ARAL SEA BASIN INITIATIVE

Towards a strategy for sustainable irrigated agriculture with feasible investment in drainage

SYNTHESIS REPORT

by

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Acknowledgements

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I had the good fortune to meet Harry Denecke, who was earlier project director of the IPTRID project, and who briefed me during the Rome visit on aspects of the history of the project not written up in the papers. I also benefited from a meeting in Rome with Yasin Sufi Mao, of Action against Hunger, who told me about his work in local rehabilitation of irrigation and drainage in Tajikistan. An email exchange with Sam Johnson III was also quite helpful. Thus Harry, Walter, Yasin and Sam provided the couleur locale I so sorely lacked. Many thanks to all.

PREFACE

The on-going shrinking of the Aral Sea in Central Asia is now considered one of several major environmental disasters that took place during the Twentieth century. With the diminishing water levels and the increasing salinization of its water, a once booming fishing industry that sustained the livelihoods of the surrounding areas has been shattered with the consequent displacement of a population faced with increasing poverty conditions. The origin of this tragedy can be traced to the withdrawals for irrigation water that took place in the 1980s and 1990s from the Syr Darya and Amu Darya rivers that flow into the Aral Sea, together the major contributors within the Aral Sea Basin. However, hidden behind the dropping of the sea level there is undoubtedly a parallel tragedy affecting a large number of farmers located in the five countries of the Aral Sea Basin: the slow sterilization of agricultural soils. A combination of climate, soils conditions and poor water management –translated into low irrigation efficiencies and insufficient drainage – led to an increasing deterioration of the land and the quality of water, increased salinization, increased water requirements to leach the affected areas, waterlogging, increased water withdrawals, and soon a vicious cycle of environmental degradation. Thus, contrary to the general belief that the falling levels of the Sea caused the surrounding salinization, it was rather the latter that eventually led to the decreasing size of the water body. In reality, these two phenomena are tightly interlinked leading to pervasive synergies to the detriment of the environment.

Against this background, IPTRID had approached the World Bank to discuss their regular support to the Programme. The discussions led to the idea of utilizing the Bank's support in an activity dealing with the situation in Central Asia. IPTRID was willing to add some of its other resources to this effort, mostly from contributions of DFID (Department for International Development), United Kingdom and DGIS (Ministry for Development Cooperation), The Netherlands. A proposal was therefore prepared that included the organization of a high-level International Conference in Tashkent, Uzbekistan to discuss the hazards of the on-going salinization process and other threats to the sustainability of irrigated agriculture, especially in the middle and lower parts of the Aral Sea basin. Furthermore, the end product would be a document entitled "Towards a strategy for sustainable irrigated agriculture with feasible investment in drainage," which would summarize the results of a number of studies that would be conducted through different institutions mobilized by the IPTRID Secretariat. This is that document which the reader now has.

The five participating institutions and their themes were, in alphabetical order:

- Alterra-ILRI, from the Netherlands, which dealt with groundwater hydrology as it relates to salinization and drainage.
- Brace Center for Water Resources Management, from Canada, which describes the existing inventory of drainage infrastructure.
- H.R. Wallingford, from UK, which looked into crop water requirements.

- Scientific Information Center-Interstate Committee for Water Commission, from Uzbekistan, which made an analysis of drainage conditions in the area.
- Water Watch, from The Netherlands, which utilized Landsat images to assess soil salinity changes.

These documents are included in the accompanying CD Rom. They are considered “working documents” meaning that only very slight editing was made and are presented as submitted by the institutions. Also, and in line with the proposed products of the study, the Proceedings of the Conference held in Tashkent in March 2004 are included in the CD Rom, again as a “working document.”

IPTRID is interested in supporting further studies and actions in this area of the world and will seek both new funding and partners to advance our present knowledge and propose remedies to a disconcerting problem. This document presents three indicative projects that address how to tackle and reverse the present trend of deteriorating drainage infrastructure of the affected area. IPTRID is to follow-up by supporting those institutions in the area that will be seeking funding with international organizations to carry out the proposals or related efforts.

The Programme would like to thank all institutions and their professionals involved in this effort. Likewise, there is a need to acknowledge the role played by my predecessor, Olivier Cogels, who was instrumental in putting together the initiative and to Harry Denecke, then Regional Manager for Asia, who carried the brunt of the implementation until his departure from IPTRID. Special thanks must go to our support staff, particularly Edith Mahabir, who provided unconditional support throughout the project. Finally, thanks to our consultant, Jacob Kijne who was responsible for the Project Summary, contained in this document. To our donors special thanks and we look forward to future support on this issue.

Please direct your comments and concerns, if any, to the IPTRID Secretariat in Rome.

Carlos Garcés-Restrepo
Programme Manager
IPTRID

Contents

CD-ROM CONTAINING:

1 Jansen, H.C. 2004. "Main characteristics of groundwater hydrology related to salinization and drainage". Alterra-ILRI, Wageningen, the Netherlands. Pp 56.

2 Pearce, G. 2004. "Overall irrigation water use efficiency in the Aral Sea Basin". H.R.Wallingford, Wallingford, UK. Pp 22.

3 Scientific Information Center-Interstate Committee for Water Coordination. 2004. "Drainage in Aral Sea basin: Towards a strategy of sustainable development". Tashkent, Uzbekistan. Pp 296.

4 Visvanatha, N. 2004. Report on Drainage for Project "Towards a strategy for sustainable irrigated agriculture with feasible investment in drainage, Aral Sea Basin, Central Asia." Brace Center for Water Management, Mc Gill University, Canada. Pp 46.

5 Water Watch. 2004. "Detecting soil salinity changes in specific parts of the Aral Sea Basin from Landsat images." Wageningen, The Netherlands. Pp 19.

6 Proceedings of the International Conference titled "Towards a Strategy for sustainable irrigated agriculture with feasible investment in drainage, Aral Sea Basin, Central Asia".

Towards a strategy for feasible investment in drainage for the Aral Sea Basin

SYNTHESIS REPORT[2]

SUMMARY

This report synthesizes five papers written at the request of IPTRID as part of the Needs Assessment and Strategy Formulation for the Aral Sea Basin (ASB). The papers describe various aspects of the drainage infrastructure and the incidence of salinity and waterlogging in the irrigated lands of ASB. These reports, presented in full on the enclosed CD-Rom, also contain action plans and investment scenarios.

The importance of irrigated agriculture in the ASB can be seen from its area and canal length. The total irrigated area is 9 million hectares, with slightly less than half in the Syr Darya river basin. There are nearly 50 000 km worth of irrigation canals in the Syr Darya and Amu Darya river basins, with 70 percent consisting of unlined canals. About half of the irrigated land was at one time served by open and sub-surface drains and, especially in Kazakhstan and Uzbekistan, also by vertical drainage. It is estimated that now at least half of the drains are no longer functional.

The five countries in the ASB differ significantly in their gross national income (GNI) and in the foreign direct investment (FDI) they attract. Kazakhstan with a population of 16 million is the richest, thanks to its oil, and has a GNI of US$1 350 per person and FDI of US$173 per person. The poorest country is Tajikistan with 6 million people; it has a GNI of US$180 per person and FDI of less than US$4 per person.

The transformation from communism to private property and shared management responsibility started in 1991 with the collapse of the former Soviet Union. It has been a difficult process which is still ongoing in some of the countries. State allocations for operation and maintenance (O&M) of irrigation and drainage infrastructure dropped to a fraction of what is needed to keep the systems in working order; commonly now less than US$1 per hectare except in Uzbekistan where it is about US$7.

The best estimate of irrigation efficiency is between 30 and 40 percent, which is not unusually low for developing countries, but as yield levels are also low the gross value/unit water supplied is much lower than in India. Half of the irrigated land is affected by salinity and one-third is waterlogged. There is considerable spatial variation in these conditions, depending on local geo-physical, soil and water management conditions.

The natural drainage capacity in ASB is insufficient to cope with recharge to groundwater from over-irrigation. Some 35 percent of the drainage flow in the Amu Darya

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[2] Written for IPTRID by Jacob W. Kijne, Water Management Consultant, Hemel Hempstead, Herts., UK

river basin flows back into the river; 60 percent is stored in shallow depressions and ponds (which are full or getting filled up), while 5 percent is reused. In the Syr Darya river basin these figures are: 60 percent to the river, 20 percent to ponds and 20 percent reuse. Of the 140 million tonnes of salt discharged into drainage water between 25 and 50 percent of the salts were mobilized from the soil profile and the aquifer. The remainder consists of salts transported in the irrigation water.

The drainage systems are characterized by deep and widely spaced drains which promote salt mobilization, by a mismatch between supply and demand of irrigation water, low maintenance and lack of equipment for maintenance. The density of the drainage network is low by international standards. (Fayziera et al, 2004).

Inadequate irrigation and drainage has led to an annual economic loss for the entire ASB of between US$1.5-1.8 billion, or about one-third of its potential production.

The analysis of remotely sensed images of the irrigated areas combined with field salinity surveys holds promise for an efficient and cost-effective method for monitoring soil salinity. This methodology could assist in the identification of critical salinity conditions without the need for costly regular field surveys.

Modeling studies have generated several drainage scenarios. For example, the Scientific Information Center of the Interstate Committee for Water Coordination (SIC-ICWC) estimates that in the Bukhara Oblast, an area of 274 000 hectares on the right bank of the Amu Darya, without major investments yearly: two percent of the irrigated land will be abandoned, about half of the irrigated lands will be without functioning drains and all of the land will be saline by 2025. It is estimated that 600 000 of the nine million hectares in the ASB have already been abandoned.

By and large, management institutions are incapable of reversing these trends. In the meantime rural people are losing their livelihood. Investments in the order of US$100 to US$300 per hectare would be required to reconstruct and repair the drainage structure, to level the land and to introduce improved water management and agronomic practices. Model studies indicate that the impact of such level of investments will be a one percent increase in production for the first ten years increasing to five percent during the next ten years. It is unrealistic to expect that enough water could be saved in the irrigated areas to restore the water level in the Aral Sea. More likely, any water that becomes available as a result of improved water management practices will be used for extension of the irrigated land. The economic viability of rehabilitation of irrigation and drainage structure depends on the location. Some areas, for example closed basins or those with severely saline land, are unsuitable for irrigation and should not be rehabilitated.

Successful drainage rehabilitation projects will need to contain an array of interventions and improvements, including capacity building for farmers, service providers and regulatory institutions. Where necessary, rehabilitation projects can also contain a research component but the essence of project formulation is the application of accumulated knowledge. Site selection for rehabilitation projects should take into account the presence of government institutions willing to contribute to change processes and also of conscientious construction companies. The effects of rehabilitation will be slow; and degradation of land and water will continue where no project has yet been started. So the development of alternative livelihoods and off-farm employment will remain important.

Three indicative concept project proposals have been formulated. They address drainage rehabilitation and enhanced drainage water reuse three areas: in the Bukhara Oblast; in Khorezm and Sahoguz provinces that discharge their drainage water into the much enlarged Sarykamysh Lake in Turkmenistan; and in the upper reaches of the Syr Darya in Kyrgyzstan where salt discharge can be reduced with beneficial effects for all the downstream areas of the river basin.

PART 1

SYNTHESIS

1. INTRODUCTION

1.1 Project background

This report synthesizes data and analyses of five reports that were commissioned under a World Bank funded project of the International Programme for Technology and Research in Irrigation and Drainage (IPTRID), located at the Food and Agriculture Organization (FAO) of the United Nations, Rome, Italy. The project's goal is to contribute to the development of a strategy for feasible investments in drainage for the Aral Sea Basin (ASB), and thereby to the economic and environmental sustainability of irrigated agriculture in the Basin.

IPTRID is an independent multi-donor trust fund programme hosted by FAO providing assistance to developing countries and development agencies for the formulation and implementation of sustainable agricultural water management strategies and programmes, focusing on capacity building. It aims to reduce rural poverty, increase food security and enhance environmental sustainability by improving the access of farmers, farmers' associations and service providers to appropriate irrigation, drainage, water harvesting, salinity management and flood management technologies and practices.

The five unpublished draft reports that form the basis for this Synthesis Report are in alphabetical order:

1 Jansen, H.C. 2004. “Main characteristics of groundwater hydrology related to salinization and drainage”. Alterra-ILRI, Wageningen, the Netherlands. Pp 56.

2 Pearce, G. 2004. “Overall irrigation water use efficiency in the Aral Sea Basin”. H.R.Wallingford, Wallingford, UK. Pp 22.

3 Scientific Information Center-Interstate Committee for Water Coordination. 2004. “Drainage in Aral Sea basin: Towards a strategy of sustainable development”. Tashkent, Uzbekistan. Pp 296.

4 Visvanatha, N. 2004. Report on Drainage for Project “Towards a strategy for sustainable irrigated agriculture with feasible investment in drainage, Aral Sea Basin, Central Asia.“ Brace Center for Water Management, Mc Gill University, Canada. Pp 46.

5 Water Watch. 2004. “Detecting soil salinity changes in specific parts of the Aral Sea Basin from Landsat images.” Wageningen, The Netherlands. Pp 19.

As part of the IPTRID project, a conference was held in Tashkent in March 2004. The first part of this report contains an Executive Summary of the five reports listed above, and also of the proceedings of the Tashkent Conference.

Many of the data used by the consultants and analysed in their reports were collected by the Scientific Information Center of the Interstate Commission on Water Coordination (SIC-ICWC). This Interstate Commission was established soon after the five Central Asian Republics (Tajikistan, Uzbekistan, Turkmenistan, Kyrgyzstan and Kazakhstan) became independent in 1991, and is responsible for the development of water management policies and the approval of annual water use limits for each of the member states. The Scientific Information Center of ICWC undertakes scientific activities and research, prepares proposals, and ensures data exchange between the states. The SIC data are included in Paper 3 listed above. Some of these data may appear to be at variance with other data reported in the literature. One example concerns the irrigated areas of Kazakhstan and Kyrgyzstan, which according to the FAO data base (http://apps.fao.org) are larger than reported by SIC-ICWC. This is due to the fact the FAO data are for the country as a whole, including land that is not part of the Aral Sea Basin.

This project did not support independent data collection and field verification, which probably limits the absolute accuracy of some of the conclusions, but is unlikely to have affected the understanding of the overall trend in crop production and of the deteriorating condition of irrigation and drainage in the Aral Sea Basin. Some comments received from Professor Dukhovny, as included in the attached CD rom, address the uncertainty in existing data where he indicates that some of the data reported in the underlying reports and in the literature are at variance with data available to SIC. Not only the data but also their interpretation is subject to an ongoing discussion. All comments on these matters are included in the CD rom. Although this discussion is bound to continue for some time, none of the authors of the reports reviewed in this Synthesis Report expressed disagreement with the overall analysis and conclusions as contained herein. The understanding attained from the analyses carried out in this project underpins the Needs Assessment and the three indicative project proposals which constitute the second and third parts of the report. The purpose of the Needs Assessment is to formulate a feasible and implementable strategy for investments as exemplified in three indicative project proposals.

In subsequent paragraphs of this Introduction, the report presents background information on the water resources of the ASB and the people of the five Central Asian republics, collected by the writer of this synthesis report[3]. Chapter 2 of the report then discusses the importance of irrigation and the opportunities to improve water use efficiency in irrigation. Chapter 3 addresses the geo-hydrology of the basin and especially the mobilization of salts that has given rise to extensive salinization of irrigated lands in the basin. This chapter also explains how soil salinity could best be monitored. Chapter 4 describes the current state of the drainage infrastructure and discusses several scenarios for drainage improvement. Chapter 5 presents the writer’s conclusions drawn from this first part of the report.

The second part of the report starts with a more detailed analysis of the scenarios as presented by Visvanatha (2004) in Paper 4. In Chapter 7 the writer briefly summarizes two other recent reports that broaden the scope of the analyses and thus help in the formulation of the needs assessment and the proposals. Chapters 8–11 present topics that were raised in the

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[3] Comments by the writer of this report are printed in italics only where otherwise confusion could arise about whose opinion is expressed.

papers and illustrate aspects of the needs assessment presented in Chapter 12. The writer's comments and conclusions of the needs assessment are presented in Chapter 12, followed by the references and acknowledgements. Finally, Chapter 15, which constitutes the third part of the report, has three indicative project proposals. These are examples of what could be done and they need much more discussion before they can be written up as full proposals for submission to interested donors.

1.2 Background on the use of water resources in the Aral Sea Basin

Figure 1.

As is well known, excessive water withdrawals for irrigation from the Syr Darya and Amu Darya rivers that flow into the Aral Sea have contributed significantly to the drying up of the Aral Sea. During the summer months when demand for irrigation water is at its highest, little water reaches the sea. Because of increased soil salinity in the irrigated areas of the river basins, additional water was applied to leach the salts from the root zone. Over time this caused high water tables and waterlogging of the land, further reducing crop yields. Moreover, leaching during winter time and the use of water by upstream reservoirs for production of electricity reduced important winter flows to the sea. Drainage systems were installed to control the water table rise but, as will be discussed in more detail later, the design of the drainage systems may have contributed to the mobilization of salts in the soil that brought them within reach of the plant roots.

The estimated annual discharge of the Syr Darya and Amu Darya rivers combined is 116 km^3 which supports some of the largest irrigation schemes in the world (see Tables 1 and 2). Some 22 million people depend directly or indirectly on irrigated agriculture for their livelihoods.

The percentage of GDP derived from agriculture ranges from 19 percent in Kazakhstan, the most populous of the five countries, to 38 percent in Kyrgyzstan, one of the smaller ones with a population of about 5 million people (World Bank, 2003).

Table 1. Irrigated agriculture in the Amu Darya and Syr Darya River basins

	Countries	Basin area ‘000 km^2	Cropland (%)	Irrigated (% of cropland)	Irrigated area ‘000 ha
Syr Darya	Kazakhstan, Uzbekistan, Kyrgyzstan	783	22	27	4649
Amu Darya	Tajikistan, Turkmenistan, Uzbekistan	535	22	35	4118

Source: World Irrigation and Water Statistics 2002, IWMI. Colombo, Sri Lanka

Table 2. Irrigation infrastructure in the Aral Sea Basin, expressed as canal length (x 1000 km)

Country	Unlined Canal (‘000 km)	Lined Canal	Total Length	Percent of total
Kazakhstan	4.0	0.6	4.6	10
Kyrgyzstan	1.6	1.1	2.7	6
Tajikistan	3.3	2.0	5.3	11
Turkmenistan	7.8	0.5	8.3	16
Uzbekistan	18.7	9.3	28	57
Total	35.4	13.5	48.9	100

Source: Royal Haskoning, Regional Report No. 2, May 2002.

