local, regional, state, international) with governmental institutions and private interest groups involved. Corruption has been noted as an acute problem within the agricultural sector (IMF 98/116). International donors (World bank, USAID, EU) have injected large amount of hard currency into various Aral Sea water management projects, with parts of it being siphoned off as it passes through the bureaucratic channels of regional and governmental agencies (Micklin 2000).

The Uzbekistan Government has adopted a three-fold strategy by (1) further liberalization of the economy to reduce graft opportunities, by (2) strengthening the legal and judicial system to ensure the rule of law and protection of individual rights, and by (3) moral and public education on the evils of corruption (Karimov 1998).

The question is: how can the Government's strategy be more effectively enforced in a system without transparent norms and procedures, and administrative controls with discretionary authority. In order to answer this question two aspects – regulatory and institutional - will have to be addressed.

In recent years the impact of legal frameworks and administrative proceedings has again been paid increasing attention. While in the debate on “good governance” **institutional structure and arrangements**, interest groups and their conduct have been recognized as decisive factors in transformation processes, only in recent times **law** “as an instrument in development” when regarded **in its context** has been fully acknowledged (Faundez 1997). A set of rules and regulations exists - within the constitution, national legislation, presidential decrees and administrative provisions – that is relevant for the issues of agricultural production and land use. This includes property guarantees, organizational laws of the institutions involved, environmental laws and standards, tax laws, company laws etc. (Butler 1999). However, in the course of the transformation process, legislation is subject to frequent changes. Uzbekistan has continued to apply legislation of the former Soviet Union as far as it has not been superseded by new Uzbekistan legislation.

The creation and maintenance of institutions which offer secure guarantees of rights and obligations is inherently an outcome of political processes. Political dynamics in terms of power configurations, interest groups, and state-society relations bear on the nature of institution building and its proper functioning. What factors create and maintain the power configuration of the State and thereby fashion the relations with society at large is often related to the ways in which State institutions function. It is vital to gain a proper understanding of the incentives and disincentives of the actors to institutionalize checks and balances as a means of regularizing power in public decision-making processes (North 1990).

In this context, supranational developments will also be of relevance, as water demand in upstream regions may jeopardize or diminish the impact of changes in regional or local water policy. Tensions between riparian states due to cyclical fluctuation of water are to be expected, as the “downstreamers” try to maximize their share of water coming from the “upstreamers” (Micklin 2000).

## Research questions

In the context of evaluating the regulatory and institutional situation it is important to assess **the implications of changes within the water- and land-use system, possible options and their legal and political feasibility and local acceptance**. Therefore, the present situation will have to be analyzed with the following questions to be addressed:

- What is the legal situation regarding property/ownership/user rights and obligations concerning resources?
- What are the institutions involved in the decision-making process on agricultural resources on the different levels?
- What has been done by the other donor organizations with regard to the legal-administrative level, and where and why did they succeed or fail?
- How are they structured, how are competences allocated and what are the respective procedures?
- What interest groups can be identified?
- How is the decision-making process functioning with regard to de-facto power relations between official and non-official actors?
- What is the local population's perception of institutions and procedures related to water- and land-use, their strategies for influencing them?
- What is the local population's attitude towards changes?

These questions will be pursued within the following three modules:

- Land allocation and agricultural use of land (Module H)
- Water administration – allocation and use (Module I) and
- Sales and Profits of agricultural products (Module K)

### 3.5.1 Land Tenancy and Land Use (Module H)

#### 3.5.1.1 Land Tenure in Transition

Following independence, all state farms were transformed into collectives (called *shirkat*, meaning company). They cultivate more than 70 percent of arable land. Internal reorganization resulted in new forms of ownership, mostly shareholder unions, but also joint stock companies and farmers associations. The Land Code has been amended several times since independence and land tenure has generally remained insecure. The agricultural land is leased for a maximum of 49 years. Some private land exists for the construction of private houses, and the small gardens around the houses (maximum of 2 500 m<sup>2</sup>) can be considered as a factual private property. As the state provides agricultural inputs (fertilizers, machinery, etc.) and is involved in the maintenance and rehabilitation of the irrigation system, the benefits of privatization are not obvious for the farmers. Privatization therefore is a controversial issue in Uzbekistan.

Some studies have been made on reform concepts regarding land tenure in countries undergoing transformation processes. China and some former socialist East European countries are prominent examples (Herrmann-Pillath 1989). Only during the last few years has there been some research concerning agricultural reform in Uzbekistan. While some research is being undertaken on restructuring the agricultural production - focusing on tracing recent economic developments, analyzing economic performance and identifying problems - few studies have been made on the latest developments in land tenure (Eckert & Elwert 2000) and the legal-institutional aspects of restructuring of the agricultural sector. Ilkhamov (1998) summarizes the positive and negative characteristics of the "Uzbek model" of transition to the market economy, focusing on the broader legal-institutional context of farm-restructuring, and especially illustrating the role played by the chronically indebted collective farms that in many respects operate as a hybrid between command and market organizational forms.

The principle of no private ownership of land in Uzbekistan has not changed after independence, and all land remains under state ownership. The constitution and most laws and decrees opt for usufruct and hereditary tenancy

as the dominant substitute for private property of land. Although private ownership is constitutionally forbidden (land cannot generally be bought or sold), the government has permitted modifications to the rule by allowing private ownership of land under certain conditions (Decree of the Cabinet of Ministers 3/1995). However, rights usually connected with ownership and possession, especially the right to raise a loan on the land, have not been clarified. It is generally assumed that the reform potential and the flexibility of the system are low, but this does not mean that the Uzbekistan Government is not interested in reform. Part of the country's transformation strategy is to insist on an "Uzbek way". This might be best explained as having to cope with the existing structures. A collective consciousness still pervades the new private farms, so that for the owner there is little contradiction between private ownership and the reality that all production from the farm goes to the state.

The existing studies indicate that unclear or contradictory legislation cause confusion and uncertainty. Agricultural policy and the legal regulations concerning access to and administration of resources do not, so far, amount to a congruent policy, but rather to piecemeal results, that come along with partial ideas of what land tenure should look like afterwards.

### 3.5.1.2 Research Demand in Module H

- **A thorough analysis of the complex land tenure legislation, its unclear areas and contradictions**
- **An evaluation of policies and resulting approaches in other countries in order to develop options for streamlining the blurred definitions of property rights**
- **An analysis of the de-facto situation of institutional and political mechanisms for land allocation and land tenure**
- **An assessment of institutional constraints for reform resulting from deficits in organization or competences, from interests, constellations, attitudes and behavior of actors**
- **The design and development of feasible ways for realizing reforms.**

Research questions are:

- How is land tenure and land use currently regulated? What types of tenancy/leases/ownership exist? What legal reforms have been introduced?
- What institutions are involved in allocation of land and what are their competences and interests?
- What is the local people's way of dealing with the situation?
- How do definitions of rights and titles, institutional structure, competences and interests and local strategies relate to present reform achievements and future reform options?

### 3.5.2 Water Administration, Distribution and Use (Module I)

#### 3.5.2.1 Water Administration in Uzbekistan

Water administration in Uzbekistan is of unusual complexity with numerous institutions involved. Not having changed much since independence, the system is highly centralized and all major decisions are taken at the highest level of the political system (President, Cabinet of Ministers). Several ministries, quasi-ministerial organizations and research institutes are in charge of water management in Uzbekistan.

The Ministry of Agriculture and Water Resources, that controls the surface waters, is considered the most powerful stakeholder in water administration. It is responsible for water policy and strategic planning, preparation of water legislation, provision of water to the agricultural sector and operating the hydraulic works and structures. The Ministry of Agriculture and Water Resources has subordinated executive bodies (Main Departments of Agriculture and Water Resources) in each oblast (province), and these supervise several District Departments on the rayon (district) level. Apart from passing data to higher administrative levels and issuing orders to the subordinated units, the Oblast Water Management Department assesses farms' water-demand plans, distributes water after supply assessments, registers water consumption, controls violations and takes care of the irrigation system infrastructure and investments.

The Hokims, as executive bodies of the president on the oblast and rayon level, approve water needs assessments, water distribution plans, and investments for operation and maintenance. They are responsible for implementing “decisions of superior agencies” (Art. 101 Const.), which also includes meeting the cotton and wheat production quota. With their political existence being linked directly to meeting the expectations (Art. 93 No.12 Const.), the Hokims play a crucial role in water administration.