It is estimated that some 33 million hectares is suitable for irrigation, which would indicate that at present only about one-quarter of the suitable land is indeed irrigated. However, as long as water is being used so wastefully, this resource is the limiting factor, not land. According to some estimates, 24 percent of the total land area is saline; 7.5 percent even strongly saline.

There are two major reservoirs on the Amu Darya river, one in the upper catchment in Tajikistan, and the other in Uzbekistan at the top of the delta (Royal Haskoning, 2002). There are three other smaller dams on the tributaries. One purpose of these dams is to generate electricity. The Syr Darya also has two major reservoirs, one in Kyrgyzstan and the other in the middle reaches of the river in Uzbekistan.

The rural population in all countries of the ASB constitutes more than half of the total with a peak of 83 percent in Kyrgyzstan (Bucknall et al., 2003). Since independence of the Central Asian Republics in 1991, maintenance of the irrigation and drainage infrastructure has been inadequate because farm and government budgets are insufficient to adequately support operation and maintenance (O&M). In addition, water management is neither effective nor efficient because of weaknesses in both government and water user institutions. Before the demise of the USSR, O&M was the responsibility of a highly centralized bureaucracy that implemented inflexible maintenance plans following from standardized and outdated norms. Since 1991, the role of the central agencies in the control of irrigation and drainage infrastructure has declined, but this role has not been taken over by autonomous Water User Associations. Even more importantly, O&M expenditure has reportedly dropped considerably. For example, in Kazakhstan, it was reduced by 21 percent during the 1990s (Bucknall et al., 2003).

Irrigated agriculture is presently in a negative spiral. As the irrigation and drainage infrastructure continues to degrade the salinity problem will become more severe, crop revenues will decline, and returns to the agricultural sector will weaken further. If nothing is done to reverse these trends, the rural poor will gradually lose the resource base on which they depend for their livelihood.

The link between resource degradation and rising poverty in the Aral Sea Basin is addressed in detail by Bucknall et al. (2003). It will also be discussed in Chapters 7.2 and 12 in the second part of this report.

1.3 Background on the countries and the people of the ASB

The Aral Sea Basin is located in the heart of the Euro-Asian continent. The countries in the basin are characterized by diverse landscapes including flat river basins, steppes and mountainous areas with altitudes up to 7 500 m above sea level. The summers are hot and the winters cold, with large spatial variations depending on the altitude. Annual rainfall in the lowland deserts of the basin ranges from 250 to 300 mm in the Hunger Steppe, southwest of Tashkent, to 100 mm in the southwest of the ASB and reaches 400-600 mm in the foothills of the south-eastern mountains. There are large yearly variations in precipitation. In the mountainous areas precipitation occurs mainly as snowfall and can be as high as 2 000 mm per annum.

Table 3 provides some demographic and economic data of the five countries of ASB. The data show some significant variations, most noticeably in population numbers and their growth rates, in their per capita GNI, their GDP growth rates, and the foreign direct investments they have been able to attract.

The latter is probably in part linked to the presence of crude oil reserves. Similarities in these countries are apparent in their life expectancy and mortality rates of the under five year old children, both of which are indicators of health care and indirectly of poverty. National poverty rates are available for only three of the five countries. Kazakhstan's national poverty rate at 35 percent is the exception. In general poverty is rural, where it is estimated that 70-90 percent of the population live in poverty. Yet data reported by Bucknall et al. (2003) indicate that in absolute terms the rural poor are only slightly worse off than the urban poor. In field assessments, reported by these authors, it was found that residents of all rural areas stated that their standard of living had much declined in recent years.

Table 3. Some demographic end economic data of the five Central Asian Republics

	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Population (million)	16	5	6	5	25
Population growth (%/yr)	-0.7	1.0	1.1	2.0	1.3
National poverty rate (%)	35	64	72	n.a.	n.a.
GNI (US$/person)	1350	280	180	950	550
Life expectancy	63	66	67	67	69
Under 5 yr mortality per 1000 children	99	61	116	87	68
Water use (% of total resource)	31	22	15	39	51
GDP growth (%/yr)	13	5.3	10	21	4.5
Foreign direct invest ment (million US$)	2763	5	22	150	71
FDI (US$/person)	173	1	3.7	30	2.8

Source: World Bank (2003), World Resources Institute (WRI, 2003); the data are usually from 2001.

Independence in 1991 brought the dismantling of huge agro-food complexes and the breakdown of traditional marketing channels. The absence of competition had contributed to low productivity and poor quality of the produce when large collective and state farms dominated agriculture during the preceding half century. Moving from communism has often depended upon political willingness to dismantle these units. As Dixon and Gulliver (2001) put it in an FAO/World Bank publication on farming systems, “The extent to which intent was translated into actual land reform – and the pace and procedures of this restructuration – varied considerably from one country to another. However, a common feature of these countries is the unforeseen complexity of this transformation process, linked to the extraordinary difficulty of ‘re-inventing’ farming systems based on individual property and management”.

2. IRRIGATION IN THE ARAL SEA BASIN (ASB)

Because of the generally low rainfall in the ASB, crop production is only possible when crops are irrigated. Some areas have been irrigated for centuries, but many irrigation systems were developed in the 1950s-1980s. Because of the central planning of the former USSR, it was possible to construct huge irrigation systems to irrigate desert or steppe areas and move hundreds of thousands of people to work in the irrigation systems. From 1970 to 1989, the irrigated area in the Amu Darya River basin expanded by 150 percent and in the Syr Darya River basin by 130 percent (Bucknall et al., 2003). This necessitated the diversion of more and more water from the rivers, which was then used inefficiently in the fields. Others, however, have claimed that the criticism of wasteful use of water in irrigation is based only on observations of the impact of water diversions on the water level of the Aral Sea, without having accurately measured water applications and water consumption by crops in the field (Murray-Rust et al., 2003).

As part of this project, Pearce (Paper 2, 2004) evaluated overall irrigation efficiencies in selected planning zones (oblasts) of the ASB. The objective was to utilise locally available information to understand the scale of water use inefficiencies in the irrigation regimes of the planning zones. The irrigated crops include cotton, rice, wheat, maize and fodder crops. Supply to the irrigated areas is supplemented by drainage water in the form of agricultural return flow and wastewater.

Crop water requirements were calculated using the FAO software CROPWAT. Input data were supplied by SIC-ICWC, including cropping patterns in each of 13 oblasts (planning zones) in the Amu Darya and Syr Darya river basins. The input information also included crop varieties, their planting and harvesting dates, and summary meteorological data. The analysis comprised calculation of reference evapotranspiration rates for each 10 day period of the year, the actual evapotranspiration and hence the amount of irrigation required, taking into account any effective rainfall. The ten-day irrigation requirements were then added for each of the years investigated – 1990, 1995, 2000.

The calculated water requirements were compared with actual amounts of water supplied to the oblasts. Water supply data was derived from the SIC-ICWC paper. These comprise the best estimates that were made year-by-year for water withdrawals for irrigation to each oblast. The irrigation efficiency at oblast level was found by dividing the crop water requirement by the amount of water actually supplied. The same calculations were carried out with an independent set of water withdrawal data to check the results. This second set of data was taken from the GEF/IFAS Programme National Report on Uzbekistan (GEF/IFAS, 2003). The data were independently calculated and included an allowance for the use of groundwater and of reused drain water. These data were available only for 2000.

Irrigation efficiencies of the major irrigation areas in the Aral Sea Basin were found to vary in the range of 30-50 percent. The average value was fairly consistently 40 percent over the period considered. This level is quite usual for surface irrigation schemes around the world (e.g. Murray-Rust et al., 2003). However, as for any other irrigated region, if irrigation is to be sustainable at this level of inefficiency the field drainage networks need to be effective.

Figure 2 summarizes the calculated irrigation efficiencies, arranged into 10 percent bands. In this figure, top to bottom, the three maps demonstrate the situation in the years 2000, 1995 and 1990 using the SIC-ICWC data. The three maps show that the situation is not significantly changing. Although the calculated irrigation efficiencies vary slightly over the period, according to the author there is no overall trend for irrigation efficiencies to decrease or increase over time. A map depicting the spatial distribution of the recalculated irrigation efficiencies for 2000 using the GEF/IFAS data does not significantly differ from the 2000 map in Figure 2, and suggests, therefore, that the analysis of water supplied to the planning zones is consistent.

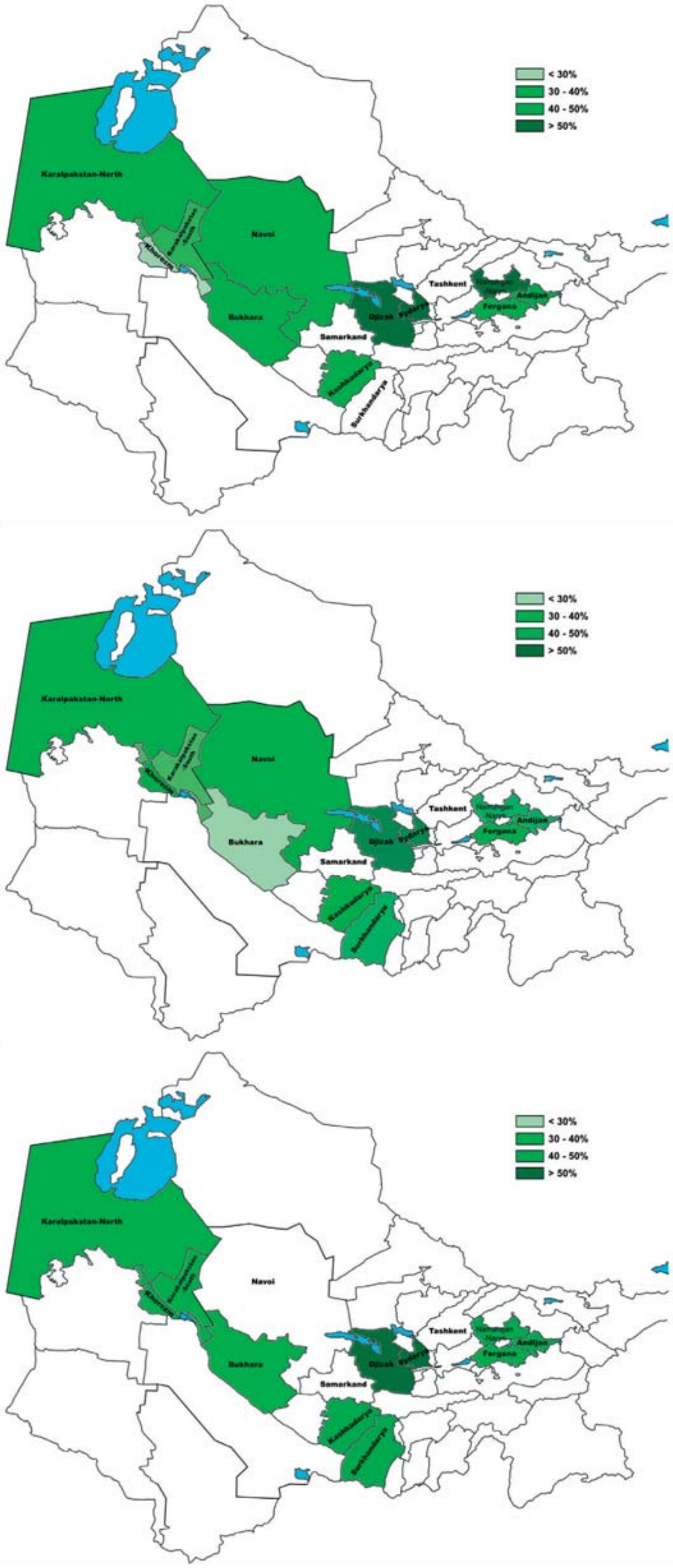
As always, averages conceal individual differences. It is interesting to note that three oblasts in the Syr Darya river basin (Djizal, Nananga and Syrdarya) have irrigation efficiencies in excess of 0.6 when using the 2000 data of SIC-ICWC. In fact, the irrigation efficiency for Djizak is consistently more than 0.6 for the three years' data. The average irrigation efficiency of the Syr Darya oblast showed a gradual increase for the time period considered in the analysis, with a value slightly more than one for 2000, which is not possible. When the same irrigation efficiency is calculated with the GEF/IFAS data its value drops to a more realistic 0.39. Also, the irrigation efficiencies for Djizak and Nanaga oblasts decrease sharply (to 0.45 and 0.36, respectively) when calculated on the basis of the GEF/IFAS data. The likely reason for the discrepancy between the two sets of calculated values is that the contributions from groundwater and drainage water are counted in the GEF/IFAS data whereas they were not included in the SIC-ICWC data set.

The average irrigation efficiency for the oblasts in the Syr Darya river basin is 0.61 when calculated with the SIC-ICWC data and 0.35 with the GEF/IFAS data, while for the oblasts in the Amu Darya river basin these values are respectively 0.38 and 0.31. These data suggest that further studies require data on groundwater and recycled drainage water for all irrigation efficiency calculations. Another aspect of future studies should ascertain whether irrigation efficiencies in the more upstream oblasts of the Syr Darya river basin are indeed higher than those of the middle and tail reaches of the basin, which is conceivable if soil salinity is less of a problem in the upstream areas and farmers would be less inclined to over-irrigate.

The available information at oblast level does not make it possible to calculate the irrigation efficiency at the level of the entire river basin. It is known that considerable reuse of drainage water takes place but more detailed localized data are needed to calculate water productivity (yield, either expressed in units of weight or monetary value, per unit of water consumed, rather than diverted from the river). Water productivity was calculated by Murray-Rust et al. (2003) for six oblasts in the upper and middle reaches of Syr Darya river basin, (two in Kyrgyzstan, one each in Tajikistan and Uzbekistan, and two in Kazakhstan). Although the irrigation efficiencies and water productivity values calculated in this study were also not unusual for developing countries, average water productivity expressed as the standard gross value of product per unit of water supplied was much lower than for example in India, especially in saline areas with very low yield levels.

Recent analyses have clarified the distinction between the traditional water use efficiency, calculated as the ratio of amount required for evapotranspiration by the crop and the amount applied to a field or to an entire irrigation system) as was described above, and water productivity expressed per unit of water actually consumed by the crop (e.g., see Seckler et al., 2003). Only more detailed analyses of the spatial and temporal variations in water productivity are likely to point out the weaknesses of the present system and to indicate options for improvement in water management. Such improvements will lead to lower applications of water to irrigated agriculture and make more water available for ecological recovery of the Aral Sea.

Visualisation of irrigation efficiency on investigated planning zones, top to bottom, for 2000, 1995 and1990



3. GEO-HYDROLOGY AND SALT IN ASB

3.1 Geo-hydrology and salt mobilization

The salinity of the headwaters of the Amu Darya and Syr Darya is mostly about 0.1 to 0.2 g/l while the river salinity at the rim stations (main reservoirs) generally ranges from 0.45 to 0.5 g/l (Smedema, 2000). In the middle reaches of the rivers, the salinity of the river water increases going downstream as saline drainage water from the irrigated areas returns to the river. The salinity of the drainage water is largely due to mobilization of fossil salts by the deep drainage and seepage return flows generated by the water losses from the irrigation systems.

Excessive irrigation, caused by either lack of information on actual crop water requirements or a recognized need to apply leaching water, has resulted in rising groundwater levels and secondary soil salinization.

Nearly half of the region's irrigated lands are affected by salinity. Analysis of the salt inflow and outflow into the irrigated areas shows that salt accumulates at a rate of 0.6–10 tonnes/ha per year in the middle and lower reaches of the Amu Darya River, especially in dry years. In the lower reaches, the annual rate of salt accumulation is 8 tonnes/ha, even in wet years, while in the Syr Darya river basin it is 5.3 tonnes/ha per year. Just under one-third of the irrigated land (30 percent) is affected by high water tables. In the past, an extensive drainage network was developed that in theory covers about 5.7 million hectares but now its actual coverage is far less because roughly half the system is no longer operational. Saline drainage water flowing into the collector drains and thence to lower parts of the irrigation system degrades the downstream water quality. Agricultural drainage water comprises about 92 percent of the total return flow. It is estimated that annually nearly 140 million tonnes of salt are discharged into the drainage water, 75 percent of which is salt brought in by the irrigation waters, but 25 percent is extra salt that is mobilized from the subsoil. Other estimates have the average percentage of mobilized salts at 40 percent of the total.

A significant proportion of the drainage water disposal is to ponds or shallow lakes in the desert near the irrigated areas. As many of the irrigation systems are far from the river, disposal of drainage water to evaporation ponds reduces the salt discharge back to the river and makes good economic sense. However, as many of these ponds have now reached their maximum capacity and few new sites are available, alternative ways of disposal need to be found.

As is discussed by Jansen (Paper 1, 2004), the introduction of large-scale irrigation has profoundly changed the regional geo-hydrological situation in the Aral Sea Basin.

The most dramatic change was the increase of groundwater recharge from the irrigated lands, which has caused the water table to rise sometimes by tens of metres, until finally the root zones of the crops were reached.

Artificial drainage systems were installed in the affected areas to alleviate waterlogging and salinization problems, but these drainage systems may also have contributed to a change in the regional geo-hydrological situation. This change could be in the spatial distribution of groundwater recharge and discharge zones, and in the recharge and discharge rates, which, in turn, impacts on groundwater flow and groundwater quality.

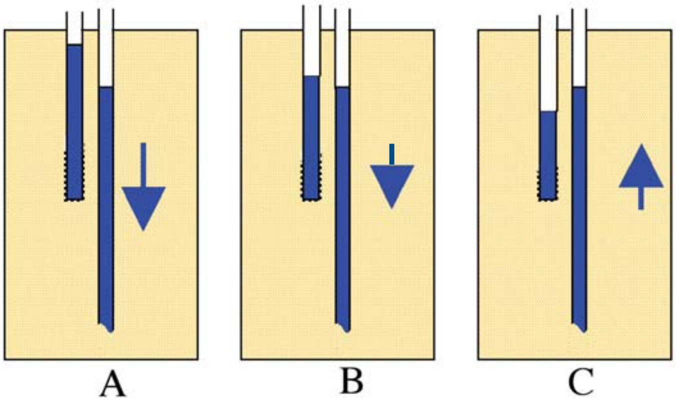
Soil formations in the ASB consist of several layers of quaternary alluvial sediments, consisting of loam and intercalating layers of sand, gravel and pebbles. In the center of the ASB the total thickness of these formations can reach up to 600 m, gradually reducing in thickness towards the edges of the basin against the valley slopes. These alluvial layers represent a freshwater aquifer that is recharged in the mountains and along the mountain slopes through rainfall and infiltration from the numerous streams. Deeper upper cretaceous formations consist of compacted sand, sandstone and some clay that contain brackish groundwater (1 to 3 g/l). Where these formations are close to the surface, some water is pumped for use by livestock or irrigation of salt-tolerant crops.

A small part of the irrigated lands in the ASB has been developed in areas with sufficient natural drainage, i.e. where the discharge of the entire volume of subsurface drainage water (including the salts), can be disposed off without artificial drainage. These areas are generally found in the topographically elevated areas (mountain slopes and small mountain plains), near draining rivers and close to the Aral Sea. However, in most of the ASB, the natural drainage capacity is not sufficient and artificial drainage is needed to supplement the natural drainage.

Information about the regional groundwater system is not readily available. In the past, not much attention was paid to what happens below the root zone. The problems in the ASB however require an integrated approach, and solutions with respect to land and water management should be developed on a river basin scale. In what follows the distinction between groundwater recharge and discharge zone is illustrated in qualitative terms.

If after the installation of the drainage system a net downward flow of groundwater is maintained (i.e. recharge to the groundwater), there will also be a net downward movement of salts, which prevents the salinization of the root zone. Some of the salts will then move into the ambient groundwater and some will be discharged by the drainage system. Conversely, in natural or drainage-induced groundwater discharge areas, there is a net upward movement of salts from the ambient groundwater. This process is referred to as 'salt mobilization'. Here all the salts need to be discharged by the drainage system, or they will accumulate in the root zone. This is illustrated in Figure 2. If the natural drainage is not sufficient, groundwater tables may rise and artificial drainage needs to be installed. Depending on the drainage depth, these areas may still remain recharge areas or, in the case of deep drainage, become groundwater discharge areas (Case C in Figure 2). In situation B, net downward percolation of groundwater occurs from the root zone to deeper soil layers (in addition to flow to the drains). The system of case B performs well if all the salts are removed from the root zone by the net flux of subsurface drainage water. Case C shows a net upward flux of groundwater into the drainage system. As a consequence, the drainage system also discharges salts from the ambient groundwater (i.e. salts are mobilized). If the drainage system performs well, these salts are discharged by the drains and salts are not accumulating in the root zone.

Figure 2.



Case A: natural drainage and groundwater recharge
Case B: irrigation with drainage and (reduced) natural drainage
Case C: irrigation with deep drainage and groundwater discharge (upward flow of water and salts).

The amount of salt that is mobilized was estimated by subtracting the salt mass introduced by the irrigation water from the salt mass discharged by the drainage system. However, since in many areas soil salinity increased substantially between 1990 and 2000, the amount of salt mobilized from groundwater is probably underestimated when calculated only from the difference between the salt loads of irrigation and drainage water. Additional reasons to doubt the accuracy of estimates of mobilized salts include the partial drainage coverage of the irrigated lands, that some parts of the drainage system are not working, and also from the fact that the salt input from applied fertilizers is not counted. The combined effect of these neglected aspects on the calculated amounts of mobilized salts is hard to assess, but it is expected that the present estimates are conservative and that individual drains probably discharged more salts from the groundwater.

The large variability in discharge and recharge zones in different oblasts is illustrated by the examples that follow. Except for some areas in Surkhandarya, Kyzyl-Orda and Karakalpakstan, most of the irrigated lands have turned into regional groundwater discharge areas. Significant amounts of salts are mobilized. This could on average be anywhere between 25 and 40 percent of the salts that are discharged by the drainage systems. The deep drainage levels combined with a less than optimal distribution of irrigation water are responsible for this phenomenon. In addition, as illustrated by Jansen (Paper 1, 2004) large spacing of open drains leads to flow lines going way below the water level in the drains and hence contributing to salt mobilization.

In the Ferghana, Namangan and Andizhan oblasts the salt mobilization does not pose a problem, as the quality of the ambient groundwater is better than the quality of the subsurface drainage water from the irrigated lands. The discharged ambient groundwater (either from horizontal or vertical drainage systems) can be re-used for irrigation. In these areas enhanced upward seepage is, to a certain extent, unavoidable as the central portion of the Ferghana Valley consists of areas with natural upward seepage and areas with a very limited natural drainage capacity. These areas are sensitive to soil salinization if the artificial drainage system does not work properly. Indeed, because of non-functioning drainage system large increases of soil salinity have occurred in Ferghana (Jansen, 2004).

In the middle and lower reaches of the river basins, the quality of most groundwater discharged from vertical drainage systems is not suitable for direct reuse and the drainage water should be removed from the catchment. Where this has not or cannot be done and the drainage water is discharged into the rivers, the downstream areas are inevitably worse affected.

The spatial variability in groundwater quality in the middle reaches of the river basins is largely related to the zones of natural recharge. Fresh groundwater is generally found in the upstream areas. If these areas, such as in Samarkand, are developed, the recharge conditions for the downstream areas deteriorate. In the long term, this will affect the quality of the ambient groundwater (which happened for example in Bukhara) as most recharge will eventually originate from deep percolation of excess irrigation water from un-drained land. If in some areas the quality of the ambient groundwater is worse than the seepage from irrigated lands, the seepage losses could in the long term improve the ambient groundwater.

In Khorezm, the Amu Darya River is the main source of (fresh) groundwater recharge. The entire area is provided with artificial drains and most of the irrigated lands have turned into groundwater discharge zones. As a consequence, the previously existing fresh groundwater resource has largely disappeared. As drainage has lowered the regional drainage base, infiltration from the Amu Darya River has most probably increased. As this water mixes with the ambient brackish groundwater and subsurface drainage water, a portion of this freshwater resource is being lost, as it is no longer available for downstream use (Jansen, 2000).

Karakalpakstan still has significant areas with natural drainage (approximately 25 percent of the land) and overall salt mobilization is much less than in all other investigated oblasts. This may, to some extent, be explained by the lowering of the water level in the Aral Sea, which has enhanced groundwater recharge from irrigated lands.

Areas drained by vertical drainage become areas where the (shallow) aquifers are recharged by subsurface drainage water. As mentioned, salts are mobilized in groundwater discharge areas. If the quality of the discharged groundwater is better than the quality of the subsurface drainage water from the irrigated lands, the quality of the drain water will improve, which is beneficial if the drain water is to be re-used. However, in the long term, the good quality groundwater will be mixed with and replaced by the sub-surface drainage water. Vertical drainage in the ASB is unlikely to contribute much to the salinization problem as most of the wells are no longer working.

A general conclusion from the analyses is that in the oblasts that were evaluated more salts leave the area than are brought in by the irrigation water. Hence one expects that in most cases there is a net discharge of groundwater and salt on the scale of the oblasts. Within the oblasts, the available data were not adequate to identify recharge and discharge patterns in more detail. Besides, there were no recent groundwater quality data. The scarce groundwater mineralization data that were available came from the 1985 hydro-geological map of Uzbekistan with a rather coarse scale of 1:1 000 000. To capture the spatial distribution of soil salinity a scale of at most 1 to 100 000 is to be preferred.

Based on this analysis, salinization problems in the ASB show important regional and local differences. However, in general they are exacerbated by the lack of safe disposal of large volumes of poor quality drainage water, the deep drainage levels which promote salt mobilization, the mismatch between demand and supply of irrigation water, and the lack of adequate maintenance of irrigation and drainage infrastructure.

3.2 Salinity monitoring

One of the prerequisites for achieving a feasible investment strategy for the ASB is to know where the salinity is manageable and where it is not. At present the soil salinity status is expressed in the number of hectares that is not slightly, moderately or highly saline for each rayon (district) but with limited spatial detail. The collection of such detailed data is time-consuming and expensive. Worse, to capture the temporal and spatial variability of soil salinity requires frequent updating of the information through additional soil surveys. One solution may be to use remote sensing to describe the spatial and temporal behaviour of soil salinity in more detail than can be achieved through traditional soil sampling. Whether this is feasible was tested on data from the Karakalpakstan and Kashkadarya oblasts, as described by Noordman (Water Watch, Paper 5, 2004).

A SPOT-Vegetation Normalized Difference Vegetation Index (NDVI) map of the basin was made by combining the NDVI of three ten-day periods in June to October 2002 into a single false colour composite. Different colours indicate biological activity (or crop growth) in the different ten-day periods. It appears that high biological activity occurred along the Syr Darya River during the first two ten-day periods, implying a later start of the growing season than in the irrigated areas of the Amu Darya river basin.

Traditional agro-hydrological studies have established inverse and linear relationships between crop yield and soil salinity (e.g. FAO Irrigation and Drainage Papers 24 and 33). These relationships typically apply to situations where soil salinity is the major constraint for crop growth. They apply to some environments with changing soil salinity, if one can assume that other factors that affect crop yield, such as pests, diseases, differences in sowing date, seed quality, etc. are constant. However, in practice these factors do affect crop yield and thus imply that crop yield cannot be predicted from soil salinity alone. The corollary is that a crop growth index alone cannot be used to infer soil salinity. Agronomic practices and consequences of farm management on yield must be identified and quantified prior to linking the actual crop yield to salinity. Against this background, WaterWatch has developed a new biophysical approach by normalizing the satellite measurements for the Leaf Area Index (LAI). The LAI is the leaf area (the upper side of the leaf only) per unit area of soil. The spatially distributed values of the LAI reflect the agronomic/farmer practices. Thus, the impact of soil salinity on crop yield cannot be derived from LAI or a spectral vegetation index that is classically derived from multi-spectral satellite measurements, but additional observations are necessary.

Stomatal closure is affected, among other things, by the matric and osmotic potentials of the plant sap. The first is a function of soil water content and evaporative demand, and the second is governed by the solute concentration of soil moisture in the root zone and the plant's tolerance for salt. For example, rice starts to reduce photosynthesis at a partial blockade of the stomatal aperture at an electrical conductivity of the saturated soil moisture extract (ECe) of 2 dS/m, but barley not until ECe is 8 dS/m, as barley is more salt-tolerant than rice.

The remote sensing model applied in this study is the Surface Energy Balance Algorithm for Land (SEBAL, Bastiaanssen, 1998 a&b). This model has been applied in many irrigation projects, including the Fergana Valley and Kazakhstan. SEBAL is propriety software of WaterWatch. SEBAL requires visible, near-infrared and thermal infrared satellite measurements to compute the bulk surface resistance for a cropped surface, r_s , and LAI. The standard options of SEBAL provide the spatially distributed data on r_s and LAI. The value of r_s is computed from the inversion of the latent heat flux (using the Penman-Monteith equation) and LAI is derived from the Normalized Difference Vegetation Index (NDVI).

In short, the following three major assumptions apply to this biophysical model for detection of soil salinity:

1. Variations of LAI are an expression of agronomical conditions and farm management, including irrigation scheduling management options.

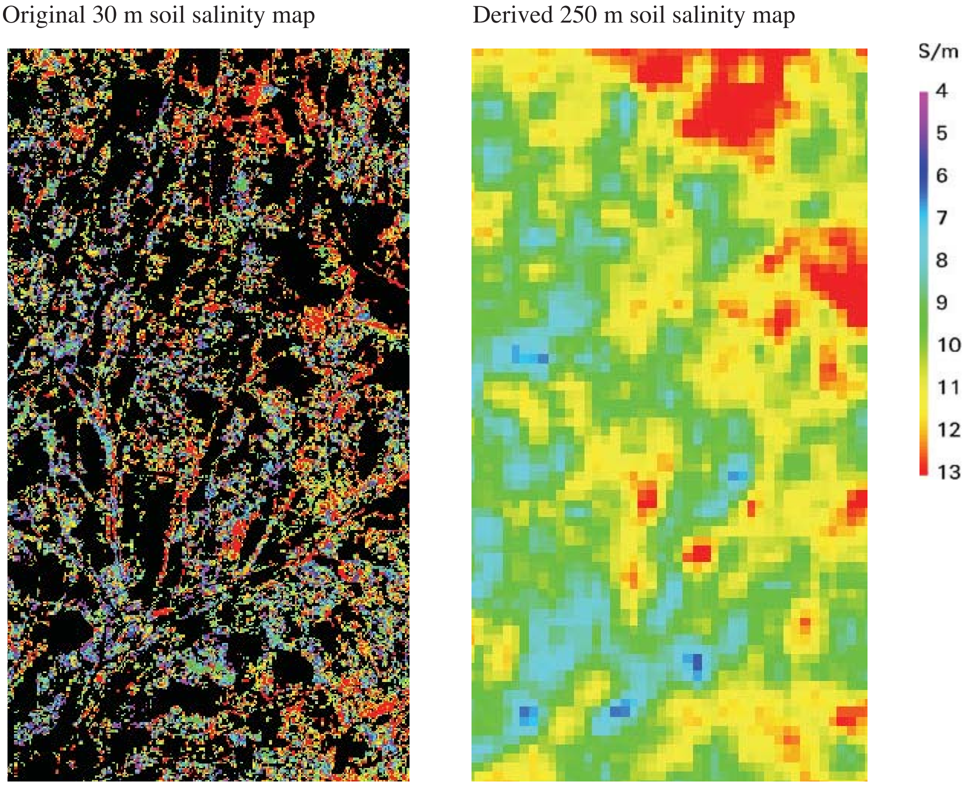
2. Variations of stomatal resistance in irrigated arid zone crops are related to the retention of moisture due to osmotic forces present in the root zone.

3. The FAO crop yield reductions as a function of soil salinity can be used to describe the impact of soil salinity on stomatal resistance.

The relevance of the third assumption has been addressed extensively in the literature (e.g. Dinar et al., 1991, Kijne, 2003 and references therein). The general conclusion from these studies is that the relation between yield and soil salinity is a complex one because of the effect of other yield-limiting factors, and as a result of feedback mechanisms between the poor stand of the crop (due to the soil salinity) and the enhanced leaching because of limited water uptake by the weak crop.

Use of the remote sensing model requires a land use map to calculate soil salinity. A simple land use classification was made on the basis of the four acquired Landsat satellite images. The main crops: rice, cotton, alfalfa, pastures and orchards, were classified. Considering the limited time for the study and the lack of field data, the resulting classification was reasonable and accurate enough to demonstrate the described method. Nevertheless, errors in the classification of the irrigated crops affect the calculated soil salinity values. A soil salinity map was obtained for the agriculture area where the four crops are grown, with a spatial resolution of 30 metres. This map then needed to be converted into a form that could be used for further analysis. For ease of interpretation, the spatial resolution of the soil salinity map for Karakalpakstan was changed such that the soil salinity map covered the whole oblast with a spatial resolution of 250 metres as shown in Figure 3. Comparison of the two maps in the figure clearly shows the large spatial variability in soil salinity, which is more clearly visible in the 30 m resolution map, and the increasing trend in soil salinity from the lower left hand corner to the upper right hand corner in the 250 metres resolution map.

Figure 3. Original soil salinity map and the final output (11 by 20 km)


Original 30 m soil salinity map

Derived 250 m soil salinity map

For the Kashkadarya area a different approach was used. A soil salinity map, based on soil sampling in Uzbekistan, was received from SIC-ICWC and this map was used to calculate the average soil salinity value from the remote sensing study for each soil salinity polygon. The soil salinity map derived from remote sensing was then compared with the soil salinity map based on soil sampling. For Karakalpakstan three Landsat TM images were processed resulting in soil salinity maps for three different dates in August 1989, August 1999 and August 2002.

Lower soil salinity levels indicated on the remote sensing map corresponded with rice growing areas. These areas are clearly visible on the 1989 image and to a lesser extent on the 1999 image but hardly at all on the 2002 image. Higher salinity levels in the 2002 image correspond to the tail-end areas in the west and north of Karakalpakstan, which is confirmed by field observations. The 1989 map shows no sign of an obvious spatial difference in salinity indicating that the irrigation and drainage systems functioned well and prevented head-tail differences. On the 1999 image, however, such a trend from head to tail reaches can be seen and from the 2002 image it appears that the tail-end areas are severely affected by soil salinity. Obviously, the irrigation and/or drainage situation deteriorated between 1989 and

2002. Salinity levels also increase with distance from the river, which could be due to lack of irrigation water or failing drainage systems, which needs to be checked in the field. Temporal variation in salinity can be explained by year-to-year variations in the amount of irrigation water available and the state of the irrigation and drainage system. The average soil salinity for all rayons (districts) in the study area did not change much over time: it was 9.7 dS/m in 1989, 8.8 dS/m in 1999 and 9.9 dS/m in 2002.

The availability of a soil salinity map for Kashkadarya from SIC-ICWC made it possible to compare between soil salinity values as calculated from the model and from soil sampling. On the soil survey salinity map there is no evidence of a head-tail trend. The soils are generally non-saline or slightly saline. A multi-temporal set of six Landsat images was used to calculate the average vegetation index from 2000 to 2002 during the growing season. The obtained vegetation index values were high and indicated healthy vegetation and thus confirm the absence of severe soil salinity or irrigation water shortages. The spatial overlay of the soil salinity map, however, with the raster layer of multi-temporal vegetation conditions shows that approximately a quarter of the polygons with moderate to very high soil salinity gradations include areas with very high vegetation conditions during the three-year period. This indicates that areas with high soil salinity also exhibit high spatial variability, which makes the drawing of isohalines (lines of equal soil salinity) questionable. The soil salinity map based on field sampling should therefore be treated with some caution.

Only one Landsat image (25 July 1988) was available for the remote sensing model calculation of soil salinity in the Kashkadarya area. There appears to be an obvious trend of increasing soil salinity levels towards the tail-end of the system which is probably linked with the (mal)functioning of the drainage and irrigation system This trend was confirmed during discussions held at the March 2004 conference in Tashkent with representatives of the Kashkadarya oblast and can be explained by the fact that these are low-lying areas with poor natural drainage and inadequate irrigation water for leaching.