The Rayon Water Management Department as the local level water administration is in charge of the allocation to the rayon’s farms, operation and maintenance of inter-farm irrigation systems. It has to determine the water requirements for each farm on the basis of cultivated area, water-holding capacity of the soil and crop type to be produced. Little attention is paid to the operation and maintenance of irrigation.

### 3.5.2.2 Reform Options in Water Management

Three reform models are relevant in the current discussion of national water management. The first acknowledges water as an economic good, that consequently should be privatized and marketed (Fishelson 1994). According to this view the lack of pricing or inadequate pricing is seen as the main constraint in using the water efficiently. “Willingness to pay studies” (WTP) show evidence that households, including poor households are willing to pay for enough water of good quality (Whittington 1992). The privatization of water resources can be implemented to various degrees. The second, “centralized” concept, on the other hand, emphasizes the role of the state in water management, using national water institutions and national regulation of water use in a centralized system (Caponera 1992, Frederiksen 1992, 1994). “Ideal” water management institutions, laws or regulations are presented as a tool to achieve “efficient” resource use. In the third model, it is not seen as contradictory to transfer part of this management task to private entrepreneurs, as long as the overall resources control remains in the hand of the state (Carney 1995). This hybrid concept, similarly to the other two, carries the danger of inflexibility, not taking into account the individual country’s or region’s conditions, such as legal traditions, local water users’ habits, etc. Researchers in the field of New Institutional Economics (NIE) and Common Property Resource Management (CPR) showed evidence that local communities are successfully managing their resources (Ostrom 1990). Ostrom argues that institutional management of the resources on local levels can be diverse and effective.

A lack of a market, even a controlled or regulated one, in water supplies has been identified as one of the primary obstacles to independent farming in Uzbekistan. Even if farmers assert their right to private land (difficult in itself), they still face great difficulties getting the local water officials, usually tied to the larger collective farms, to provide them with the water they need. Reports indicate that the enforcement of water pricing laws is used more as a carrot or stick to ensure political loyalty or elicit bribes than as a real means to distribute water efficiently or increase state revenues (Nunn / Rubin / Lubin 1999).

Pricing water, a policy often recommended by foreign advisers, remains controversial. Water has been allocated without charge through administrative decisions, a system that encourages waste. Some form of pricing will ultimately be necessary to give consumers an incentive to use this scarce resource wisely and to pay for the maintenance and improvement of the vast system used for its distribution. As with land reform, however, sudden and drastic implementation of new water pricing laws could have a destabilizing effect because enterprises and individuals may not have the financial resources to pay water charges. Fair and comprehensive water pricing may be impossible in the short run in any case, since many areas lack equipment for measuring water consumption (Nunn / Rubin / Lubin 1999).

As mentioned above, water administration in Uzbekistan is of unusual complexity. There are many institutions involved in water administration with activities being highly fragmented - all pursuing their own interests, all somehow in charge of something related to water policy. The elaboration and implementation of an integrated coherent water policy that takes economic and ecological requirements into account seems extremely difficult. Cooperation between the various institutions seems to be lacking. Competences and responsibilities of the various institutions are not clearly defined. In practice, functions and activities overlap. On the other hand, certain issues seem to be completely neglected.

Regulatory and institutional aspects have been identified as crucial for improving water allocation. Recent research indicates: “Generating rules for the allocation of water and the formation of water use associations remains the most fundamental need for managing irrigation water resources” (Babu & Tashmatov 2000).

Before introducing any changes – for decentralization or privatization - the existing water allocation system needs careful study.

### 3.5.2.3 Research Demands in Module I

- **An analysis of the legal framework, structure, competences and procedures of allocation of water**
- **A study of the institutions involved in water allocation at the different levels, the political rational and the national water policies**
- **A study of the water allocation at the local community level, the difficulties and options**

Research questions are:

- What are the regulations and principles on which water allocation is based?
- What are the institutions involved at the different levels, and what competences do they have?
- How is the agricultural producers’ perception of the system and what are their strategies for obtaining water?
- What are the changes in the institutional system necessary to move towards efficient water allocation that balances the requirements of users and of the environment?
- What are the institutional and political difficulties on the local level that have to be overcome for the implementation of reforms?

### 3.5.3 Sales and Profits of Agricultural Products (Module K)

The economic transformation of the agricultural sector raises questions of institutional, political and social feasibility. Political power dynamics, interest groups, incentives and disincentives for following certain decision-making processes may all be at odds with the transformation process.

The position of the agricultural producer in Uzbekistan at this stage of transition is marked by the uncertainty whether he/she will be able to make a living from his own production. This uncertainty is reflected in the fact that the agricultural producer generally has several sources of income. The income often results from misuse of the infrastructure and resources of the kolkhoz with the effect, however, “to render the Kolkhose both necessary and inefficient”. The state tolerates many of these practices as a compensation for the devaluation of regular income, as they also represent an essential element in securing the basic income. Thus the kolkhoz plays a key role in the strategy of the rural population. (O.Roy 1997) His situation is compounded by the changes in laws and regulations to which he/she has to continuously adjust. The farmer’s position varies depending on the type of agricultural production unit he belongs to.

During the last few years state orders on agricultural products have changed. Almost two thirds of the cotton and wheat crop may be sold in Uzbekistan under free market conditions by the agricultural producers and only about one third is supposed to be sold to the state. Nevertheless, authorities have de facto maintained a system that ensures sales of the major crops to the government at low state order prices (IMF 98/116). This is not only due to certain strongly entrenched interests, but also to under-development of local agricultural markets. From the local perspective the marketing of self-manufactured products represents a major problem, since small private producers - which make up most of the so-called “grey sector” of the economy - are frequently at the mercy of non-registered marketing groups for the transportation of their products to the markets.

An additional problem is that some regulations with regard to sale at markets contradict each other, and in some cases impede improvements in other areas (savings in water, mitigating environmental stress). The implicit and explicit state support for agricultural producers, which has included the subsidized or free provision of inputs (e.g. water, fertilizer, electricity), investments financed from state budget, tax exemptions or debt cancellation apparently needs to be adjusted parallel to other reforms.

### 3.5.3.1 Research demand in Module K

- **A study of legal and de facto marketing opportunities, regulations and institutions that takes into account the agricultural producer's level of information and legal status**

Research questions are:

- What is the producer's current legal position as to the control over his products?
- How do institutional structures and interests affect a producer's position with regard to the marketing of his products?
- How can the institutional framework with regard to the marketing of products be restructured to better serve the local agricultural producer?

#### 4 Human Capacity Building

UNESCO (2000 a) has stated that education and science culture in relation to water management require an urgent and complete overhaul in Central Asia. (“The Academies of Sciences have not been able to come up with coherent plans to reorganize taking into account the changed economic and political situation. There is very little long-term ecological research going on and there are no young scientists”; UNESCO 2000 a). Restructuring and change both need education and training.

The majority of research and teaching institutes in Uzbekistan were part of a larger regional system organized and funded by the former Soviet Union. Many of these institutes had a worldwide reputation for excellent research, however, since the breakdown of the Soviet Union, the funding to these institutions has become very limited. Their role as part of a centralized, but dynamic research organization has been drastically diminished. The lack of improvement in human resources together with low wages have created a research environment that is not responsive to the real needs of the transformation and development processes. Researchers in Uzbekistan are experiencing an ever-growing sense of isolation, resulting from a lack of access to current scientific literature and contacts with colleagues in the well-funded research institutes outside the country. Investments in human capital will raise education levels, contribute to higher living standards, and provide the Central Asian countries with well-trained people that can lead them in the transformation processes.

Therefore the ZEF project approach includes a strong teaching and training component. A key element of the proposed program is a series of activities that will build the linkages needed to give young researchers in Uzbekistan access to the modern scientific community. Among these are: a program for Ph.D. and M.Sc. students, special training courses, short-term stays of guest scientists at ZEF in Germany, and workshops. The project will develop a specific environment for fostering an interdisciplinary approach to the project-relevant research questions.

Long-term arrangements (Ph.D. and M.Sc. students): The implementation of the project will need considerable work of M.Sc. and Ph.D. students. Students will be selected from among the most qualified students from Germany (Western Europe) and Uzbekistan (Central Asia), particularly from the universities of Urgench, Nukus, and Tashkent, aiming at parity in numbers from the two cultural backgrounds. The students will become involved in research through their Ph.D. or M.Sc. theses. The Central Asian students will have the option to participate in the Ph.D. program at ZEF (if they speak English) or in Uzbekistan. Generally, one to two master students will cooperate with a Ph.D. applicant. The Ph.D. students will be supervised and supported by a scientist from Uzbekistan and another from Western Europe. Scientists working in the project will also be invited for lectures. ZEF can draw on its pool of internationally leading scientists who, together with scientists from Uzbekistan, can be integrated into the studies program as visiting professors. Thus, we hope to be able to establish a dynamic and flexible education program.

The project will develop a scientific study center at the University of Urgench (SUU) that will provide the intellectual framework as well as the structural facilities for students from Uzbekistan, Germany, and eventually other countries to carry out their studies locally in the district of Khorezm with relative ease and comfort. Laboratory and office facilities and a project guest house will be set up in Urgench, providing work space and housing for students, their supervisors, and guest researchers. ZEF’s previous evaluations in Uzbekistan showed that renting a building for this purpose will be unproblematic and costs relatively little.

Short-term arrangements: Training courses will be offered on special topics, i.e. GIS and remote sensing, modelling, survey methods etc. Scientists from Uzbekistan will be offered the opportunity of scientific work at ZEF or other research institutes in Germany. Workshops will be held regularly to strengthen the interdisciplinary exchange within the project and to provide internationally recognized opportunities for scientific presentation including publishing of peer-reviewed workshop proceedings. Special emphasis will be put on activities that allow Uzbek government officials and scientists to get a grasp of the methods, concepts and technologies to be introduced during the implementation of the project.

## 5 Scientific Cooperation

The project is based on a cooperation axis between two main centers: State University of Urgench (SUU) and Center for Development Research (ZEF, Bonn). As the project is focusing on the region of Khorezm, the projects' central installations will be at the campus of the SUU. SUU has already earmarked about 10 laboratory rooms on two floors in one of its buildings for the project. The rooms include lab and office space as well as one small auditorium (see Space needs).

The project will be executed under the auspices of the UNESCO, a centrally important partner for ZEF. UNESCO will serve as the primary interlocutor with the Uzbek government for the project. A liaison office has been set aside in its headquarters in Tashkent. It will also help establishing the necessary structure (refurbishing of the lab and office buildings at SUU) and facilitate import of equipment. Any payments to scientists and institutions in Uzbekistan will be channeled through UNESCO. All equipment imported into Uzbekistan under the auspices of UNESCO will eventually become property of the receiving institution.

Scientific projects partnerships include but are not restricted to the following partners:

The Forestry Research Institute (Tashkent) and the State Forestry Committee of the Republic of Karakalpakstan (Nukus) will work on the forestry studies (Task A1). Forestry experiments (nurseries) will be set up at appropriate places in Khorezm and at the nucleus in Nukus.

The Agricultural Production Systems (Task A2) will be implemented with the help of SUU, TIAME and the Institute for Aquaculture Research. Possibly, other partners will be asked to join (e.g., the Uzbek Institute for Crop Production Research in Tashkent).

Several institutes work together on Module B. For the irrigation water aspects, the renowned institution SANIIRI in Tashkent is the ideal partner. Most soil analyses will be made under contract research at the Soil Institute in Tashkent; however, a basic soil lab will also be set up in Urgench. Another participant will be Dr. Khazankhanova at the Institute for Agriculture and Water Resources of Uzbekistan (UZGIPROMELIOVODKHOZ).

The Fraunhofer Institute for Environmental Atmospheric Research (IFU) in Garmisch-Partenkirchen and the Center for Ecology of Water Management at the State Committee for Nature Protection of Uzbekistan (Gozkompriroda; Tashkent) will coordinate the activities within Module C, in which the SUU, ZEF, and TIAME (see below) will also participate. The Center for Water management Ecology has an excellently equipped specialized lab for pesticide analysis.

The German Space Agency (Deutsche Luft- und Raumfahrt, DLR) in Oberpfaffenhofen (see below) will take the lead in module D; carrying out the research together with ZEF, SUU, the Karakalpakstan State University (Nukus), and the Institute of Geography remote sensing group, at the University of Bonn. As the GIS/remote sensing activities are at the core of the project, providing the central data base compilation for the project, a GIS lab will be set up by the SUU, in close cooperation between the institutions, and backed by DLR and Nukus. This may also serve as the starting point for a GIS lab for Khorezm in the future, building on the experience of a former project by the DLR and Karakalpakstan State University.

The Max-Planck-Institute for Ethnology (Max-Planck-Institut für Ethnologie) in Halle will cooperate with ZEF in Module K. Especially the Department for Legal Pluralism and Ethnology (Rechtspluralismus und Rechtsethnologie) will participate in Module H to contribute its expertise concerning the social-anthropological aspects with regard to land tenancy.

The teaching cooperation will consist of a partnership mainly between ZEF's Doctoral program, the SUU and the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers (TIAME). Students from Uzbekistan suitable for ZEF's Ph.D. program will be invited to apply for the program and possible DAAD stipends. Suitability is assessed from analyzing the grades ("Baccalaureat" or Magister; or possibly the old Russian Diplome), and English language skills (a TOEFL score of 550 points is needed) of the candidate. Candidates not conversant in English will

be encouraged to seek graduation in Uzbekistan. Good baccalaureat candidates can apply for admission in the Masters program ARTS at the University of Bonn.

Cooperation with international donor agencies in the Republic of Uzbekistan in the Research Cluster Economy: Centre for Economic Research (CER), Tashkent. Several international donor agencies are providing technical assistance in an effort of the government of the Republic of Uzbekistan to strengthen the country's economic research capacity. Most notable is the support granted to the "Centre for Economic Research" by The World Bank, TACIS, UN and other international and national donor agencies. The CER not only carries out sophisticated economic research of international standard but more importantly makes the respective results accessible on its well-documented homepage ([www.cer.uz](http://www.cer.uz)). The economic research reports of the CER will provide good coverage of economy-wide developments which can serve as starting points for addressing the more detailed regional analysis of economic forces shaping land and water use in the Khorezm region. Any open questions on the links between macro-economic developments and the development of regional agricultural markets, policies, and other economic developments should be coordinated with the CER in an attempt to produce synergies.

Médecins Sans Frontières. MSF has initiated a project that attempts to mitigate the negative effects of current land and water use practices in the Aral Sea basin. An exchange of ideas and scientific approaches with the local team should be helpful. ZEF has established contacts with the local MSF team .

### 5.1 The German Remote Sensing Data Center

The German Remote Sensing Data Center (DFD) Oberpfaffenhofen is a research institute and service provider dedicated to the task of remote sensing within the organizational structure of DLR. DFD operates a complete ground segment for the acquisition, processing and distribution of remotely sensed parameters of the oceans, the land surfaces, and the atmosphere. The activities include methodological issues, the development of processors, and most important the investigation of the utilization potential by developing methods and value-added products to promote both the scientific and public application of earth observation data. The transfer of these prime objectives into operational systems requires a complex service infrastructure, a large software and hardware capacity, experience in operational handling of huge data amounts, and a widespread national and international co-operation. The long-term nature of this service provision implies clear concepts and functional capabilities that are very general, open in their approach and adaptable to change. About 60% of this work is carried out on a contractual basis in the form of projects. DFD co-operates with universities, with other DLR institutes, and with governmental agencies.

The thematic fields DFD is specialized in, which are relevant for the project, can be summarized as:

- Remote Sensing Ground Segment for various satellite missions, e.g. ERS-1/2, Landsat 7, IRS-1C/D, NOAA-AVHRR, TERRA-MODIS, etc.;
- Remote Sensing Applications and GIS, e.g. Land-use classifications using multispectral and synthetic aperture radar (SAR) data from various sensors, environmental monitoring and analyses.

Relevant project experience. In the framework of research work carried out at the DFD in the years 1993-99 in cooperation with international partners, a prototype GIS of the Amu Darya region has been developed. The GIS integrates remote sensing data as well as other data sources (e.g. from digitized maps). It has been installed at the Ministry of Agriculture and Macroeconomy in Nukus. Furthermore, multi-criteria analyses have been developed for the optimization of irrigated agricultural lands in the Amu Darya lower course and its delta area. The major goal was the reduction of the agricultural water demand through alternative land use models and the creation of a monitoring instrument for the ecological development of the region. Within this framework sophisticated methods for information extraction from satellite data have been developed.