The two soil salinity maps, one from the remote sensing model and the other from soil survey data, show two striking differences: the first is that the absolute values from the remote sensing are generally higher (9 dS/m on average) than the ones from the official soil salinity map (2 dS/m), and the second difference is the absence of a head-tail trend in the soil survey salinity map. [*If the caveat expressed above with respect to the third underlying assumption applies to this case study, the difference in soil salinity of the two maps may not be as large as it appears. If other yield-reducing factors played a role, soil salinity would affect crop yields at lower salinity values than suggested by the threshold values of Maas and Hoffman (1977), which are the basis of the salt tolerance values in CROPWAT. In the absence of any specific information on this point, it must be concluded that there is no obvious correlation between the two soil salinity maps*]. Recognizing that soil salinization can be a very local process, which changes over time, it can be asked if the procedure of extrapolating point measurements to arrive at isohalines is correct. Nevertheless, if the method of determining the soil salinity from soil samples is carried out correctly, both in the field and in the laboratory analyses, the average soil salinity level will be correct for the time the samples were taken if the sample density was sufficiently high. With the data available and the experiences from the field one can conclude that the actual soil salinity levels are best displayed by the soil survey salinity map and that the spatial distribution is better captured by the remote sensing method. Only a thorough validation, in which point data from traditional soil sampling are compared with the individual pixel values from the remote sensing, can give a conclusive answer on the accuracy of the remote sensing method.

Successful monitoring of soil salinity of the entire ASB may be possible by combining the remote sensing methodology based on high-resolution images (because of the need for a land use map) with low-resolution images.

The crucial point is whether calibration in combination with limited ground truth data can yield reliable results. The present constraints on the use of the remote sensing method are its experimental status and the need to validate the high-resolution results in the field. However, the methodology shows considerable promise and its major advantage would be that soil salinity can be monitored for the entire ASB in a cost effective way.

As mentioned above, soil salinity is only one of the factors affecting agricultural production. If monitoring agricultural production is the main objective, checking actual evapotranspiration and biomass growth through the application of SEBAL is effective and takes less effort than collecting field data. On the basis of low-resolution data this method can yield valuable information for the whole ASB with little effort and a very limited need for field data. The advantage of using low-resolution satellite images (>1-km pixels) is the high revisit frequency and thus the likelihood of obtaining cloud-free images that regularly capture the growing season. Another advantage is that the size of these images is around 2 500 by 2 500 km and thus covers the ASB on one image, reducing the time needed for processing the data. The disadvantage is the limited spatial resolution that precludes analysis on local (field, crops) scale.

The evapotranspiration and biomass growth derived from a low and high-resolution satellite images combines the best of both worlds. The field validation campaign should be such that clarity is obtained about inter-field variability and seasonal trends in soil salinity. Firstly, it is necessary to measure inter-field variability in soil salinity and also within the oblast as a whole. There is some indication that the variability of soil salinity within fields can be very high. If the inter-field variability is of the same magnitude as the variability within an oblast the result is not useful for the selection of areas for drainage rehabilitation. The second issue is to quantify seasonal trends in soil salinity and to assess the spatial patterns of such trends within an oblast. It is necessary to measure soil salinity at the same locations during the growing season (e.g., after leaching, middle wheat season, beginning cotton season, end cotton season, after crop growing season, and preferable at time of satellite overpass). Finally, there needs to be greater confidence in the possibility of using point measurements to generate soil salinity maps at oblast level.

From the above it is obvious that it will be a major effort to collect enough samples for a quick and reliable way of measuring soil salinity. The EM38 may be the proper instrument for the collection of soil salinity data, but the readings of this instrument are sensitive to soil moisture conditions and multiple calibrations are required for its use in irrigated lands. A training course would be needed for the proper handling of the equipment.

4. DRAINAGE IN ASB

4.1 Recurrent problems with existing drainage systems

The most detailed account of existing drainage in ASB and its problems is given in SIC-ICWC (Paper 3, 2004). An overview of the extent of drainage network in the basin as presented by SIC is given in Table 4.

Table 4. Aral Sea Basin drainage systems

Irrigated land (million ha)	**7.9 million ha**
With surface water	4.9
With pumped water	3
Drained land (million ha)	**5.3 million ha**
With surface drainage	3.5
With horizontal sub-surface drainage	0.6
With vertical drainage	0.6
Collector drains (serving about 5 million ha), in 1000 km **Total length (‘000 km)**	**200 (‘000 km)**
On-farm collectors (‘000 km)	155
Off-farm collectors (‘000 km)	45

Although the drainage system is extensive serving about 60 percent of the irrigated land, only some 50 to 60 percent of the drainage system is said to be still operational.

The overall picture is that in the Syr Darya basin, 60 percent of the drainage flow is discharged into the river, 21 percent is disposed of in depressions, while 19 percent is reused in irrigation. In the Amu Darya basin as a whole some 35 percent of the drainage flow is discharged into the river, 60 percent disposed of in depressions and the remainder is reused in irrigation. Although 60 percent of drainage flow is discharged into ponds and shallow lakes in the Amu Darya basin, some of these ponds are now full. The largest of these is the Sarykamysh Lake, which since 1960-65 has served as a recipient of drainage flows from Khorezm (Uzbekistan) and Dashoguz (Turkmenistan) oblasts. The lake is located in Turkmenistan. Between 1981 and 1997, the lake’s water level rose by more than 35 metres and its surface area increased from 1 020 to 2 900 km^2. It appears to have now reached a balance between inflow and evaporation.

Discharging between 35 and 60 percent of the drainage flow back into the river is inevitable in the absence of sufficient natural water depressions or evaporation ponds in the upper and middle reaches of especially the Syr Darya basin. Hence the main drainage water recipients in the ASB are the rivers.

The surface drainage system, which was installed at different times, is at depths of 3.5 metres and spacing of 250-400 metres, some of the open collectors being up to 7 metres deep.

The horizontal subsurface drainage system was installed about 3 metres below ground and 150-400 metres spacing, depending upon the soils in the area. With such a depth and wide spacing, it is likely that control of water tables and of salt mobilization will not be efficient or effective. This is borne out by the transport of large amounts of salt in the drainage flows to downstream irrigated areas.

There have been substantial changes in the extent and type of crops grown since 1990. In overall terms, cotton was by far the most important crop until 1990. Since then the cotton crop has shown a decline to an average of 35 percent although it is still the major crop in some of the areas. During the past decade, wheat has taken the place of cotton, particularly in Uzbekistan and Turkmenistan. The design of the drainage systems was originally based on a monoculture of cotton, and considerable redesign of the drainage may be required for different cropping patterns, especially if high value crops, such as fruit trees and vegetables are to be introduced.

Because of lack of adequate maintenance many of the open drains suffer from major weed growth, bank sloughing and consequent loss of hydraulic gradient. Many of the horizontal sub-surface drainage systems are impaired as a result of drain clogging, hydraulic back-up due to high water levels in surface drains and submerged outlet conditions.

Lack of maintenance, as alluded to earlier, is the result of shortage of funds. In Uzbekistan, for instance, O&M expenditure is estimated to be about half of what is needed and in Kyrgyzstan less than one-third. In Tajikistan, it is still less at about 20 percent of the required expenditure. Likewise, in Kazakhstan, O&M for irrigation and drainage has fallen from US$25 million in 1990 to US$1.2 in 2000. With respect to maintenance of on-farm drainage systems, the expectation is that less than 20 percent is cleaned and maintained. Here some of the shortfall is due to lack of appropriate equipment, such as flushing machines.

Most of the horizontal subsurface drains are located in the recently (since the 1960s) developed areas in Uzbekistan. In Uzbekistan, about 70-75 percent of the irrigated areas have open drains, while sub-surface drainage is installed in about 15 percent of the area.

The sad state of affairs is clearly illustrated by the data in Table 5 for the Kyzyl-Orda oblast, in Kazakhstan.

Table 5. Condition of open drainage network in Kyzyl-Orda oblast

Years	Total length of collector-drainage network (km)	Of which now no longer working (km)	Condition in:			
			Off-farm sector		On-farm sector	
			Total (km)	Non-working (km)	Total (km)	Non-working (km)
1990	5 140	1 590	1 000	200	4 150	1 390
1995	4 740	2 020	1 000	280	3 750	1 740
2000	3 230	1 550	1 000	410	2 240	1 140
2002	2 600	1 490	1 000	530	1 700	960

Evidence of poor performance of existing drainage systems is also found in the increasing areas of shallow water tables (i.e. less than 2m below ground level). For example, the data indicate that the proportion of irrigated lands with shallow water tables increased from about 20 percent in 1990 to 30 percent by 1999, and probably continued to increase at similar rates since then. In the Syr Darya river basin, the most rapid increase has been in the Syr Darya and Ferghana oblasts. In the Amu Darya basin, the maximum increase is in the delta areas of Khorezm, and Karakalpakstan, where by 1999 80 percent of the irrigated area had shallow water tables. Again, data for the Kyrzyl-Orda oblast clearly illustrate the problem of the resulting salinization (Table 6.)

Table 6. Salinization of irrigated land (hectares) in Kyzyl-Orda oblast

Salinization level	1990	1995	2000	2002
Slightly saline	44 650	131 920	153 280	113 620
Medium saline	180 700	132 950	71 250	43 080
Strongly saline	60 680	21 050	53 150	58 200
Total	286 030	285 020	277 680	214 900

In none of the republics, except Uzbekistan, is drainage water discharge and salinity monitored at all any more because of lack of funding. With restructuring of the former collective farms, drainage problems were exacerbated because all field drains were suddenly off-farm drains and no one felt responsible for their O&M. Detailed analyses were carried out of the drainage systems in nine oblasts. The relevant data are shown in Table 7.

The annual loss in production due to waterlogging and soil salinity is estimated for the entire ASB at about US$1.4 billion or some 32% of the economic value of potential crop production.

The extent of losses is greater in the Amu Darya basin than in the Syr Darya basin. The decline in cotton yields in Uzbekistan is illustrated in Figure 4.

Figure 4. Trends in cotton yield (tonnes/ha) in Uzbekistan (Source: IMF, 2000)

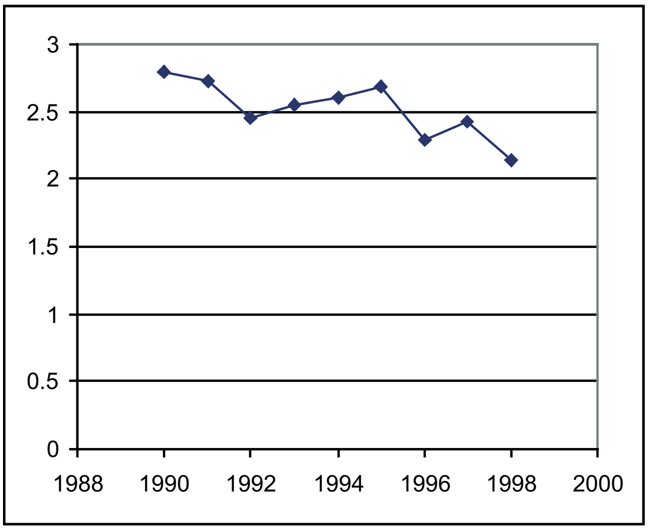


Table 7. Drainage specifics of nine oblasts (Sources: Papers 3 and 4)

	Karakal pakstan	Khorezm	Bukhara	Kashka-darya	Ferghana	Syr Darya	Kyzlorda	Sogdi	Tashauz
Total drained area '1000 ha	372	250	218	304	261	289	278	89	407
Collector drain, km/ 1000 ha	53	15	9	46	15	7	12	6	8
On-farm open drains, km/1000 ha	42	28	18	15	38	17	8	33	11
Irrigated land with shallow wt (%)	78	94	23	3	49	47	4	27	1.5
Medium and strong salinity (%)	51	47	41	16	27	32	45	18	94

Notes: There is some uncertainty about how much of the irrigated area in Khorezm and Tashauz oblasts is drained. Of the collector drains in Kaskhadarya oblast 42 percent are operational; of the on-farm open drains 55 percent. For the Sogdi oblast these figures are 63 percent and 27 percent, respectively. According to various sources, the recommended intensity of the drainage network should be between 50 and 70 km/1000 hectares.

Karakalpakstan, the first oblast of Table 7, is located in the lower part of the Amu Darya River basin. It is a closed basin with artesian groundwater conditions and high salinity conditions in the irrigated areas. Artificial drainage was installed during the period of rapid growth in irrigation in the past few decades. One of the major challenges of this area is improving the safe disposal of the drainage effluent from nearly 100 000 hectares of irrigated land in South Karakalpakstan. As a result of waterlogging and salinity many areas experience loss of irrigated land. It is estimated that 600 000 of the nine million hectares in the ASB have already been abandoned. For example, in Karakalpakstan, moderate and severely saline areas (ECe of 4 to 9 dS/m) increase at an annual rate of 2 000-3 000 hectares, while land with high water tables increases by 2 percent each year. Although the effects of high water table levels are to some extent seasonal and have yearly fluctuations, the large extent of such areas with high water tables is a major concern. As a result of these factors cotton yields declined during the past decade by about 1.3 to 2.3 tonnes/hectares, corresponding to some US$4.7 million per year (or US$10/ha/yr). Silting of collector drains as a result of poor maintenance is also a recurrent problem, which adversely affects the performance of the on-farm drainage network (Visvanatha, 2000).

In the Bukhara oblast, inadequate intensity of the surface and subsurface drainage network contributed to a significant increase in shallow groundwater and waterlogged conditions, which in turn increased the salinity levels within the root zone. Moreover, much of the vertical drainage is in poor operating condition, some of it because of lack of spare parts. The irrigation water quality has been continuously decreasing in the past thirty years; the salinity of the water has increased from 0.6 g/l to 1.16g/l.

4.2 Drainage improvement

Drainage improvement is essential for the mitigation of the waterlogging and salinity problems which are widespread in ASB and prevent improvements (and often lead to reductions) in crop production. SIC-ICWC (Paper 3, 2004) developed three scenarios for selected oblasts and projected future conditions of irrigation and drainage systems for the period 2001-2050.

The SIC study describes an extensive modeling exercise involving the frequency distributions of groundwater depth and of soil salinization, drainage performance and age of the drainage systems. The model assessed present efficiency of existing drainage and the possible efficiency of future drainage systems, and also the impact of salinity and water table levels on crop production. It considered the effect of three O&M investment strategies, i.e. full investment for full technical rehabilitation, a more modest investment level and no investment at all. A failure equation was developed to describe drain degradation.

The SIC model was applied to the state of drainage and land reclamation in Bukhara oblast, which has 274 000 hectares of irrigated land, of which 218 000 hectares were at one time provided with drainage. The modeling study leads to the following recommendations (among others):

- Unless more of the infrastructure in the Bukhara oblast can be repaired and rehabilitated, more and more irrigated land will be retired each year as the drainage system fails completely.
- Increased salinity of irrigation water (from 0.7 g/l twenty years ago to the present 1.15 g/l) of the Bukhara oblast and the resulting additional salt influx to the irrigated areas makes it necessary to revise current leaching practices.
- The lower salt load in the collector drains from Bukhara oblast is the result of poor management.
- Because the collector drains are old, even if repairs were done according to the standard norms the area without adequate drainage would still increase to 60 000 hectares. But with the present reduced rate of repairs the non-drained areas will increase to 130 000 hectares.
- If repair work were to stop on all land with sub-surface and vertical drains, and reduced to 30 percent on the land with open horizontal drains, all arable land would be strongly saline by 2025.

In addition the SIC study (Paper 3, 2004) recommends:

- Priority in rehabilitation should be given to areas where the horizontal and vertical drainage systems are destroyed.
- Some main collectors need reconstruction to make them deeper and wider.
- To improve water quality in the Amu Darya river, a branch canal and the Bukhara main collector need to be built to take the drainage water away from the river.
- New equipment is needed in order to be able to reclaim saline and waterlogged land.

SIC-ICWC blamed management weaknesses for the lack of responsibility for O&M of on-farm drains and for non-cooperation between agencies for water management and land reclamation. Insufficient funding and lack of competent staff exacerbated the problems. However, the situation is not as bleak in all of the five Central Asian Republics. For example, Tajikistan has been reported as having functioning water user associations.

The SIC-ICWC study was extended to other areas as reported by the Brace Center for Water Management (written by N. Visvanatha, Paper 4, 2004) using data from SIC-ICWC. For example, the situation in Khorezm Oblast (Uzbekistan) is presented in Table 8.

Table 8. Characteristics of drainage situation and its impact on in Khorezm Oblast

Total length of drainage network	10 600 km	
Off-farm collector drains	3 700 km	
On-farm open drains	6 900 km	
Non-functioning off-farm and on-farm drains	65%	
Sub-surface drains	504 km	
Non-functioning sub-surface drains	80 %	
Waterlogged area	234 000 ha	94% of irrigated land
Slightly saline land (ECe = 2-4 dS/m)	140 800 ha	59%
Medium saline (Ece 4-8 dS/m)	87 700 ha	35%
Severely saline (Ece 8-15 dS/m)	29 600 ha	12%
Annual increase in medium and severely saline land	4 000–5 000 ha	
Estimated economic loss due to lower cotton yield	US$ 2.8 million/year	

Paper 4 argues that sustaining and preserving the useful life of the existing investments is essential for sustaining an economically viable level of agricultural production. As such, it was felt that rehabilitation of on-farm systems should be undertaken on a priority basis, with the caveat that off-farm systems should not be in such bad state of repairs that the functioning of on-farm drainage systems would be interfered with. In all likelihood, results of any implemented reforms will be slow to manifest themselves. Therefore, a twenty-year period (up to 2025) is considered appropriate for purposes of this study. Projections beyond this period are considered highly unrealistic at this time.

> Because neither the governments nor farmers currently maintain their infrastructure properly, there is a good chance that once the first round of rehabilitation reaches the end of its natural life, governments would be faced with the same quandary. Therefore, government commitments to farmer education, motivation and institutional capacity building constitute a set of conditions to enhance long-term sustainability of the investments.