The main part of this work was carried out in the framework of a Ph.D. thesis (Ressl 1999) and in cooperation with international partners funded e.g. by the NATO Science for Peace Program or the SPOT Vegetation Program. An overview is given on the DFD web page [www.dfd.dlr.de/app/land/aralsee/index.html](http://www.dfd.dlr.de/app/land/aralsee/index.html)

## 5.2 The Fraunhofer Institute for Atmospheric Research (IFU)

The Fraunhofer Institute for Atmospheric Environmental Research (IFU) conducts studies into the influence of human activities on the chemical composition of the Earth's atmosphere, and the consequent effects on the environment. The work of the Fraunhofer IFU focuses on hazardous substances of relevance to the environment that contribute to climate change, UV radiation and regional pollution. The Institute employs an integral approach to determine emission levels, the atmospheric transport and the chemical transformation of pollutants, and to ascertain their effect, for example on natural and agricultural ecosystems, thereby taking synergies into account. These activities include long-term measurements of trace substances and UV radiation at local stations, backed up by measurement campaigns in the field and laboratory investigations. The development of numerical models for simulating the atmospheric transport and the chemical composition of pollutants, as well as regional climate change, plays a role that is constantly gaining in importance. These models are used to derive measures towards reducing emissions, to assess environmental compatibility, and to determine suitable locations for wind power stations. Collaboration takes place with industry to further develop and market measuring systems, including software, for monitoring of emissions and their environmental impact, and for measurements under external contract.

The Institute has vast experience in studying environmental problems in developing countries. Previous research projects include studies on 1) atmospheric pollution in Mexico-City, 2) air chemistry in East and South Africa, 3) regional climate and hydrology in Ghana, 4) methane emissions from Asian rice fields and from the Amazon and 5) microbial processes in tropical forest soils.

## 5.3 Space Needs

The State University of Urgench (SUU) has already agreed to provide a building which offers the necessary office and lab space for the project, as well as running costs for electricity, hot water and heating. The building will be empty, but SUU will provide basic fixtures. Nevertheless, the building will need to be reformed and equipped to western laboratory standards. A suitably equipped staff/student hostel (guest house) will also be needed under the living conditions in Urgench. Such facilities can be rented near the SUU campus, but they will need to be brought to western sanitary and furnishing standards. As a large part of the activities (especially the Economy and the Legal-Administrative Studies Research Clusters) is to be carried out in Tashkent, and in view of the hotel costs in Tashkent, a small apartment will be rented here to be able to provide basic living space for scientists. Unesco will support the reformation of the building with architects. When finished, the building will also be a visual demonstration of the long-term commitment of the partners in this cooperative project.

## 6 Time Plan (Schedule of Activities)

The time schedule is to be detailed for each task at the beginning of the project by the scientists involved in the task.

## 7 Costs

Costs will occur for initial investments in laboratory and office establishment (cf. Chapter 6 Space Needs), and for running costs during the three project years. Initial investments concern upgrading and refurbishing of lab and office space, and the scientific equipment needed for the project at the University of Urgench, as well as cars and field measuring equipment for experimental work at the intended project center. Running costs relate to salaries for a German/West European scientist (project coordinator), the salary of the GIS coordinator in Urgench (expected to be an Uzbek scientist), BAT1/2 salaries (for German Ph. D. students) and stipends (for Ph.D. students from Central Asia) and M.Sc. students (from Uzbekistan), as well as travel costs. Research costs will cover expenses for small equipment, gasoline, and work-related consumable materials (stationery and lab requirements). We further request an amount for public relations material (to be produced in Uzbek, Russian, and English language), workshop organization and publication costs, and service contracts to Uzbek research institutes and individual counterparts. This is justified in view of the small budgets most research institutes face in Uzbekistan, to allow for the adequate execution of these tasks. Roughly, the project will require an amount in the order of 3.9 million Euros, of which 0.5 million Euros are expected for stipends to Uzbek students from the Ministry of Science and Research of the State of Northrhine-Westfalia, with the remainder coming from the German Ministry of Science and Education (BMBF).

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Table 2: Some parameters of the Aral Sea; historically, currently and in the future. (Ivanov et al. 1996)

	1960	1992	2015?
Lake Area (km <sup>2</sup> )	66900	30900	13000
Water Volume (km <sup>3</sup> )	1056	255	n.a.
Salt concentration (g l <sup>-1</sup> )	10	40	100

Table 3: “Effective norms” for an optimum share of forest shelterbelts, established by the All-Union Research Institute for Agroforestry Melioration (Kayimov 1993, Tarasenko 1988)

Region	Optimum Percentage of forest in landscape
Ukraine	7.9
Caucasia	6.7
Russia	2.2-6.7
Khazakhstan, Middle Asia	3.5
Belorussia and Baltic Republics	2.0

Table 4: Climatic data (long-time averages) from the meteorological station in Urgench (Matyakubov 2000; Bogdasarov et.al. 1997) Et<sub>0</sub> = Evapotranspiration

Month	Air Temperature °C	Air Humidity %	Precipitation mm	Et <sub>0</sub> (Penmann) (1998) mm	Absolute Minimum Air Temperature °C
1	- 3.7	86	15.8	12	- 17.3
2	- 2.3	79	7.9	22.9	-15.4
3	4.9	74	17.5	48.3	-8.7
4	14.4	48	17.3	131.6	0.1
5	21.6	53	10.5	168.6	7.4
6	26.4	50	2.2	226.9	12.5
7	28.2	49	0	224.5	15.9
8	25.7	56	3.5	181.6	12.8
9	19.4	51	1.9	128.4	5.5
10	11.4	59	3.3	68.3	-2.6
11	3.8	62	14.6	39.9	-9.6
12	-1.6	77	0.9	20.2	-14.8
<u>Sum</u>			95.4	1273.2	
<u>Average</u>	12.4				

Table 5: Monthly average meteorological parameters for the meteorological station Chimbay (Ressl 1999)

	Month					
	April	May	June	July	August	Septemb.
Temperature [ $^{\circ}$ C]	13,1	20,5	25,2	27,1	24,1	18,6
Precipitation [mm]	13	16	3	4	3	2
Air humidity [%]	57	50	49	48	50	52
Wind speed [km/d]	354	371	320	294	276	233
Sunshine [h]	194	270,1	369,2	357,6	361,5	303,2
Et <sub>0</sub> /d [mm]	5,91	8,26	9,20	10,08	8,43	6,67
Sum Et <sub>0</sub> [mm; over 3 decades]	59,1 (over 1 decade)	256,1	276,0	312,5	261,3	200,1

Table 5a: Production of rice in the Khorezm oblast (Baraev 1989)

	Unit	1970	1975	1980	1984	1985	1986
Cultivation area	thousand ha	7,0	10,3	18,2	26,8	25,1	20,0
Production	thousand t	28,9	55,8	96,7	113,2	117,8	96,0
Yield	dt/ha	40,4			42,3	46,0	43,0
Irrigation application	mm	6540	6900	7000	6830	6400	6000

Table 6: Statistics of the Khorezm fish farm “Viloyat” in the district of Khorezm

	1990	1991	1992	1993	1996	1998
Ponds in ha	1224	1305	1305	1416	1324	1309
Product. in 1000 tons	3377	3504	3500	3604	1482	1118
Including com. carp	1978	1473	1685	1846	621	360
Including silver carp	1399	1440	1821	1758	857	757
Artificial food in ton	8769	9440	9032	10770	1954	2448

Table 7: Annual river flow (km<sup>3</sup>) in the Aral Sea basin (annual averages). From Ivanov et al. (1996)

Total water resources in the Aral Sea basin	123.31
Amu Darya basin	77.27
Syr Darya basin	37.58
Chu with Talas river basin	5.80
Tedzhen with Murgab river basin	2.66

Table 8: Variation of soil texture in the Urgench area (Tursunov &amp; Fathy 1984)

Coarse sand (1.0...0.1 mm)	Fine sand (0.1...0.05mm)	Coarse silt (0.05...0.01mm)	Fine silt (0.005...0.001 mm)	Clay (< 0,001 mm)
0.4...42%	5...72%	4...50%	8...24%	8...30%

Table 9: Change of GDP and other economic indicators in Uzbekistan. Source: International Monetary Fund: Republic of Uzbekistan. Recent Economic Developments (1998).

Real GDP (percentage change)	1993	1994	1995	1996	1997
Total	-2,3	-4,2	-0,9	1,6	2,6
Agriculture	1,5	-3,4	2	-7	4,2
Industry	-4,2	-6,6	-5,6	1,7	2,2
GDP at factor costs (percentage shares)					
Agriculture	31	38	32	26	29
Industry	25	19	20	20	19
Construction	6	6	8	7	7
Transport and communications	10	8	8	9	9
Trade	7	8	6	8	9
Other services	22	22	25	29	27

Table 10: General indicators on the government budget (percent of GDP) in Uzbekistan. Source: International Monetary Fund: Republic of Uzbekistan. Recent Economic Developments (1998).

	1993	1994	1995	1996	1997
Revenue	36	29,2	34,6	34,3	30,5
Expenditure, net lending, extrabudgetary funds	46,4	35,3	38,7	41,6	32,8
Balance	-10,4	-6,1	-4,1	-7,3	-2,3

Table 11: Production of selected industrial and agricultural products. Source: International Monetary Fund: Republic of Uzbekistan. Recent Economic Developments (1998)

	1991	1992	1993	1994	1995	1997
Mineral fertilizers (thousand tons)	1.660	1.361	1.273	811	943	954
Tractors (thousand)	21	19	12	2	4	3
Cotton harvesters (number)	5.800	2.350	2.155	651	1.121	1.049
Cotton sowing machines (number)	1.800	1.800	1.350	970	330	411
Cotton fiber (thousand tons)	1.532	1.404	1.258	1.385	1.238	1.125
Raw cotton (thousand tons)	4.646	4.128	4.235	3.938	3.934	3.641
Grains (thousand tons)	1.908	2.257	2.142	2.467	3.215	3.788
Potatoes (thousand tons)	351	365	472	567	440	686
Livestock poultry (thousand)	800	777	841	827	853	801

Table 12: Medical and health care indicators for Uzbekistan. Source: CER: National Human Development Report 1999 (<http://www.cer.uz>).

	1992	1993	1994	1995	1996	1997	1998
State expenditure on health (as % of total state exp.)	11,3	11,5	10,7	9,8	9,8	9,5	9,9
Total expenditure on health (as % of GDP)	5,5	5,7	4,6	4,3	4,4	4	3,6
Population per doctor	282	282	296	298	302	328	295
Deaths from circulatory diseases (as % from all causes)							
Total	43,4	45,4	46,2	46,5	46,7	47,2	50
Deaths from malignant tumor (as % from all causes)							
Total	7,9	7,3	6,8	6,9	6,8	6,8	6,8
Life expectancy at birth	1985-86		1990	1995	1996	1997	1998
Total	68,2		69,3	70,2	70,2	70,25	70,3
Men	65,1		66,1	67,8	67,8	68,1	68,2
Women	71		72,4	72,6	72,7	72,7	73

Table 13: Mortality rates in Khorezm. Source: CER: National Human Development Report 1999 (<http://www.cer.uz>).

Mortality rate by selected causes of death (per 100.000 people)				
	1996	1997	1998	
All causes	575,9	550,5	598,5	
Circulatory diseases	301,5	284,1	335	
Malignant tumor	31,1	25,4	29	
Respiratory illnesses	106,9	114	117	
Infant mortality rate (number of children died under age one, per 1.000 live births)				
	1995	1996	1997	1998
Total	25,9	23,6	25,1	24,7
Urban	27,7	27,8	34,4	34,4
Rural	25,3	22,4	22,6	22,1

Table 14: Selected Demographic and Health Status Comparison of Uzbekistan with other Countries. Source: World Development Report 1992, World Bank.

Indicator	Uzbekistan	Russia	Turkey
Birth Rate (per 1.000)	34,5	13,4	38
Life Expectancy at birth (years)	69,5	69,4	67
Total Fertility Rate	4,1	2	3,5
Infant Mortality	35,5	19,4	60
Maternal Mortality Rate	65,3	49	207
Population per:			
Physician	297	217	1390
Nurse	93	74	1030
% Urban Population	23%	52%	77%

Table 15: The allocation of tasks (legal-administrative research cluster) with regard to the main objects of research

	Land Use	Water Allocation	Agricultural Production
legal-regulatory	H1, H2	H2, I1	H1,K1
political-institutional	H1, H2	I1, I2	K1
social-anthropological	H1	I2	K1

10 Figures

Figure 1: The project activities are organized into three “research clusters” and 10 different “modules”

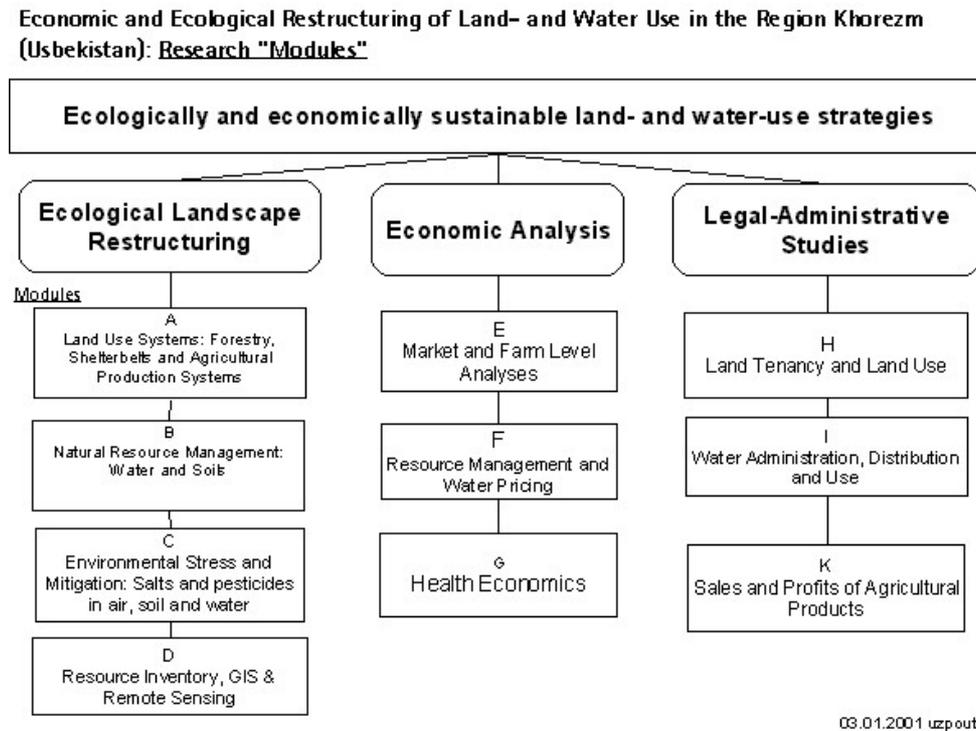


Figure 2: The hydrological system of the Aral Sea Basin (Bos 1996)

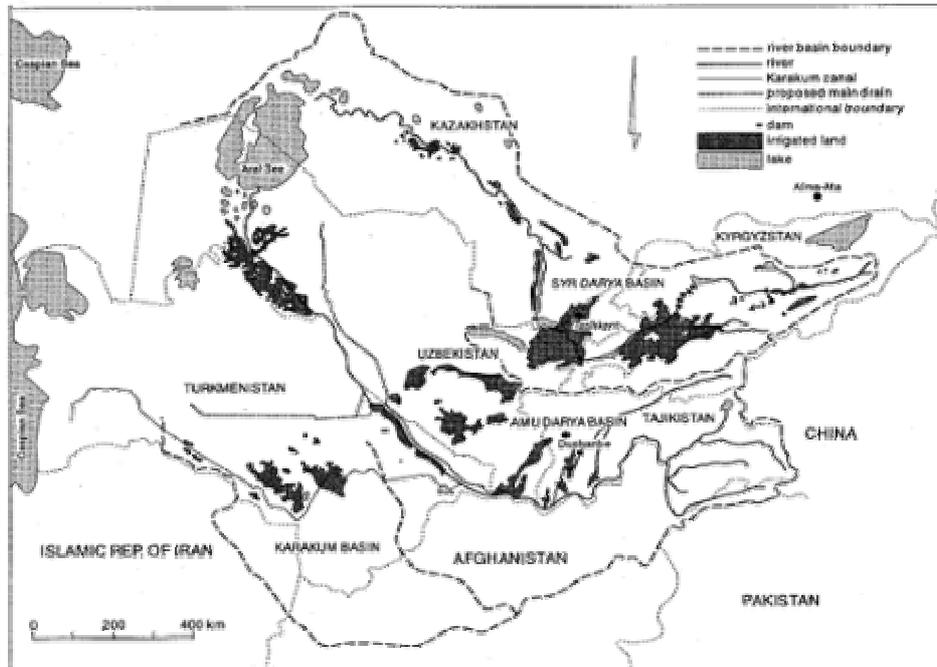


Figure 3: Expansion of irrigated area in the Aral Sea Basin 1900-2000 (Shirokova 2000)