Based on assessments over the past decade for Central Asian countries, the following list of key trends was compiled:

1. Approximately 600 000 hectares of irrigated cropland in Central Asia have become derelict.
2. In Uzbekistan, around 200 000 hectares (or 20 000 ha/year) have been lost due to severe salinization and waterlogging.
3. In Kyrgyzstan around 80 000 hectares of land, over seven percent of the total, have

been removed from cultivation owing to severe land salinization and waterlogging.

4. Farmers plant less land due to incursion of salt and about three percent of land is abandoned for this reason.
5. Without rehabilitation, the irrigated area will gradually contract at a rate of several percentage points per year over a ten-year period.
6. Even with proper O&M and rehabilitation, the deterioration of irrigated land can only be partially halted as it is unrealistic to assume improvements at a uniform rate throughout the region given the investment limitations and the lag in the uptake of the required reforms.
7. During the period 2000-2020 without rehabilitation, it is expected that crop yields in the main irrigated zone will have declined by a further 30 percent from current averages, and by even more in the already severely saline lands.

Considering the above trends, and coupled with other factors, best guess estimates are provided for three scenarios that will be discussed in the second part of this report.

5. CONCLUSIONS

1. Many of the available data are not recent. The amount of data collection and monitoring of water management conditions has declined.

2. Low expenditure for O&M of irrigation and drainage infrastructure threatens rural people with the loss of their livelihood.

3. The average irrigation efficiency of 30-40 percent at the scale of oblasts is low but not unusual when compared with other irrigation systems in developing countries. Additional data at river basin level are needed to assess whether water is wasted, especially data on the use of groundwater and the reuse of drainage water.

4. Irrigation efficiency appears to be higher in the more upstream oblasts of the Syr Darya river basin than in most of the other studied oblasts, which would indicate rational behaviour by farmers trying to meet the leaching requirements of their soils.

5. Groundwater recharge due to seepage from irrigated land has led to a large-scale rise of water tables.

6. Installed drainage systems have contributed to change in the geo-hydrology of the ASB, especially with respect to groundwater discharge and recharge zones and the rate of discharge or recharge. Deep drainage and wide spacing have probably contributed to salt mobilization.

7. Groundwater recharge and discharge zones exhibit large spatial variability.

8. Present estimates of the amount of mobilized salts, obtained from a simplified water and salt balance, probably underestimate the discharge of salts by drains.

9. Salinity problems in ASB are made worse by the lack of sufficient evaporation ponds, or by available ponds reaching their maximum capacity; this prohibits the environmentally-sound disposal of large volumes of poor quality drainage water.

10. Analysis of Landsat TM images indicates rapid deterioration of drainage infrastructure between 1989 and 2002.

11. The advantage of using remote sensing methodology for monitoring soil salinity lies in the possibility it offers to monitor the entire ASB cost effectively. The disadvantage is the present experimental state of the technology, and the need to validate high resolution results in the field.

12. Serious shortfalls in current expenditure for O&M of irrigation and drainage infrastructure resulted from lack of institutional responsibility for O&M after restructuring of the former collective farms since independence of the Central Asian Republics.

13. The current lack of maintenance has led to annual yield losses in cotton production that are estimated at US$10 per hectare.

14. Management structures and institutions are weak because of lack of funding, knowledge and coordination.

PART 2

NEEDS ASSESSMENT

6. INTRODUCTION

In recent years several published reports have addressed the needs of the Aral Sea Basin, ranging from the rather narrow perspective of how to improve the sustainability of irrigated agriculture in the Basin to the much wider question of the restoration of the Aral Sea to its former water level and biodiversity. This second part of the report looks first in some detail at the three scenarios discussed in the Brace report (Visvanatha, 2004). Thereafter it summarizes two additional reports which were prepared independently of this study but which will help formulate steps towards a strategy for feasible investment in drainage for the Aral Sea Basin.

Although there is a direct link between irrigation expansion in the Aral Sea Basin and the drop in water level of the Sea, restoration of the water level in the Aral Sea is not an issue that will be discussed here.

The possibility that through irrigation and drainage improvements some of the water that is currently used for agriculture could be discharged into the Sea cannot be ruled out, but it is in all probability far into the future. In the medium term, it is more likely that water made available as a result of improved water management in the ASB will be used for irrigation of additional land than for restoring the water level in the Aral Sea.

It has been estimated that even with an average annual inflow of 15 km^3 from the Amu Darya it would take about 30 years to reach a salinity level in the still existing western part of the Aral Sea to allow a return of a healthy biodiversity. With less inflow, restoration of biodiversity in the western Aral Sea will take much longer. Allocating such an annual flow to the lake would require a major policy decision by the countries concerned (Haskoning, 2002).

Studies of water productivity in the upper areas of the Syr Darya basin indicate that water use in irrigation could become more efficient and thereby require less water for the same irrigated area. However, there is a real danger that instead the conserved water would be used to increase the irrigated area. If this happens, production will increase as water is used more effectively, but it will not result in water savings that can be transferred to the Aral Sea (Murray-Rust et al., 2003). For the latter to happen, the ecological value of the wetlands and the Aral Sea has to be recognized and binding transboundary agreements made to transfer water from agriculture to the environment. At present there are few signs that these conditions will soon be satisfied.

6.1 Scenarios and action plans developed as part of the project

The development of scenarios for drainage improvement by Visvanatha (Paper 4, 2004) benefited from the modeling studies and analyses of SIC-ICWC, and also took into account scenarios and analyses in the Haskoning (2002) and World Bank (Bucknall et al., 2003) reports.

The first scenario considers the consequences of continuing as usual, while the other two scenarios dwell on the consequences of different levels of investments to allow improvements to be made in the current situation.

6.1.1 *Business-as-usual scenario*

The business-as-usual scenario assumes a slow pace in institutional and policy improvements, no change in the current state allocations for O&M expenditure, and further deterioration of infrastructure because of deferred maintenance.

The expected impact of this scenario is that within the next 5-10 years, all vertical drainage will be ineffective; that within the next 10-20 years, most of the sub-surface drainage will also have ceased to work or be ineffective. Likewise, the condition of the on-farm drainage system will continue to degrade and the entire on-farm drainage system is likely to become largely ineffective within 5-10 years.

Hence, land retirement due to waterlogging and soil salinity, combined with yield losses will force farmers to find off-farm employment to maintain essential quality of life; therefore an enhanced exit from farming is a distinct possibility. The largest land abandonment would take place in Kazakhstan and Turkmenistan, where it is expected to be in the order of 10 000 to 20 000 hectares per year.

6.1.2 *Moderately improved scenario*

The second scenario is similar to Scenario 1 in also assuming slow progress in implementing policy reforms and deferred maintenance needs. The aim would be to increase funds to facilitate moderate, selective rehabilitation to prevent further deterioration of infrastructure. These improvements would include cleaning of main and secondary collector drains, deepening, alignment and grade improvements. At farm level this scenario includes selective rehabilitation of open drains and horizontal subsurface drains; intensification of on-farm drainage network in priority areas; and demonstration and adoption of integrated water and agricultural management practices.

For this moderate investment scenario, the estimated budget requirements are in excess of US$200 per hectare for Uzbekistan, >US$100/ha each for Turkmenistan, Tajikistan and Kazakhstan, and US$50/ha for Kyrgyzstan. Current state expenditure for drainage O&M is less than US$1 per hectare, except for Tajikistan where it is US$1.85/ha and for Uzbekistan with US$7.20/ha.

The main impact would be reconstruction and rehabilitation of some 20-25 percen of the horizontal drainage system; some on-farm minor canals and pipelines; and of 20-25 percent of the existing length of subsurface drainage systems; laser leveling of 5-10 percent of irrigated farm lands; and reconstruction of essential vertical drainage. This would make it possible to maintain productivity at the existing levels with marginal recovery expected at one percent per year over the next 20 years. The additional funding would have to come from a mix of local governments, private agencies and farmers, and probably mostly from Official Development Assistance (ODA).

6.1.3 *Higher Investment scenario*[4]

The third, higher investment scenario assumes major rehabilitation works will take place. Improvements include: major rehabilitation of on-farm surface and subsurface drainage

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[4] This scenario was called the 'optimistic scenario' in Visvanatha (2004). Considering that in the current world view optimism is usually thought of as unfounded, the scenario's name has been changed to a more neutral 'higher investment scenario'.

systems; drainage intensification, on-farm development works, such as laser leveling; and large-scale adoption of improved water management and agronomic practices. Under this scenario the merits of a combined horizontal and vertical drainage systems in addition to rehabilitating essential vertical drainage systems will be thoroughly investigated. Budgetary requirements per hectare are expected to be twice to three times those for the second scenario.

This scenario would see both improvement in infrastructure and recovery of the farm economy; full reconstruction of lined and unlined canals, of pipelines for 30-50 percent of the existing length; full reconstruction of horizontal sub-surface drainage for 50-70 percent of the existing length; laser leveling of 50-70 percent of the farm land; and reconstruction of essential vertical drainage. Details of these three scenarios and a case study of the Bukhara oblast, one of the worst affected oblasts, are presented by Visvanatha (2004).

In the Higher Investment Scenario, marginal economic recovery is expected at the rate of 1% per year during the first 10 years, and 5 percent per year for the next10 years.

6.2 Action Plans

Several of the papers, especially Paper 3 (by SIC-ICWC), have developed action plans stipulating the way forward. They have been collated below:

1. The general approach:
    - Concentrate first on quickly rewarding positive activities and underline gains.
    - Build awareness and the information base; enhance transparency; start public debates on the multi-functionality of the resource system.
    - Make financial resources available for dedicated activities.
    - Recognize, mobilize, and empower other stakeholders besides agricultural producers.

2. Plan and implement pilot projects
    - Use an integrated approach to drainage improvements by looking at all costs and benefits.
    - The integrated approach should be pragmatic.
    - Learn before doing.
    - Governments and International Development Assistance must insist on the integrated approach to drainage.

3. Institute a National Drainage Policy

Each of the Central Asian Republics governments should assess its needs for institutional capacity building with respect to operation, management and maintenance of agricultural drainage and develop policy changes to promote an integrated approach to drainage management.

4. Prioritize drainage intervention

Refine and develop land classification categories to help in prioritizing drainage interventions, considering both physical and social determinants. The following land classification categories are recommended for purposes of developing an integrated approach to drainage management:

- Class I – Good productive lands, but in danger of salinization and waterlogging due to poor maintenance.
- Class II – Low soil salinities; sufficiently deep water tables; and good water management available.
- Class III – Higher salinities and/or shallower water tables than Class II lands.
- Class IV – Worst lands; completely salinized and/or waterlogged, retired lands.

5. Prioritize the timing of reclamation and rehabilitation pilot programmes
   - To start immediately (as soon as possible) - Lands in Classes I & II that promise short-term results.
   - To start in the medium term (2-5 years) - Lands in Class III.
   - Start in the long term if at all (beyond10 years) – Lands in Class IV, some of which may be permanently retired.

6. Implement field plots following the integrated approach to drainage management
   - Evaluation of different drainage design criteria, including site-specific needs.
   - Development of low cost O&M procedures.
   - Establishment of institutional management systems to implement, operate and maintain drainage systems at all levels.
   - Development of strategies for drainage water disposal, considering the ecological and environmental sensitivities.

7. Develop and improve databases

This should ensure more effective communication among stakeholders, and improve transparency and access of relevant information and data for stakeholders. Data categories include: soil conditions and trends in soil quality, water table depth and their change over time, emerging cropping patterns, farm budgets, and estimates of the costs of rehabilitating on-farm and off-farm structures.

8. Build capacity in drainage, mass communication and training programmes.

Initiate various types of drainage-related capacity building programmes to impart regional and local drainage management cultures, recognition of the need for change, and enhance motivation amongst all stakeholders. Capacity building should include the development and recognition of the decisive factors of long-term sustainability of irrigated agriculture. Key elements of sustainability are:

- To recognize drainage as an integral part of irrigated agriculture.
- To recognize drainage and irrigation as equally important parts of water management.
- To recognize that water management systems (including drainage) must be designed and managed taking into account both agricultural and environmental objectives.
- To recognize that the development of optimal soil moisture conditions for crop growth, depending on the site-specific conditions, is governed as much by drainage, drainage restriction, and sub-irrigation, as by irrigation.

- To accept and adopt best management practices in agriculture as these will benefit the environment.
- To strive to improve production efficiency by raising production per hectare, production per unit of water diverted from the source, and also by boosting the product's quality.
- To recognize the ongoing importance of repair and maintenance of existing systems, including the replacement of deteriorating systems so long as they are not harmful to the environment, wildlife, or other interests.
- To maintain a proper balance between agricultural interest groups and other interest groups in accomplishing related legislative objectives.
- To support the introduction and enforcement of government policies and regulations that aim to strengthen the long-term sustainability of irrigated agriculture in the Central Asian Republics.

SIC-ICWC (Paper 3, 2004) sees the way forward in terms of enhancing public awareness of the importance of drainage in land use sustainability, combining public and private involvement in drainage rehabilitation, and providing training in integrated management of irrigation and drainage water, low-cost drain maintenance, and on how to minimize salt mobilization from groundwater and its discharge into rivers. The Interstate Commission recommends that rehabilitation, modernization and improvement of drainage should start where reclamation is most needed, i.e. in order of priority in Karakalpakstan, Bukhara, Syrdarya, Djizak, Tashauz, Chardjou and Kzylorda oblasts.

In another part of Paper 3, SIC-ICWC also formulated prioritized actions for short-term, medium and long-term implementation, as shown in Table 9 below. These are priority measures aiming to control salinization and waterlogging of the land. The most urgent ones focus on the repair of drainage infrastructure, for which resources and training are required. They also address the need for changes in cropping patterns and better leaching practices. The medium-term measures aim to increase the productivity of irrigation water which requires control over the quality of irrigation water, including the reuse of drainage water, and the introduction of appropriate irrigation technologies for new cropping patterns. The medium term measures also include reclamation of saline land by leaching. Extension services and the allocation of responsibilities for sustaining irrigated agriculture, i.e. preventing further land degradation, need to be secured. It is obligatory to take socio-economic aspects into account comparing the cost of system rehabilitation with the cost of subsidizing farmers. The long-term measures consist of the development of new technologies and practices for the control of waterlogging and salinity of soil and water, recognizing the need for year-long cultivation and increasing scarcity of good quality irrigation water.

Table 9. Priority measures to control salinization and waterlogging of the land

Time-scale of implementation	Recommended measures
Short-term (urgent)	1. Cleaning and repair of existing drainage systems, prevention of further rise in water tables (drainage flows).
	2. Providing material resources and stimulating qualitative soil desalination through leaching (irrigation and drainage equipment, fuel, sufficient amount of water, salaries and others).
	3. Training, specifications and control of leaching quality. Training to evaluate soil salinity by means of a simple method.
	4. Revision of cropping pattern in relation to actual soil salinity on the farm.
	5. Application of leaching regimes for agricultural crops under all-year-round land use, with deep plowing and soil loosening to aid in reclamation.
Midterm	1. Improving irrigation water quality at source.
	2. Control on limitations in the reuse of drainage water for irrigation.
	3. Carrying out large-scale leaching as part of land reclamation of saline lands.
	4. Replacing furrow irrigation of industrial crops on sloping land with garden-vine perennial with drip irrigation, impulse irrigation or other water saving irrigation methods.
	5. Increase monitoring of soil salinity, providing extension services, and effective control of and responsibility for soil degradation.
Long-term	1. Develop new ideas and technologies on soil water-salt management under conditions of: - year-long cultivation on saline lands - scarcity of water and material resources; and - shallow <3 m) water table as main source of salts.

Writer's comments: There is some overlap between the suggested actions, especially if one understands the integrated approach to drainage to include farmers' training, capacity building, involving the private sector in the development of service providers to farmers, policy development and enforcement of water management regulations. In addition, actions plans should take cognizance of the legitimate demands for good quality water, e.g. as household drinking supplies, and take into account possible negative impacts on the environment that could result from the suggested actions. Such an integrated approach could lead to action plans with a research component. Also, the papers do not discuss the possibility that some of the irrigated land is in such poor condition that rehabilitation could never make economic sense and should be abandoned forthwith. In these areas, the focus should not be on rehabilitation but on finding alternative employment opportunities for the affected farmers.

The need to evaluate the economic viability of rehabilitating irrigation and drainage infrastructure has not been mentioned explicitly in these action plans. The World Bank report (Bucknall et al., 2003) that will be discussed below compares the cost of rehabilitation with the cost of subsidizing farmers when cultivating their lands becomes uneconomical. It could be argued that the five background papers stress the physical aspects of rehabilitation while overlooking the importance of policy changes (such as liberalizing markets, raising prices that farmers get for their products, and then reducing subsidies on water) that would make irrigated agriculture more economical and hence sustainable.

7. OTHER REPORTS ADDRESSING THE NEEDS OF AGRICULTURE IN THE ARAL SEA BASIN

The first of the two additional reports consulted by the author was carried out by Royal Haskoning (2002) for the Global Environmental Facility (GEF) agency of the International Fund for Saving the Aral Sea (IFAS) and the other was written for the World Bank (Bucknall et al., 2003). The first discusses water and environmental management and the second addresses the social, economic and environmental considerations of irrigated agriculture in ASB, especially the relation between irrigation and poverty.

7. 1 Haskoning report

The main conclusion of this report is that with reasonable standards of management, the water resources of the Aral Sea Basin are sufficient to meet current irrigation requirements and provide an adequate volume for environmental purposes in the lower reaches of the rivers and the delta areas. The contention is that at present most of the water diverted for irrigation purposes is wasted, either entering the groundwater by seepage or discharging directly from the canals into the drainage system. In addition, in the downstream systems almost half of the drainage water is lost permanently in desert sinks. Although it would be difficult and expensive to eliminate the seepage losses from the canal network, it should be possible at reasonable cost to reduce substantially the proportion that is lost due to direct discharge into drains. The authors state that annually an estimated 8 km^3 could be saved by improvements in canal operation and on-farm water management.

These conclusions are based on three scenarios developed for the period 2001-2025 which consider country–specific attributes. The scenarios describe a declining, a consolidation and a revitalization situation.

The total economic losses to the States attributable to shallow water tables and its induced increased soil salinity, as mentioned, are estimated at US$1.4 billion annually. This report argues that much of this loss could be prevented by better agronomic and irrigation practices, e.g. improved field grading, which would eliminate bare patches in crops caused by high soil salinity levels or under-irrigation. Irrigation should no longer be supplied in three or four large applications (as was intended in the design) but be replaced by 7-10 smaller applications, requiring about the same amount of irrigation water. The report refers to studies showing that laser land levelling and irrigation improvements often offer internal rates of return of over 30 percent.