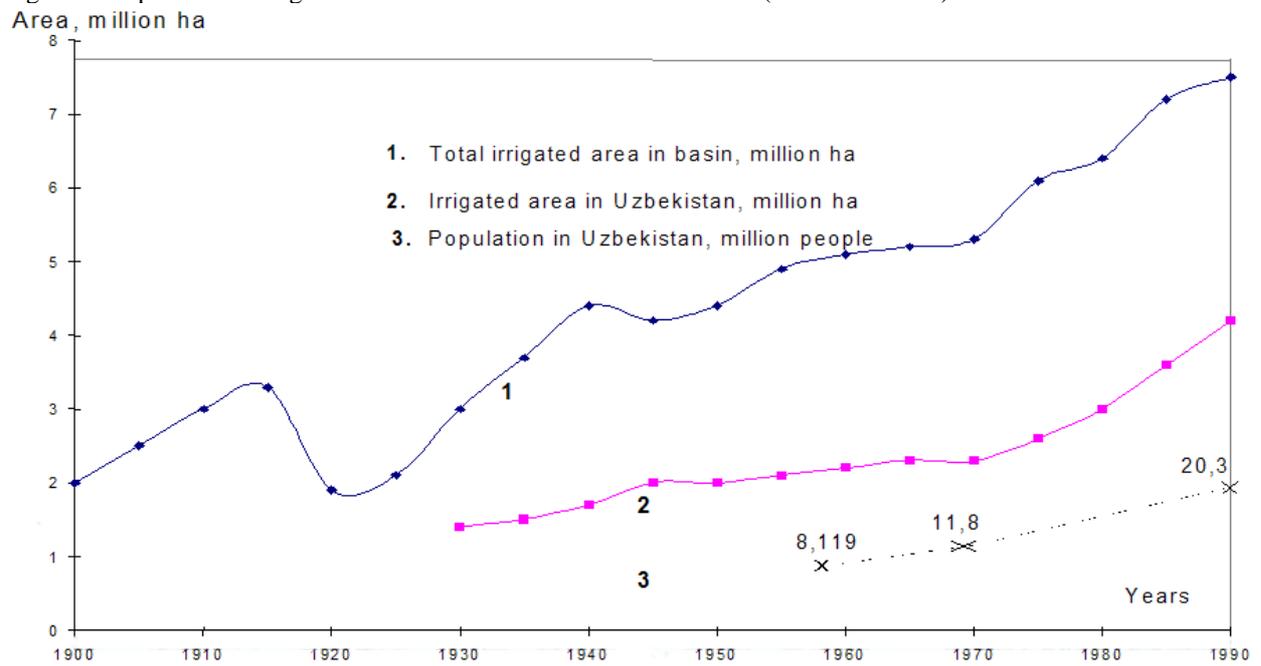


Figure 4: Characteristics of cotton production in the Aral Sea Basin 1900-2000 (Shirokova 2000)

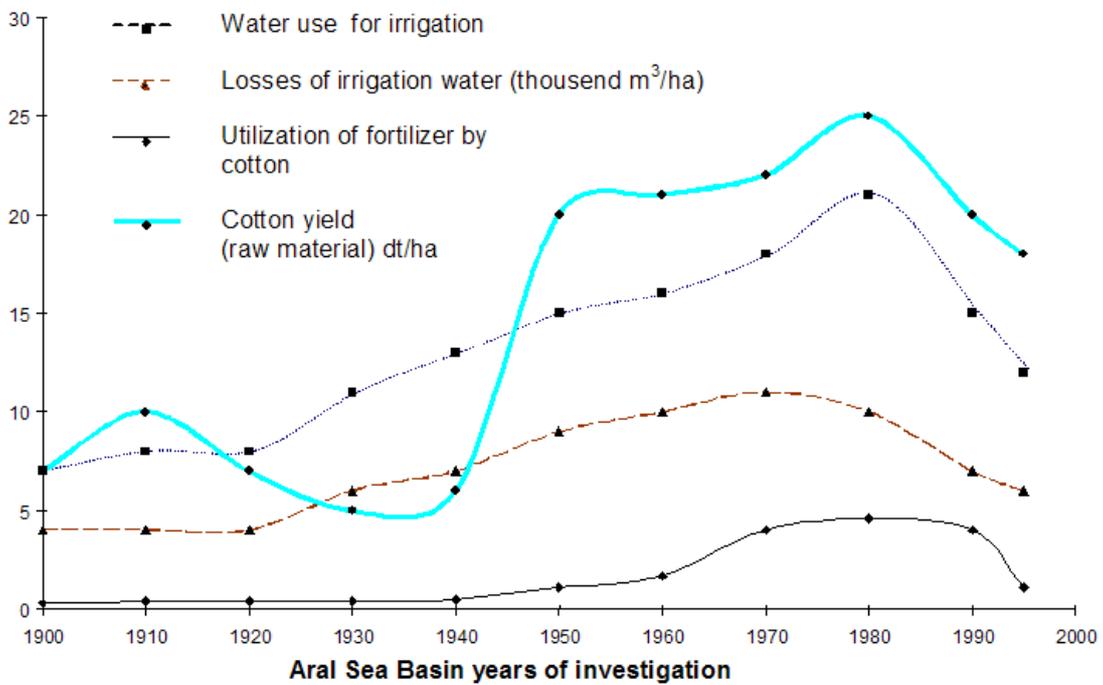


Figure 5: Cotton productivity in dt/ha during 1982-1999 in Khorezm (Matyakubov 2000)

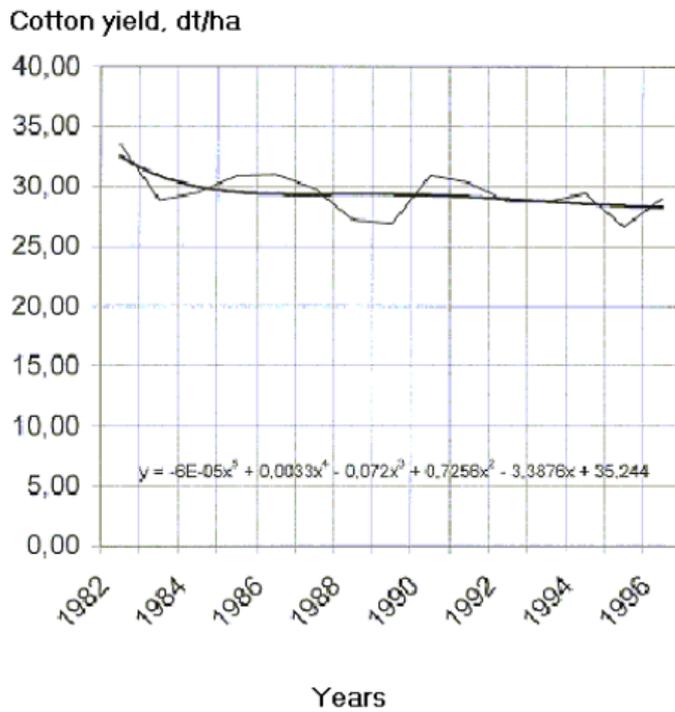


Figure 6: The irrigated area in Khorezm has steadily increased towards 275,000 ha in 2000 (Matyakubov 2000)