The report states that salinity levels in the Amu Darya and Syr Darya rivers are about 20 percent lower than the peak in the 1980s, and are unlikely to increase significantly in future. Still, in the downstream areas river water salinity levels are almost twice the permissible standard for the production of drinking water. Hence, groundwater is used for drinking water supplies, but in dry years levels drop fast and the required capacity fails.

The report accepts that substantial investments would be required to rehabilitate the irrigation and drainage infrastructure, but sees as the greatest challenge changing the attitudes of the people involved.

Desired policy changes include *inter alia* the establishment of new interstate water sharing agreements, and a general commitment to saving water. Improved on-farm water management is seen as the central theme for all water and salt management strategies.

Considering the current macroeconomic conditions in the Central Asian Republics and the outlook for the future, estimated levels of investment proposed in most of the preferred scenarios could be higher than can be afforded, possibly leading to longer implementation periods than desired. The report foresees that investment capacity may pose a major macro-economic constraint for years to come for agricultural and energy sector development.

The current interstate water allocations do not include an allocation to sustain the wetlands in the most downstream reaches of the rivers. And there is no provision for water allocation to the Aral Sea other than stipulating that a minimum flow of 100 m^3/s (3 $km^3/year$) for Amu Darya and 50 m^3/s for Syr Darya has to be maintained in the rivers for sanitary purposes. Presently, on average the two rivers discharge each year about 10–12 km^3 into the Aral Sea[5].

7.2 World Bank report

This report looks at what happens to communities as the irrigation infrastructure declines, whether farmers find employment elsewhere, and if there is a relationship between poverty and irrigation in Central Asia. It also addresses the general economic viability of irrigated agriculture in ASB. The aim of the report is to help policy makers arrive at the best possible investment decisions in view of the discrepancy between investment needs and available resources.

The authors see three different opinions among donors and policy makers. One group holds that villagers have no alternative for irrigation in the medium term, which implies that investments should be made in irrigation and drainage before the infrastructure collapses altogether. A second group is of the opinion that irrigation and drainage schemes are not economically viable and thus that it makes no sense to invest in unprofitable infrastructure. The last group asserts that international donor organizations should assist governments in phasing out irrigation in many areas, because they are not and never can be environmentally sustainable in those areas.

The report confirms the inadequacy of available data but the field work carried out as part of the study supports the general perceptions about degrading infrastructure, precipitous drop in farmers' income, and institutional weaknesses. Analysis of household incomes and consumption surveys indicates that rural poverty is widespread. Poverty is worse for those in tail reaches of command areas. In addition, those farmers are most affected when saline or waterlogged land has to be abandoned.

Whether irrigation is economically viable depends on its location. In Uzbekistan, the use of groundwater for irrigation is too limited. A large number of groundwater-supplied irrigation systems are economically viable even at full economic prices, including electricity for pumping.

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[5] This estimate seems too high compared with the 5 km^3 that according to V. Dukhovny et al., (2002) reaches the Aral Sea (Case study 1, pages 111-112 in FAO 61).

Only 12 percent of the land would produce at a loss under the most pessimistic assumptions. However in Tajikistan, the authors report that in their representative sample of districts (rayons) between one-half and two-thirds of the land was unprofitable. It appears that it is also necessary to survey at district level or below as aggregate numbers can still be highly positive while some parts of the land are severely affected by salinity or waterlogging and would not be viable at all. The issue is confounded by the fact that many farmers are not achieving the full potential from their land due to institutional weaknesses or adverse policies.

Others, belonging to the second group who consider rehabilitation non-viable, base their opinion on environmental considerations. The authors of this report included in their economic evaluations also a partial assessment of the environmental externalities associated with specific rehabilitation investments and found that in some of the scenarios the net present value then switched sign from positive to negative. The weakness of the analysis arises from the inability to calculate the value of ecosystem and health damage. They state that "in the short run, the cost/benefit ratio of trying to include the environmental externalities in the analyses of other irrigation rehabilitation projects in the region may not be positive, given the large data requirements and complex natural systems involved".

The report finds that if in the absence of rehabilitation farmers are given a cash payment equal to the value of income from irrigation alone, paid to all affected workers over the life of the project, the net present value of the subsidy required for rehabilitation would be greater than the cash payments in all but the most pessimistic project scenarios. For social reasons, the creation of subsidized jobs and relocation may be preferable to handing out cash payments. Under conservative assumptions concerning the number of farmers who would stay on the formerly irrigated land and who would move away, it would be cheaper for the government to subsidize unprofitable rehabilitation project under all scenarios. The report argues that this area requires further work and more data on soil conditions, cropping patterns, farm budgets, and estimated costs of rehabilitating off-farm structures.

But the simplified analysis indicates that it may be cheaper for the government to consider subsidizing a few, carefully selected uneconomic rehabilitation projects, than to try to create jobs and income transfers for some of the affected people.

Finally, the report suggests that the transition period between beginning a policy reform process and the effects being felt in rural areas can be long. The analyses indicate that governments should consider first those rehabilitation projects that are economically the strongest. Additional criteria include the presence or absence of national and local institutions that are strong or realistically stand a chance of being reformed. How to decide whether or not this is the case would require further research.

It is necessary to take into consideration that rehabilitation of irrigation and drainage infrastructure is needed and economically sound for conditions of the region. These measures will provide conservation of water, which is presently released into rivers polluting their flows and partially wasted in evaporation ponds. At that, the main effect of these measures is formed by improving the productivity of irrigated lands and living standards of the poorest rural population.

7.3 Writer's comments on the two reports

According to both reports rehabilitation of irrigation and drainage infrastructure is feasible. It would lead to 'saving' of water that is presently wasted in evaporation ponds or seeps to the groundwater. Whether rehabilitation is economically sound is still an open question. The analysis of the World Bank report compares rehabilitation projects with cash payments but does not consider most of the environmental and health externalities. At present, the probability of a positive net present value (NPV) of investments in irrigation/drainage rehabilitation appears to be at best 50 percent if environmental and health issues are also considered. A simple Bayesian evaluation (Press and Tanur, 2001) indicates that for a probability that donors are willing to invest in rehabilitation projects of greater than 50 percent, the probability of the benefit/cost ratio of such investments being greater than one must be at least 70 percent. In this calculation, the prior probability of investments in rehabilitation projects (i.e. prior to knowing what value the benefit/cost ratio of such investments will be), is conservatively estimated at 25 percent (Kijne, November 2004, not published). In other words, if donor funding is to be attracted the positive NPV of rehabilitation projects needs to be convincingly established, which argues (like the World Bank report) for governments to start with those rehabilitation projects that are economically strongest.

Secondly, according to both reports the effectiveness and efficiency of rehabilitation efforts is conditional on institutional and policy changes. It is unlikely that this condition will be satisfied to the same extent in each of the five Central Asian Republics. This point also emphasizes the importance of strict selection of locations for rehabilitation projects where the conditions for success are most likely to be met. These conditions include a careful planning process that includes the participation of all potential beneficiaries, the presence of reliable, trustworthy construction companies, agencies prepared to and capable of carrying out the operation, management and maintenance of the rehabilitated infrastructure, and also the implementation and enforcement of supportive policies.

Both reports clearly suggest that rehabilitation is not just a matter of improving irrigation and drainage infrastructure. Physical improvements should go hand in hand with improvements in water management, irrigation and agronomic practices, capacity building and strengthening of institutions and service providers.

The issue of capacity building and institutional strengthening is particularly important in IPTRID's sphere of activity. The need to go much beyond the physical aspects of rehabilitation substantiates the notion that the time lag between initiating rehabilitation and policy reform and the time that these changes have an effect in the field could be long, which requires patience from beneficiaries, governments and donors alike.

8. NEED FOR BETTER DATA

As mentioned in the first part of this report, many of the data were inadequate or out of date. The need for building a more comprehensive and reliable database is therefore obvious. Field monitoring of water and salt balances is expensive and careful consideration should be given to what data should be given collection priority.

One example is the groundwater assessment referred to in this report, which in both quantitative and qualitative terms was made with limited data and information (Jansen, Paper 1, 2004). The identification and assessment of feasible options for drainage (and irrigation) investments is conditional on better quantification of the geo-hydrological parameters, especially those relating to groundwater flow and salt mobilization patterns, and their historical and expected future trends. Without better data, minimizing the adverse impacts of salt mobilization from ambient groundwater cannot be done successfully. This is one specific example, but considering the expressed need for an integrated approach to water management at several scales from farm to district and river basin level, additional data collection efforts are needed in other aspects of water management as well.

According to Jansen (Paper 1, 2004), specific examples of the geo-hydrological data requirement include:

- The mapping of shallow and deep groundwater, the development of piezometric contour maps of deep groundwater and the use of a Geo Information System (GIS) for the analyses.
- Data for correlating recharge/discharge flows with drainage
- Assessment of natural drainage capacity through data on the hydraulic properties of aquifers
- Hydro-chemical analyses of irrigation and drainage water, and of shallow and deep groundwater to improve understanding of salt mobilization processes
- Data to assess temporal and spatial variability of soil salinity in relation to recharge and discharge flows
- Specifics, including the spatial coordinates, of all groundwater abstraction

Specific studies are recommended on the interaction between alluvial deposits and Phocene (e.g. in Kashkadarya), and on the occurrence of natural drainage in Karakalpakstan. Both studies would contribute to the understanding of specific groundwater flow patterns. A third study should address the management and economics of salinity control through shallow drains, rather than the existing deep drainage levels and wide drain spacings, combined with improved irrigation practices.

The next three sections of this report discuss specific topics that need to be included in action plans and project proposals. The first of these sections looks at ways to monitor soil salinity cost-effectively, the second discusses options for drainage water disposal, and the third considers the need for transboundary agreements.

9. ALTERNATIVE METHODOLOGIES FOR SOIL SALINITY MONITORING

As detailed in Paper 5 (WaterWatch 2004) and briefly described in Section 3.2 of this report, monitoring soil salinity can either be done by extensive and fairly frequent soil sampling in the field or through the analysis of satellite pictures. The cost of a field survey obviously depends on the size of the area to be surveyed and the sampling density required for statistical analysis. The cost can be reduced by the use of an electro-magnetic sampling probe, e.g. EM38, the readings of which can be interpreted in terms of soil salinity profiles. However, the calibration is affected by soil water contents and for accurate interpretation readings should be taken as near as possible at the same water content. In fields with non-uniform irrigation applications this is difficult and then also soil moisture contents need to be determined. Training in the use of the probe and the analysis of the readings is required, which adds to the costs.

A cost estimate for processing one high-resolution Landsat image path/row combination with an area of 185 by 185 kilometres (3.4 million hectares) is about US$50 000, which in all probability is less than the cost of a soil survey for a similar sized area. Since May 2003 unusual artefacts began to appear within image data of the Landsat-TM7 satellite with the result that part of the image (around the edge) is missing. For studies since that date, Landsat-TM5 images could be used as an alternative. The old Landsat-TM5 satellite is already past its economic life cycle and might stop functioning in the near future. ASTER data can also be used as an alternative. Soil salinity values based on the interpretation of satellite images need to be validated by comparison with field survey data. Hence, the quality of the satellite-derived soil salinity data is related to the accuracy of the soil salinity measurements from the field surveys. Appropriate measures should be taken to ensure that the field measurements have a high accuracy.

When monitoring the agricultural production is the main objective, it is more efficient to monitor the actual evapotranspiration and the biomass growth through the application of SEBAL. This methodology was developed for this purpose and requires only standard meteorological data. It can be applied with little time for preparation. The results can be obtained for any time period, from one day to one year, but usually a two-week interval is sufficient. The standard output biomass growth and evapotranspiration is calculated in the SEBAL model from a set of low-resolution images that cover the whole year with an interval of approximately 2 weeks. This kind of monitoring system is very suitable for comparing different oblasts; but even within an oblast productive and non-productive areas can be differentiated. Agricultural production at basin level could be monitored for as little as US$40 000. From the results at the scale of an oblast, areas for more detailed studies can be identified. It is also feasible to ascertain through field visits whether areas that the SEBAL analysis indicated as having low relative evapotranspiration rates and low biomass production are in fact salt-affected areas. This would be an indirect way of obtaining some indication of the spatial distribution of harmful salinity levels.

10. OPTIONS FOR DISPOSAL OF DRAINAGE WATER

According to its geological, geomorphologic, climatic and hydrographic conditions, the upper part of the Syr Darya river functions as a regional drain. As there are no sinks or depressions that can serve as evaporation ponds in the region, the bulk of collector-drain outflows with its salt load has to go back into the river channel (SIC-ICWC, Paper 3, 2004). The annual salt transport in this part of the river is estimated at 15 million tonnes, and, as a result, the river water salinity reaches 0.9-1.2 g/l at the reservoirs at the end of the upper reaches. Controlling the water quality in the upper reaches of the Syr Darya river by reducing drainage outflow should have the highest priority. This could be done by reducing the amount of water supplied as irrigation per unit land and the development of large-scale reuse of drainage water in the area where it arises rather than transporting it down river.

In the middle reaches of the river basin, the water quality and underlying drainage problems could be solved by disposing of part of the outflow from collector drains (up to 60 percent) into the Arnasay depression. Disposing of drainage water in depressions when its quality is still good enough for irrigating salt-tolerant crops is of course wasteful. This option should therefore be implemented together with more extensive reuse of drainage water prior to the disposal of the concentrated drainage water in depressions. In the lower reaches, drain water from collector drains (about 1.2-1.3 km^3 or 60 percent) can be discharged into artificial lakes as part of the programme to restore biodiversity. This leaves 40 percent of the drainage flow to be disposed of in the river channel.

Also, in the Amu Darya river basin most of the collector drain outflow from irrigated lands in Turkmenistan and Uzbekistan goes back into the middle and lower reaches of the river. SIC-ICWC (Paper 3, 2004) opines that the water quality in the river, and hence agricultural productivity, would be enhanced if the flow from the collector drains in the middle and lower reaches of the river basin could be disposed of in the Aral Sea by the construction of the Right Bank Outfall Drain, bypassing the river altogether. This would of course reduce the river flow. However, it is thought that the possible improvements in agricultural productivity that would ensue from the construction of the Outfall Drain would far outweigh the possible negative effect arising from the reduced river flow. This solution also eliminates the need for large amounts of leaching and provides substantial greater amounts of water, albeit saline water, for environmental improvements in the lower reaches of the river basin.

According to SIC, a feasibility study of this right bank outfall drain was carried out in 1980. It was designed to convey drainage waters from irrigated fields located within an area of one million hectares in the upper, middle and part of the lower reaches of the Amu Darya river and would run on the right bank parallel to the Amu Darya river through the desert to the Aral Sea. The total annual flow of the outfall drain is estimated at 3.5 km^3. Its length is more than 308 km and the estimated cost is about US$1 billion. According to the design, once the canal was constructed, operational salinity of the river water in its lower reaches would be less than 1.0 g/l. Weak points of the feasibility study include the absence of any technical alternatives for the reduction of drainage flow, its management and the high construction costs.

Construction of the outfall drain was started in 1987 and progressed slowly due to insufficient funding. An application for financial support from the World Bank is still pending, in spite of several more studies since.

In addition, the Government of Turkmenistan has in principle decided to create a grand lake/reservoir, referred to as "The Lake of the Golden Age of Turkmenistan", through collection and disposal of collector-drainage waters from five oblasts in Turkmenistan and Khorezm oblast in Uzbekistan. The collected flow will be discharged through nine off-farm collector drains of 936 km length into two planned main canals, 1 080 km long, and from there into the lake. It is evident that implementation of such a grand project will affect environmental and land reclamation processes both in Turkmenistan and in the lower reaches of the Amu Darya river.

11. TRANSBOUNDARY FLOWS

Drainage flows that arise within the boundaries of one State but discharge into rivers and lakes in another State, polluting the latter, are transboundary return flows. Many of these transboundary flows contribute considerably to pollution in the recipient country.

As specified by SIC-ICWC (Paper , 2004), development of a regional management strategy for the treatment of such transboundary flows involves the following:

- States and planning zones (oblasts) should establish mutually acceptable limits for the volume and the pollutants permitted in transboundary flows.
- Procedures should be developed for the application of sanctions in case of violation of the agreed limits.
- Responsibilities for the management of transboundary flows should be distributed fairly between national, regional and where appropriate local authorities.
- Salts transported with the transboundary flows should be distributed by agreement between the regions (e.g. oblasts) where the salt accumulation originated.

New regional and national organizations or extension of existing institutions need to be established and agreements made to strengthen institutional capacity of those water and environmental organizations that are or will become responsible for the management of trans-boundary flows.

12. NEEDS ASSESSMENT

The action plans, scenarios and data requirements discussed in the previous paragraphs have two obvious shortcomings: they do not specify who should do what nor the cost involved in implementing the various actions. It also means that there is no clear picture yet about the costs and benefits of moving from the business-as-usual scenario to the improved or the higher investment scenarios. That makes it hard to prioritize.

The writer of this report distilled the following preliminary list of needs from the various action plans and scenarios mentioned in the previous paragraphs, with the categories: resources, physical improvements, institutional arrangements, data collection (research) and new ideas:

Resources

- Water
- Funds
- Equipment, e.g. to clean drains, farm machinery, post-harvest processing equipment
- New irrigation technology, e.g. drip irrigation, laser leveling equipment

Physical improvements

- On-farm drains
- Off-farm collector drains
- Vertical drains
- Irrigation structures

- Locally developed technology and equipment
- Land levelling

Institutional arrangements and enforceable policies and regulations

- Regarding land tenure and private ownership
- Water rights
- Recognized responsibility for operation and maintenance of on-farm and off-farm infrastructure
- Extension services for support in new cropping patterns, irrigation methods and O&M
- Private sector service providers
- Trade liberalization and market support
- Accountability for maintaining water quality
- Penalties for over-irrigation and discharge of more salts than permitted
- Transboundary agreements on discharges and water quality
- Farmer participation in decision making, management and maintenance
- Support for poor farmers adversely affected by breakdown of irrigation and drainage facilities

Data collection/research

- Cost and benefits of various proposed rehabilitation and repair actions
- Geo-hydrological information, e.g. on groundwater discharge and recharge areas
- Land and water productivity (e.g. gross value of product per cropped area and per consumed amount of water)
- Soil salinity monitoring, including by satellite imagery
- Water quality in all water resources (e.g. deep and shallow groundwater, drainage water)
- Temporal and spatial distribution of salinity and water quality
- Groundwater use in irrigation
- Value of ecosystems and health hazards
- Value of water for environmental use in wetlands and the Aral Sea
- Reuse of drainage water
- Poverty and out migration

New ideas

- Options for disposal of water from collector drains other than back to the rivers
- Evaluation of possible improvements in nutrition and health of poor farmers
- Diversity of cropping patterns
- Creation of off-farm employment
- Introduction of new crops and varieties
- Bio-saline agriculture for the production of fodder for livestock

12.1 Writer's comments and conclusions

In the context of this project which aims to contribute to the development of sustainable irrigation with feasible investments in drainage, some items of each of the categories of needs have relevance. To achieve sustainable agriculture, physical improvements in drainage and irrigation infrastructure are essential. There can be no doubt about that. In terms of institutional arrangements, all of the listed needs should be addressed. It has to be made clear who should take the initiative and in what order these institutional changes need to implemented. Probably, some of these needs should be addressed with priority in any integrated water management improvement plan. Data collection and related research efforts cannot be given high priority other than to the extent that these efforts are indispensable for the effectiveness and efficiency of the rehabilitation measures. The first mentioned item in this category, namely, the cost and benefits of various proposed rehabilitation and repair actions surely demands high priority. At present, there are only incomplete and perhaps outdated estimates of some of the cost components of rehabilitation measures.

New ideas are always welcome. However, considering the dire state of on-farm and off-farm irrigation and drainage in many parts of the Aral Sea Basin, it is hard to justify high priority for expensive solutions to the disposal of water from collector drains, such as the right bank outfall drain in the Amu Darya river basin and the Lake of the Golden Age of Turkmenistan. As indicated in the introduction to this report, restoring the water level and biodiversity of the Aral Sea is beyond the scope of this study. However, ecological externalities of proposed rehabilitation projects should be taken into account. These could be positive or negative.

Critical Questions

1. How to select sites? The worst affected sites where infrastructure is all broken down first, or sites with the greatest chances of success?
2. Should an oblast be selected or better to start with a district (rayon)? (oblast 250-500 000 hectares irrigated land; rayon 20-30 000 hectares).
3. Are worse-affected areas then written off?
4. Is presence of strong institutions important in selection?
5. Should rehabilitation at all selected sites have positive Net Present Value?
6. How much of a selected site should be repaired to call rehabilitation complete?
7. Could rehabilitation be financed not knowing its likely profitability?

Critical questions that need to be asked are:

1 How should the site for the first repair/rehabilitation action be chosen? Should it be the worst affected area, i.e. one where the infrastructure is all but completely broken down, yields are low because of the incidence of soil salinity and/or waterlogging, and the farmers are poor or attempt to leave agriculture to find employment elsewhere? Or should it be a site where the chances of success are higher, where at least some of the infrastructure is still operational, where existing institutions show some promise of change, and where a strong case can be made for a positive net present value (NPV) of the investment?

2 Should a site for rehabilitation encompass an entire planning zone (oblast), or is it feasible to start with one or several districts (rayons)?

3 If, as this writer supports, rehabilitation should in the first instance be carried out at a site with the greater probability of a positive NPV, does this imply that some areas will be abandoned and other options should be offered to the affected farmers?

4 What effect should present institutional arrangements have on the choice of a site for rehabilitation, and what criteria could be applied in assessing the likelihood of supportive institutional arrangements at a chosen location?

5 How many sites should be considered in the first tranche of rehabilitation? If more than one, should they all have a greater than 50 percent probability of having a positive NPV, or should it include a site with a somewhat lower or considerably higher probability of success?

6 To what level should the selected sites be rehabilitated? The intermediate scenario anticipated repair/rehabilitation of only 25 percent of the length of horizontal drains, 20-25 percent of sub-surface drains, and marginal recovery of production at a rate of one percent per year for twenty years. The higher-investment scenario expected rehabilitation of 30-35 percent of horizontal drains and full recovery of sub-surface drains, with one percent recovery rate of the production over ten years and thereafter at five percent per year.

7 Could financial support for rehabilitation be obtained from the private sector or official development aid (ODA) without a strong probability of viability or when economic viability still needs to be ascertained in a pilot scheme?

The following paragraphs provide an answer to these questions.

12.1.1 Question 1: Where to start, at the worst or somewhere in the middle of the range?

As mentioned in section 2.3 above, the report prepared for the World Bank (Bucknall, 2003) compares the expected benefits from rehabilitation with the probable cost of compensating farmers for their loss of income from irrigation. It concludes somewhat tentatively, as the environmental and health externalities are not included in the analysis, that the benefits of rehabilitation will probably exceed the costs of compensating farmers. This argument was supported by a Bayesian probability analysis. Although the problems of irrigated agriculture in the Aral Sea Basin have been known for quite some time, the many feasibility studies since have not led to major investments, which also suggests that proposed interventions should be economically viable.

For the last twenty years or so, the climate for major irrigation and drainage investments has not been very good. Investments by major multilateral donors declined, in part because of low world market prices for commodities and in part resulting from negative environmental externalities associated with many large-scale dam constructions and other irrigation-related projects. There are signs that this may be changing (*vide* the interview with John Briscoe, senior water advisor to the World Bank in the November/December issue of WorldWater, volume 27, issue 6). Apparently, the Bank, in response to demand for its input in big infrastructural developments in the middle income countries, such as India, China and Brazil, will expand its portfolio in support of irrigation projects in developing countries. This does not however diminish the need to present to funding agencies projects for support that are likely to have a positive NPV.

12.1.2 Question 2: Should a rehabilitation project tackle an entire oblast?

The first two areas with highest priority proposed by SIC-ICWC are the Karakalpakstan and the Bukhara oblasts. Karakalpakstan oblast has an irrigated area of about 500 000 hectares and 16 districts. The average irrigated area in each district is therefore more than 30 000 hectares.

For the Bukhara oblast with 274 000 hectares and 12 districts the average size of the irrigated area per district is nearly 23 000 hectares. The size of the irrigated area in a district makes this the more obvious choice for a pilot project on the feasibility of rehabilitation. Whether a district is the right choice depends on the hydrological context. Oblasts and rayons are administrative units; rehabilitation should take place in a hydrological unit, e.g. a canal command area and its associated drainage network that may or may not coincide with a rayon.

Presumably not all of the irrigated land in any rayon or oblast needs to be rehabilitated. For example, vertical drainage in the Bukhara oblast is said to function well. However, only 80 percent of the area is now provided with drainage, but the entire land area is in need of it. Hence on some 20 percent of the irrigated land in Bukhara, i.e. nearly 60 000 hectares, drainage needs to be installed which is more expensive than rehabilitating an existing system. The density in drainage networks differs between the rayons. The horizontal drainage systems in Bukhara oblast were designed for the production of cotton, and this system could be inadequate when other crops, e.g. wheat, are grown. All this indicates considerable variation in the needs for rehabilitation and new construction in different rayons, which makes it difficult to estimate an average cost of rehabilitation even at the scale of a rayon.

12.1.3 Question 3: If rehabilitation does not start with the worst affected areas, does this mean they are written off?

For some of this worst affected land, the answer to this question is ‘probably, in the medium term, yes’. The crux of the matter is that there is a shortage of water. Or to put it differently, there is too much irrigated land for the available water as long as much of the water is used inefficiently. As long as the irrigated area remains the same, crop evapotranspiration remains constant. Any excess irrigation water supplied to the land passes through the soil profile and seeps to the groundwater or flows into drains. The reduction has to come from reducing the irrigated land and hence from lowering the demand for river water. This way a better balance between irrigated land and available water could be achieved.

During rehabilitation and for some time thereafter reclaimed land will continue to need leaching supplies to lower the salt content in the rootzone. If the drainage system is working well and does not mobilize salts from below the drain depth, the salt content in drain water will start to drop. This will reduce the need for leaching but never completely eliminate it. Although some leaching water is still needed, more water will be available in the system, especially if at the same time irrigation efficiencies are improved. There are various possible uses for this water. It could be used for expansion of the irrigated area, which would be the wrong choice as it leads to a return of the current problems. It could be used for environmental uses in the delta and for refilling the Aral Sea, or it could be used in the process of reclaiming other areas. It is thus conceivable that in the long term even those lands that now need to be abandoned could be brought back into production. However, that is surely a long time off.

An alternative to complete abandonment of severely saline lands is the introduction of biosaline agriculture in which saline irrigation water is used to grow salt-tolerant crops, such as fodder crops that could stimulate animal production in the area; and ensure continuous employment to some of the affected farmers. Other crops that have been introduced under similar conditions elsewhere are tree crops, sometimes grown more to help drain waterlogged land (bio-drainage) than for the production of timber.

12.1.4 Question 4: How important are institutions in the choice of the project area for rehabilitation?

Renewal of institutions, policies and regulations are all very important. Examples include the allocation of water, responsibility for operation and maintenance of the rehabilitated structures on-farm and off-farm; the financing of O&M; disposal of drainage water; accountability and the issuing of penalties if commitments are not kept or agreements broken; and finally willingness to have farmers participate in decision making, management and maintenance. If there is good reason to suspect that considerable institutional resistance to change exists in the institutional arrangements in an area selected for rehabilitation, another one should be selected.

12.1.5 Question5: Should more than one site be selected and should they then all have high probability of success?

Not necessarily. It is recommended that one site be selected to see what can be done at a physically more difficult site but where perhaps the institutional arrangements appear more promising. This could be a location with functioning water user associations and where farmers show themselves eager to assist in the improvements. Variation in location-specific attributes and physical conditions could speed up the learning process of what works and what does not. Conditions for success are unlikely to be constant throughout the large river basins.

12.1.6 Question 6: Is there a predetermined level at which rehabilitation is considered complete?

Even the higher-investment scenario covers repairs of only 30 to 50 percent of the horizontal drainage system, which is sufficient if only half of the system is defunct. Most likely whatever part of the drainage system is not functioning well needs to be repaired and improved before one can consider rehabilitation complete. In addition service providers, such as technical assistance and extension services, should be in place to assist farmers with new irrigation and agronomic practices and with the technical aspects of maintaining rehabilitated infrastructure. If this is not achieved, the investments will probably be wasted.

Support will be needed for a long time, especially if there are future events with an impact on agricultural productivity in the region. Such impact could come from increased water use in northern Afghanistan, which would have repercussions for water supplies in the Amu Darya river basin (Ahmud and Wasiq, 2004). Also climate change, which is said to bring hotter and drier weather to the Aral Sea Basin, would affect water management issues. Whether irrigated agriculture functions well in an area can be measured by its resilience in the face of change. The aim of rehabilitation should be to make these systems and the farmers who live there resilient and capable of dealing with change.

12.1.7 Question 7: Would funding agencies invest in drainage rehabilitation not knowing whether the project is economically viable or not?

The case for intervention has been made many times before. By one count since 1975 (mostly since 1991) 140 studies were carried out on drainage, salinity control and irrigation in the Central Asian Republics (Dr Rien Bos in an unpublished note for IPTRID), 22 of which addressed the economics of drainage. Still funding for rehabilitation has not been forthcoming. It is a conundrum for funding agencies when so many things are wrong at the same time. This report argues for an integrated approach in the rehabilitation of irrigation and drainage infrastructure, introduction of better irrigation and agronomic practices (including new cropping patterns) and institutional change.

It is complex and no-one can be sure of success, let alone of positive NPV of the investments in the short term. However, doing nothing is not an option. The system will deteriorate even further and the livelihood of probably over twenty million people is at stake.

The first phase of rehabilitation could be at the relatively small scale of several districts (some 25 000 to 30 000 hectares each), to be followed in the second phase of a project by rehabilitation of several more areas of such size.

Use of the term “pilot study” for a limited scope at first does not imply insufficient understanding of the basic principles of irrigation and drainage in the Aral Sea Basin. Much more is known than is unknown. For example, FAO Irrigation and Drainage Paper No. 61 (2002) deals exclusively with best practices in the management of agricultural drainage water in arid and semi-arid areas. It describes various physical and non physical options for managing saline drainage water, including the issuing of drainage permits which, for instance, has been quite successful in Australia and elsewhere. It has been argued that some aspects of salt mobilization in horizontally and vertically drained land still need to studied in greater detail, especially where the drainage is deep and the spacing wide. But even on this topic there is a wealth of information from studies in other countries (e.g. Kelleners, 2001 who conducted field studies in Pakistan, and also from India and Egypt which have many years of experience with drainage). What is lacking is the application of this accumulated knowledge in the Aral Sea Basin. That is what this project is about.

As conclusion, the previous discussion leads to five tenets for the way forward:

- Sites selected for rehabilitation projects should have the greatest probability of success.
- Drainage rehabilitation is part of an array of interventions leading to integrated water management, and including institutional strengthening, capacity building and applied research.
- Resource degradation will continue in the many areas where rehabilitation projects have not been started.
- Alternative livelihoods and off-farm employment remain important for the affected farmers.
- The essence of project formulation is the application of accumulated knowledge.

Mindful of what needs to be done and could be done, three project proposals, in outline concept form, have been drafted and are presented in the last part of this report. Implementing all three would only address the problems in a small part of the Aral Sea Basin – the tip of the iceberg – but it may give the people who live there hope for a better future.

PART 3

INDICATIVE PROJECT PROPOSALS

13. CONCEPT PROJECT PROPOSALS

ASB Concept Project Proposal 1

- **Project Title:** Improving irrigation and drainage infrastructure in the Bukhara Oblast
- **Expected Budget and Duration:** US$ 10 million, 5 years
- **Potential Donor(s):** World Bank
- **Potential Partner(s):** SIC-ICWC, HR Wallingford, Brace Center for Water Management, ALterra-ILRI, WaterWatch
- **Supervisor:**
- **Relation to other World Bank projects:**

The problem and why it is urgent

Bukhara oblast with 274 000 hectares and 12 districts (rayons) is located on the right bank of the Amu Darya river in Uzbekistan. Much of its agricultural land is in terrible condition. Low intensity in the drainage network has contributed to waterlogging in about one-quarter of the area while some 40 percent of the irrigated land has medium to severe soil salinity. According to information collected during the IPTRID project, much of the vertical drainage is also in poor operating condition, partially due to lack of spare parts. Salinity in irrigation water has increased during the past thirty years and the salt content is now about 1.2 g/l.

Unless most of the infrastructure can be repaired and rehabilitated, more and more of the irrigated land in Bukhara will be retired each year because of complete failure of the drainage system. According to SIC, collector drains are old, and the area without adequate drainage will increase to 60 000 hectares even if repairs are done according to standard. However, at the present reduced rate of repairs the non-drained areas will increase to 130 000 hectares, which will greatly worsen the waterlogging and salinity problems. If all repair work was stopped on land with sub-surface and vertical drains and reduced to 30 percent on the land with open drains, it is expected that all arable land will be strongly saline by 2025. All irrigated land in Bukhara therefore needs to be drained, and drainage now needs to be installed on an additional 60 000 hectares, which is more expensive than rehabilitating an existing system. In addition, the horizontal drainage systems in Bukhara oblast were designed for the production of cotton. If the intent is to grow other crops, such as wheat, the system will be probably quite inadequate.

The proposed project, to tackle the oblast's drainage problems, will be expensive since it contains a large construction component. Rehabilitation of infrastructure in Uzbekistan may cost as much as US$250 per ha and the project aims to rehabilitate 40 000 hectares. It is expected that rehabilitation of part of the selected area can be accomplished at lower cost. At the end of the project 40 000 hectares, or nearly 15 percent of the irrigated land, will be fully operational and capable of producing at full potential.

The project's implementation needs to be conditional on explicit and specific commitment by the Government of Uzbekistan to support the necessary institutional changes required for success. Another condition might be to require the project to be managed by a foreign engineering firm who could subcontract with local firms as needed. It is suggested that the project be executed in two phases, with a first phase of at most a year for careful site and contractor selection. If possible, the project should be implemented at sites where vertical and horizontal drainage could complement each other well.

Goal, Objectives and Activities

Goal: To improve productivity of irrigated agriculture in the Aral Sea Basin.

Objectives

a. To improve existing irrigation and drainage infrastructures on 80 000 hectares.
b. To balance the supply and demand of irrigation water and hence reduce drainage flows.
c. To stimulate local reuse of drainage water.
d. To reduce soil salinity.
e. To enhance the livelihoods of the farmers in the selected areas.

Activities

a. To clean main drains and restore their cross section and slopes to the design values.
b. To repair horizontal on-farm open and sub-surface drains of selected areas and where necessary intensify the drainage network.
c. To repair vertical drainage facilities of selected areas to their original design and where necessary intensify the network of vertical drains.
d. To improve irrigation water distribution and allocation.
e. To reduce soil salinity in the selected areas by suitable leaching practices.
f. To strengthen farmers' capacity to produce marketable crops, including new crops and/or varieties, by introducing new agronomic practices and training farmers in these practices.
g. Build the capacity of institutions to operate and maintain irrigation and drainage infrastructure and to provide the necessary services to farmers.
h. To stimulate the development of water user associations and strengthen their ability to maintain and operate on-farm irrigation and drainage facilities.
i. To stimulate the development of private sector service providers to assist farmers in O&M of infrastructure and in developing suitable agronomic and water management practices.
j. To work with all stakeholders in the development of appropriate regulations and policies for the betterment of irrigated agriculture in the selected area by introducing supporting policies and regulations intended to prevent excessive irrigation, by reducing soil salinity, and stimulating local reuse of drainage water and the introduction of new crops and marketing facilities.
k. To monitor the effect of the various interventions on the use of irrigation water, the drainage flow, and the salt balance, as well as on yields and family incomes.