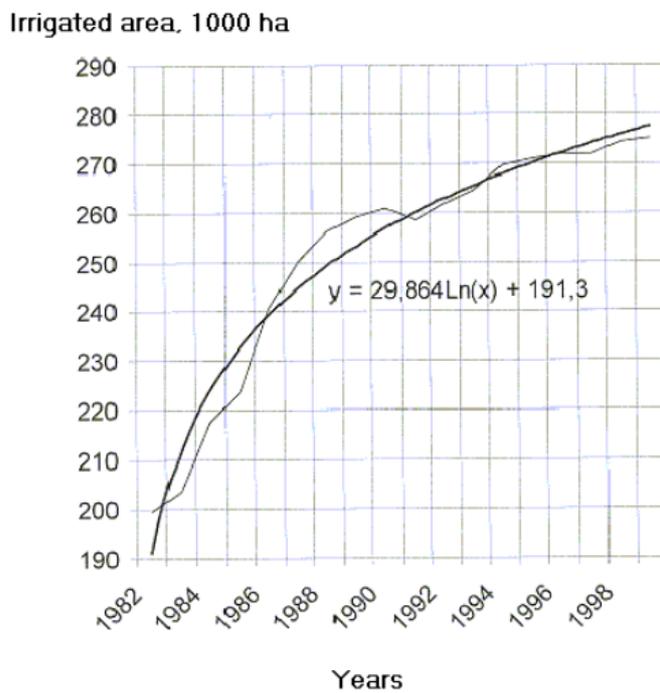


Figure 7: Dynamics of the ground water table between 1982-1999 in Khorezm (Matyakubov 2000)

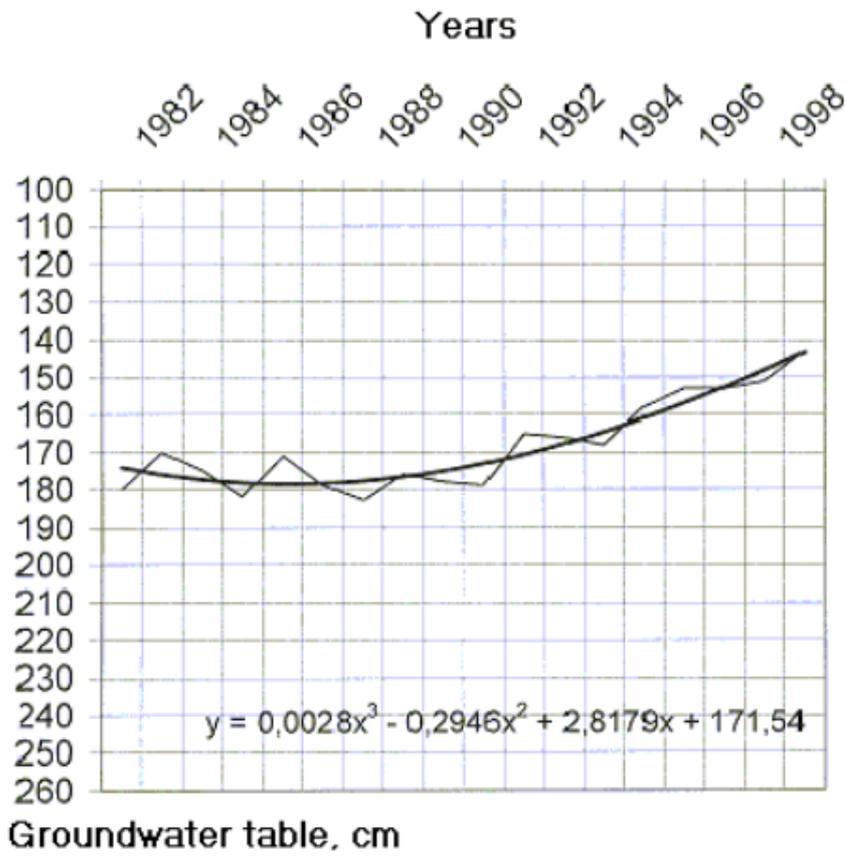


Figure 8: Cereals production and NPK fertiliser consumption in developing countries (compiled from FAOSTAT online, 1996)

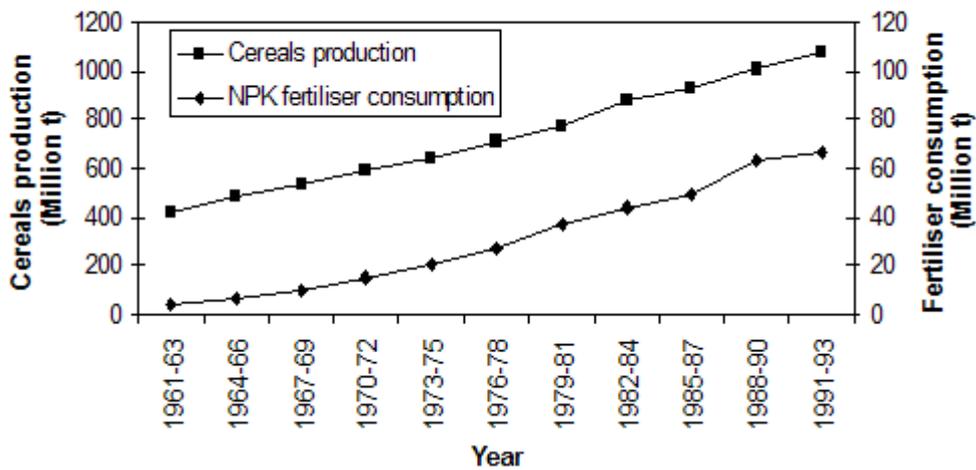


Figure 9: Salt affected irrigated area in some oblasts in Uzbekistan (Shirokova 2000)

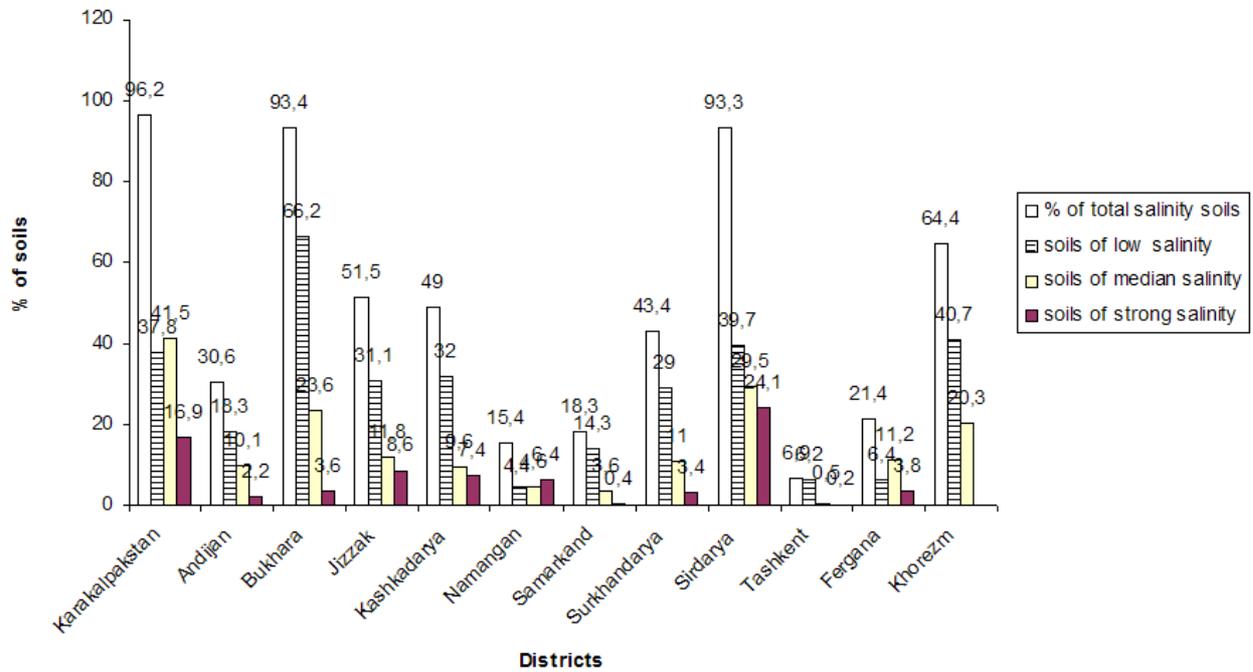


Figure 10: Pesticide use in Uzbekistan from 1985 to 1995

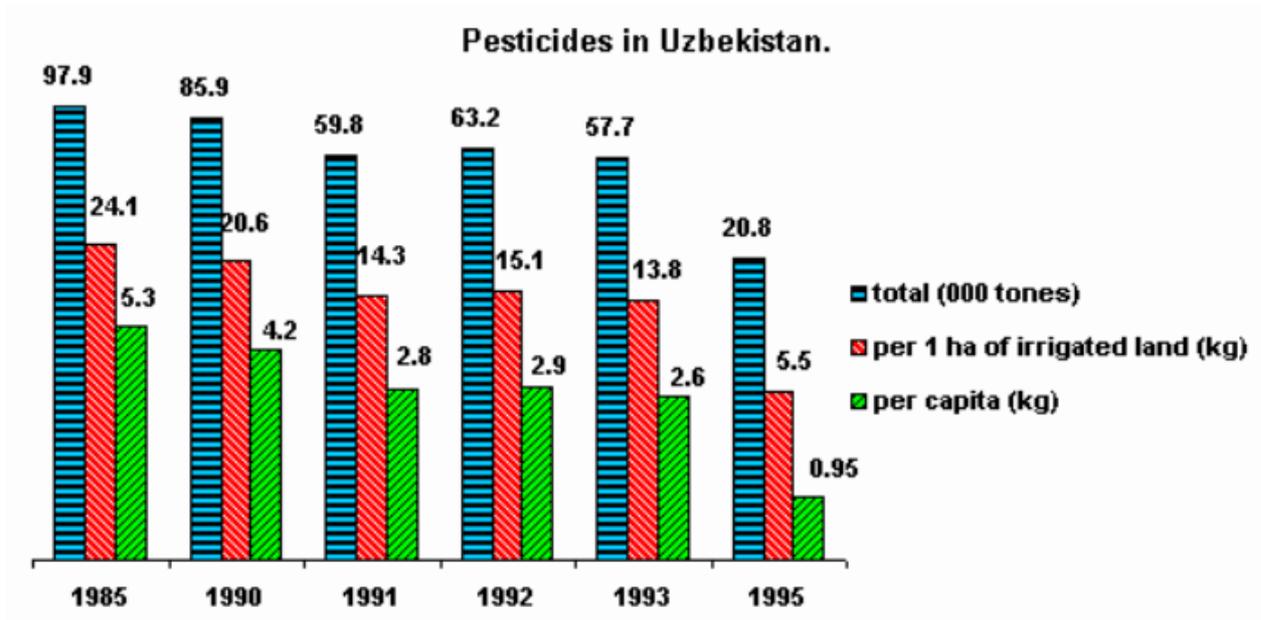


Figure 11: GIS Concept of the project (Module D)

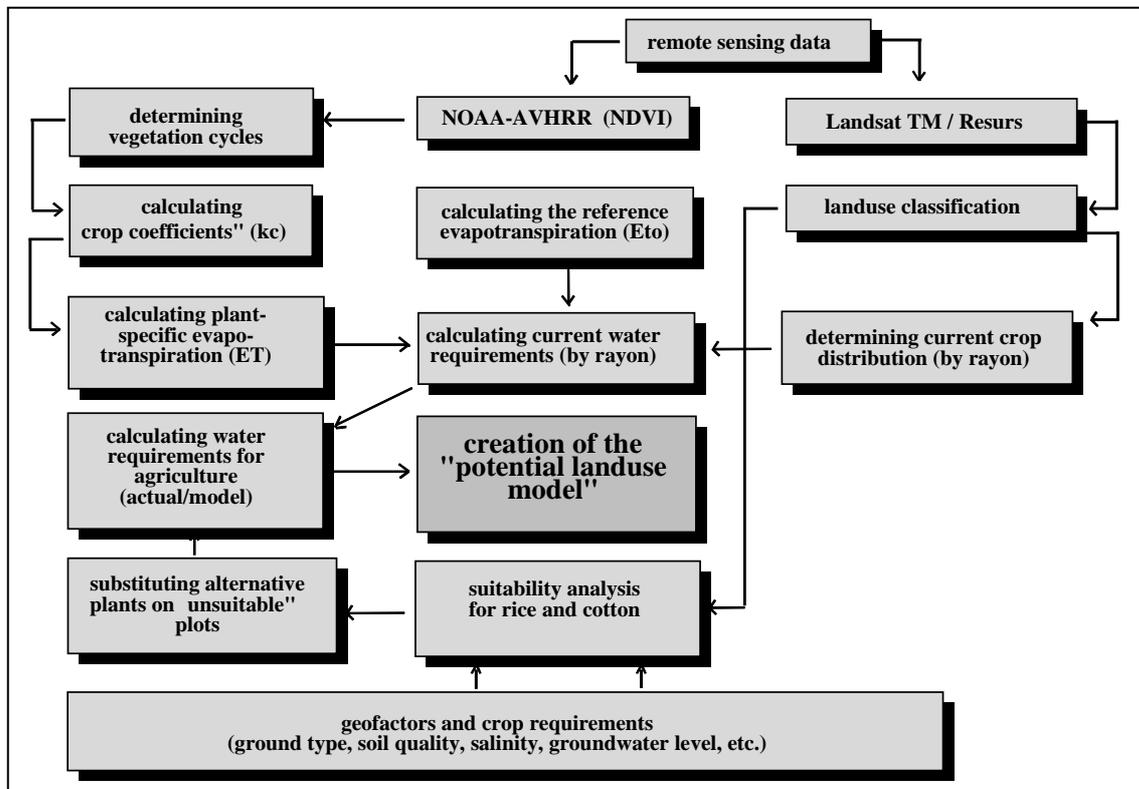


Figure 12: Development of gross domestic product and gross agricultural output in Uzbekistan in comparison to other countries in central and eastern Europe and in the Former Soviet Union (changes in % between 1990 and 1998). Source: own presentation; data from World Bank Development Indicators (1999)

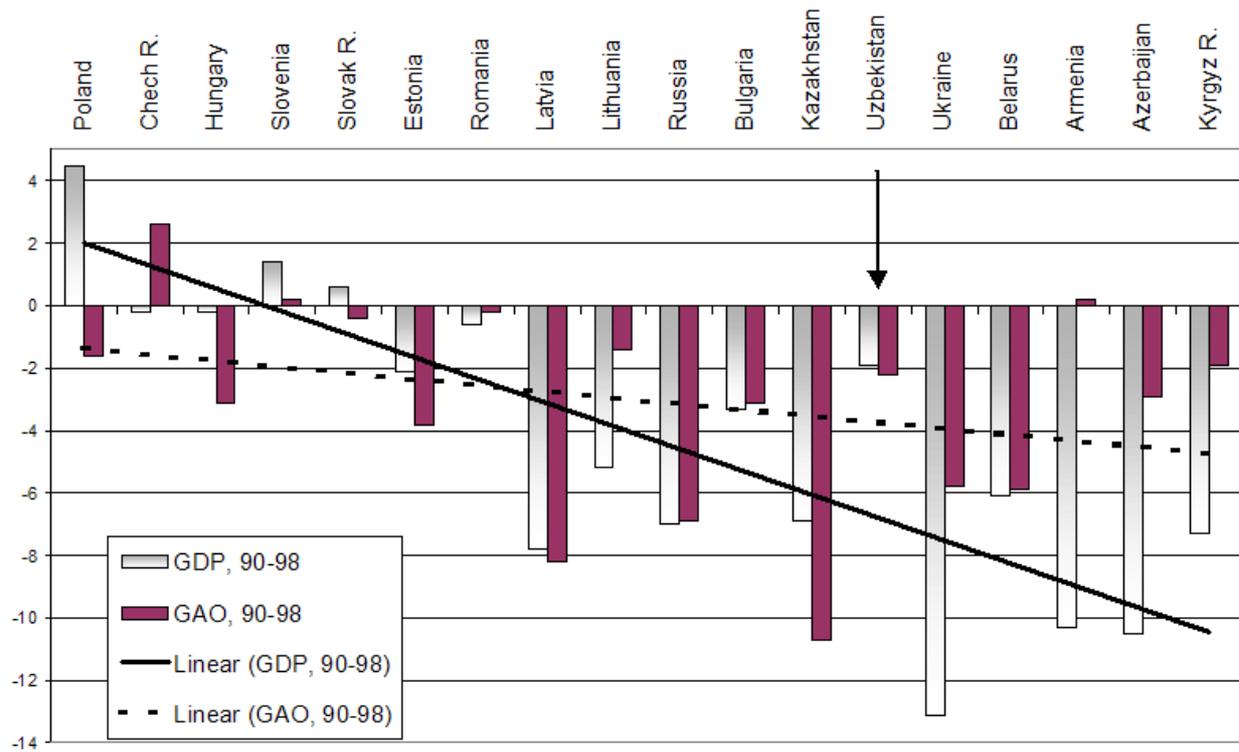


Figure 13: Concept of the MRA-GIS to be used in drinking water assessments (Task C3)