Inputs and Project Management

Inputs

a. Contractors to clean and improve the main drains.
b. Equipment and spare parts, such as flushing machinery and pumps, to clean and restore sub-surface and vertical drains.
c. Laser leveling equipment to level farmers' fields.
d. Trainers and supervisors to train and assist farmers in the rehabilitation, maintenance and operation of the drainage and irrigation facilities.
e. Capacity building experts to strengthen the required institutions and service providers.
f. Irrigation engineers to draft new water distribution and allocation schedules and supervise their introduction, and together with the project economists monitor the productivity of used and diverted water.
g. Measuring equipment for monitoring irrigation and drainage flows, water quality and soil salinity levels.
h. Agronomists to assist farmers with the introduction of new crops and varieties.
i. Social scientists to stimulate and guide farmers in establishing water users associations, and to evaluate livelihood changes resulting from the project's interventions.
j. Economist to assess changes in agricultural productivity and to evaluate the need for market development.
k. Project manager to coordinate the diverse activities.

Project Management: to be decided

Outputs, Beneficiaries and Impacts

Outputs

a. Length of main drains cleaned and rehabilitated.
b. Length of open and sub-surface drains restored to full working order.
c. Number of pumps and vertical drains restored to full working order.
d. Number of hectares that were laser levelled.
e. Amount of drainage water that is locally reused versus discharged into main drains.
f. Number of water user associations started.
g. High rate of fee collection or some other measure of success of water users associations.
h. Number of farmers trained in O&M of irrigation and drainage infrastructure.
i. Number of institutions and service providers capable of implementing operation and maintenance of rehabilitated infrastructure, c.q. providing the necessary supervision of operation and maintenance as carried out by others, including farmers.
j. Number of hectares sown with new crops.
k. Improved crop yields by measurable amount.
l. Quantifiable reduction in soil salinity.
m. Measurable increase in rural incomes.

Beneficiaries

a. Rural population, especially the farmers in the selected areas, as a result of raised household incomes, better diets and higher calorie intake.
b. Urban population because of availability of greater diversity of crops and varieties at reasonable prices.
c. Downstream water users because of lower salt load in the drainage water and ultimately in the river downstream.

Impacts

a. Improvement of rural livelihoods.
b. Improved water productivity (higher irrigation efficiencies and less waste of water) in selected areas.
c. Restoration of irrigation and drainage infrastructure and its improved O&M.
d. Reduction in salt load in downstream river.
e. Enhanced sustainability of irrigated agriculture in ASB.

ASB Concept Project Proposal 2

- **Project Title:** Reducing drainage flows and increasing reuse of drainage water in Kyrgyzstan
- **Expected Budget and Duration:** US$ 3 million, 3 years
- **Potential Donor(s):** World Bank
- **Potential Partner(s):** SIC-ICWC, HR Wallingford, Brace Center for Water Management, ALterra-ILRI, WaterWatch
- **Supervisor:**
- **Relation to other World Bank projects:**

The problem and why it is urgent

In Kyrgyzstan, the rural population constitutes 38 percent of the total, the highest percentage of the five ASB countries. Kyrgyzstan is also one of the smaller countries with just five million people. It has the second lowest Gross National Income per person (US$280) and by far the lowest Foreign Direct Investment (US$ five million/year in 2002). Kyrgyzstan derives more of its GDP from agriculture (38 percent) than any of the other ASB countries, and an even higher percentage of the population is dependent on agriculture. All of this points to the importance of sustaining agricultural production for the future. But around 80 000 hectares of land, or more than seven percent of the total, have already been removed from cultivation owing to severe land salinization and waterlogging. Other farmers cannot achieve their full potential because of the adverse salinity and waterlogging conditions.

Because of the geological and hydrological conditions of the upper part of the Syr Darya river basin, the river functions as a regional drain. There are no sinks or depressions that can serve as evaporation ponds in the region and the bulk flow in drainage canals, with its salt load, has to go back into the river channel. The annual salt transport in this part of the river is estimated at 15 million tonnes. As a result, the river water salinity reaches 0.9-1.2 g/l at the rim stations (i.e. the reservoirs for hydropower generation) at the transition between upper and middle reaches of the Syr Darya river. Salinity levels of up to 1.2 g/l (equivalent to an electrical conductivity of the water of slightly less than 2 dS/m) in the irrigation water are not detrimental to the production of most crops. Yet it is not necessary to have such salt levels in the upper reaches of the river. All along the river some part of the drainage water flows back into the river channel and the accumulated effect on irrigated agriculture in the middle and lower reaches of the river basin is damaging indeed.

The action of highest priority in the upper reaches of the Syr Darya is therefore to control the quality of the river water by reducing the drainage flows. This should be done by reducing the amount of water supplied as irrigation per unit of land and the development of large-scale reuse of drainage water in the area where it arises rather than allow the drainage water to be transported down river.

The intent is to achieve a selective rehabilitation of main and secondary collector drains and, at farm level, of open and sub-surface drains as necessary. It will also be necessary to intensify the on-farm drainage network and to link it with the irrigation network, thereby making reuse of drainage water possible. Estimated budget requirements for such improvements are in the range of US$50-100 per hectare for Kyrgyzstan. The aim of the project is to rehabilitate about 30 000 hectares of irrigated land such that its full productive capacity can be utilized. The construction component of the project explains a large part of the project expenditure. Implementation of the proposed project needs to be conditional on the explicit commitment of the Government of Kyrgyzstan to support the necessary institutional changes required for its success. It is advisable to contract a foreign engineering firm for project management with project implementation by local trustworthy sub-contractors. The proposed project could be executed in two phases, with a first phase of at most six months for careful site and contractor selection.

Goal, Objectives and Activities

Goal: To improve productivity of irrigated agriculture in the Aral Sea Basin.

Objectives

a. To improve existing irrigation and drainage infrastructures.
b. To balance the supply and demand of irrigation water and hence reduce drainage flows.
d. To stimulate and facilitate local reuse of drainage water.
e. To initiate monitoring procedures to ensure the continued reuse of drainage water and reduce as much as possible the discharge of drainage flows into the Syr Darya river.
f. To reduce soil salinity.
g. To enhance the livelihoods of the farmers in the selected areas.

Activities

a. To clean main drains and restore their cross section and slopes to the design values.
b. To repair horizontal on-farm open and sub-surface drains of selected areas and where necessary intensify the drainage network.
c. To link drainage and irrigation canal networks to extend the opportunities for reuse of drainage water.
d. To improve irrigation water distribution and allocation.
e. To reduce soil salinity in the selected areas by suitable leaching practices.
f. To introduce and train farmers in the use of improved agronomic practices, including new crops and/or varieties.
g. To stimulate the development of water users associations and strengthen their ability to maintain and operate on-farm irrigation and drainage facilities.
h. To stimulate the development of private sector service providers to assist farmers in O&M of infrastructure and in developing suitable agronomic and water management practices.
i. To work with all stakeholders in the development of appropriate regulations and policies for the betterment of irrigated agriculture in the selected area by introducing supporting policies and regulations intended to prevent excessive irrigation, by reducing soil salinity, and stimulating local reuse of drainage water and the introduction of new crops and marketing facilities. This includes the introduction of penalties for violations of agreed limits of salt and drainage water disposal back into the river channel.
j. To monitor the effect of the various interventions on the use of irrigation water, drainage discharge, reuse of drainage water, and the salt balance, as well as on yields and family incomes.

Inputs and Project Management

Inputs

b. Contractors to clean and improve the main drains.
c. Equipment and spare parts, such as flushing machinery and pumps, to clean and restore sub-surface and vertical drains.
d. Laser leveling equipment to level farmers' fields.
e. Trainers and supervisors to train and assist farmers in the rehabilitation, maintenance and operation of the drainage and irrigation facilities.
f. Irrigation engineers to draft new water distribution and allocation schedules and guidelines for local reuse of drainage water, and to supervise their introduction, and together with the project economists monitor the productivity of used and diverted water
g. Measuring equipment for monitoring irrigation and drainage flows, water quality and soil salinity levels.
h. Agronomists to assist farmers with the introduction of new crops and varieties.
i. Social scientists to stimulate and guide farmers in establishing water user associations, and to evaluate livelihood changes resulting from the project's interventions.
j. Economist to assess changes in agricultural productivity and to evaluate the need for market development.
k. Project manager to coordinate the diverse activities.

Project Management: to be decided

Outputs, Beneficiaries and Impacts

Outputs

a. Length of main drains cleaned and rehabilitated.
b. Length of open and sub-surface drains restored to full working order.
c. Measurable increase in drainage reuse and concurrent major reduction in drainage flows that go back into the river.
d. Improved water allocation and distribution schedules.
e. Number of hectares that were laser levelled.
f. Number of water user associations started.
g. High rate of fee collection or some other measure of success of water user associations.
h. Number of farmers trained in O&M of irrigation and drainage infrastructure.
i. Number of hectares sown with new crops.
j. Improved crop yields by measurable amount.
k. Quantifiable reduction in soil salinity.
l. Measurable increase in rural incomes.

Beneficiaries

a. Rural population, especially the farmers in the selected areas, as a result of raised household incomes, better diets and higher calorie intake.
b. Urban population because of availability of greater diversity of crops and varieties.
c. Downstream water users because of lower salt load in the drainage water and ultimately in the river downstream.

Impacts

a. Improvement of rural livelihoods.
b. Improved water productivity (higher irrigation efficiencies and less waste of water) in selected areas.
c. Restoration of drainage infrastructure.
d. Reduction in salt load in downstream river.
e. Enhanced sustainability of irrigated agriculture in ASB.

ASB Concept Project Proposal 3

- **Project Title:** Reduce drainage flow into the Sarykamysh Lake in Northern Turkmenistan
- **Expected Budget and Duration:** US$ 12.5 million, 5 years
- **Potential Donor(s):** World Bank
- **Potential Partner(s):** SIC-ICWC, HR Wallingford, Brace Center for Water Management, ALterra-ILRI, WaterWatch
- **Supervisor:**
- **Relation to other World Bank projects:**

The problem and why it is urgent

The Sarykamysh Lake is the largest irrigation-drainage lake in the ASB. It is located in Turkmenistan near the border with Uzbekistan, on the left bank of the Amu Darya river. It receives drainage water from about 500 000 hectares of irrigated cotton grown in the Khorezm (Uzbekistan) and Dashoguz (Turkmenistan) provinces. Between 1971 and 1985, the water level in the lake rose by 35 metre and its surface area increased from 1 020 to 2 900 km^2. Now inflow into the lake and evaporation appear to be in balance. Out of 7.6 km^3 of water diverted for irrigation in those two areas, 2.2 km^3 flows as drainage water into the lake.

More than 170 000 hectares of the irrigated land have watertables at less than one metre below the surface and in 2002 about half the land in Khorzem province was moderately to severely saline, the remainder being slightly saline. In 1994 the cotton yield was about 3 tonnes/ha; by 2003 it had gradually decreased to only 1.6 tonnes/ha. Since 1991 repair work on the collector drains in Khorzem has nearly stopped. Unless more of the drainage system can be repaired and rehabilitated, more and more of the irrigated land in Khorzem and Dashoguz will go out of production.

Two things could be done about this alarming situation. The first one is to reduce the water level in the lake by digging a canal of some 280 km to the Aral Sea. Lowering the water level in the Sarykamysh Lake would improve the hydraulic gradient in the drainage system and thus improve drainage and lower water tables in the irrigated land. The second option is to improve water management of the irrigated areas by preventing excessive irrigation, stimulate reuse of drainage water and thus reduce discharge into the lake. Over time, the water level in the lake would start to drop and the hydraulic gradient in the drainage system would improve.

In principle, the choice between the two options should be dictated by a cost-benefit analysis of both. However, the ecological advantages of increasing the total flow into the (west part of) the Aral Sea are difficult to quantify. Also the canal would have to be constructed in total before any benefits of the investment would ensue, whereas the second option can be done in stages. The project proposal assumes that the second option is to be preferred.

Estimated budget requirements for rehabilitation are in excess of US$200 per hectare for Uzbekistan and more than US$100/ha for Turkmenistan. Assuming an average cost of US$200/ha, the total expenditure for the two provinces would amount to some US$100 million.

Considering that the total economic losses for ASB are estimated to be at least US$1.4 billion per year, an investment of US$ 100 million becomes perhaps less intimidating. Nonetheless, this project proposal favors a smaller and incremental approach. It is reasonable to assume that rehabilitation of some part of the irrigated land, where the irrigation and drainage infrastructure is not completely defunct, can be achieved at lower cost than US$200/ha. The aim of the project is to have at the end of the five-year project about 80 000 hectares, or 16 percent of the irrigated land of the two oblasts fully operational. The sites for rehabilitation need to be selected carefully for likely success. Implementation of the proposed project should be conditional on the explicit commitment of the Governments of Turkmenistan and Uzbekistan to support the necessary institutional changes which are required for its success. It is advisable to contract a foreign engineering firm for project management with project implementation by local trustworthy sub-contractors. The proposed project could be executed in two phases, with a first phase of at most one year for careful site and contractor selection.

Goal, Objectives and Activities

Goal: To improve productivity of irrigated agriculture in the Aral Sea Basin.

Objectives

a. To improve existing irrigation and drainage infrastructures.
b. To balance the supply and demand of irrigation water and hence reduce drainage flows.
c. To stimulate local reuse of drainage water.
d. To reduce soil salinity.
e. To enhance the livelihoods of the farmers in the selected areas.

Activities

a. To clean main drains and restore their cross section and slopes to the design values.
b. To repair horizontal on-farm open and sub-surface drains of selected areas and where necessary intensify the drainage network.
c. To line canals where excessive seepage occurs.
d. To improve irrigation water distribution and allocation.
e. To reduce soil salinity in the selected areas by suitable leaching practices.
f. To introduce and train farmers in the use of improved agronomic practices, including new crops and/or varieties.
g. To stimulate the development of water users' associations and strengthen their ability to maintain and operate on-farm irrigation and drainage facilities.
h. To stimulate the development of private sector service providers and strengthen existing institutions in assisting farmers in O&M of infrastructure and in developing suitable agronomic and water management practices.
i. To work with all stakeholders in the development of appropriate regulations and policies for the betterment of irrigated agriculture in the selected area by introducing supporting policies and regulations intended to prevent excessive irrigation, by reducing soil salinity, and stimulating local reuse of drainage water and the introduction of new crops and marketing facilities.
j. To monitor the effect of the various interventions on the use of irrigation water, the drainage flow, its local reuse, on the water level in the Sarykamysh lake, as well as on crop yields and family incomes.

Inputs and Project Management

Inputs

a. Contractors to clean and improve the main drains and intensify the drainage network where required.
b. Equipment and spare parts, such as flushing machinery and pumps, to clean and restore sub-surface and open drains.
c. Laser leveling equipment to level farmers' fields.
d. Trainers and supervisors to train and assist farmers in the rehabilitation, maintenance and operation of the drainage and irrigation facilities.
e. Capacity building experts to assist in the establishment and strengthening of suitable institutions and service providers.
f. Irrigation engineers to draft new water distribution and allocation schedules and supervise their introduction, and together with the project economists monitor the productivity of used and diverted water.
g. Measuring equipment for monitoring irrigation and drainage flows, drainage reuse, water quality and soil salinity levels.
h. Agronomists to assist farmers with the introduction of new crops and varieties
i. Social scientists to stimulate and guide farmers in establishing water user associations, and to evaluate livelihood changes resulting from the project's interventions.
j. Economist to assess changes in agricultural productivity and to evaluate the need for market development.
k. Project manager to coordinate the diverse activities.

Project Management: to be decided

Outputs, Beneficiaries and Impacts

Outputs

a. Length of main drains cleaned and rehabilitated.
b. Length of open and sub-surface drains restored to full working order.
c. Number of hectares that were laser levelled.
d. Amount of drainage water that is locally reused versus discharged into main drains.
e. Number of water user associations started.
f. High rate of fee collection or some other measure of success of water users associations.
g. Number of farmers trained in O&M of irrigation and drainage infrastructure.
h. Number of hectares sown with new crops.
i. Improved crop yields by measurable amount.
j. Quantifiable reduction in soil salinity.
k. Measurable lowering on lake level.
l. Measurable increase in rural incomes.

Beneficiaries

a. Rural population, especially the farmers in the selected areas, as a result of raised household incomes, better diets and higher calorie intake.

b. Urban population because of availability of greater diversity of crops and varieties.
c. Farmers in other non-selected parts of the irrigated land because of an overall improvement in the drainage flows.

Impacts

a. Improvement of rural livelihoods.
b. Improved water productivity (higher irrigation efficiencies and less waste of water) in selected areas.
c. Restoration of drainage infrastructure.
d. Reduction in drainage discharge into the lake and overall improvement in drainage situation.
e. Enhanced sustainability of irrigated agriculture in ASB.

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ANNEX 1

COMMENTS RECEIVED FROM SIC-ICWC TEAM

The following comments were received from the SIC-ICWC team. The IPTRID Secretariat made corrections of factual errors and has chosen to present the full note for the benefit of readers. In many cases where the discrepancy between the Report and the SIC-ICWC were too large the Secretariat chose to include the source in the former rather than change the text. It is for the reader to judge the nature of the discrepancies.

From: Albert Shapiro [mailto:dfa@icwc-aral.uz]

Sent: 11 March 2005 07:15

To: Mahabir, Edith (AGLW)

Subject: RE: Aral Sea Basin Synthesis Report

Dear Carlos,

Sorry for delay of reaction on ASBSR, because we translated part of text and submitted to experts.

I agree with Geoff Pearce that level of technical content and attempts of Jacob's report to come to proper ideas from the big scope of materials, which he got from our multinational team of projects' executors (being not involved in drainage situation in Central Asia) are enough relative.

There are understandable difficulties of his task, when he has reports of such respected and well-known organizations as WB (Buckman), GEF (Haskoning) with one-sided information and very complicated and sometime controversial reports on our projects, where local team collected data and gave own view on real land reclamation state with review by foreign consultants. Harry Denecke, who has been working in the region during almost 8 years, had proper ideas of our work composition but, unfortunately, by unknown for us reasons he didn't get ability to finalize it and assist to the Aral Sea basin in promotion of drainage improvement. He also couldn't merge in some misunderstanding existing between local specialists and some of our foreign consultants (H.C. Jansen, E. Noordman) that got huge criticism at our conference.

Mr. Kijne should be appreciated for his obligation to reveal real situation and complete FAO report. In my case, he created proper framework for debate between stakeholders (as mentioned in Geoff's letters) even without correct understanding situation.

The report can be divided into three parts:

- principal positions taken in frames;

- text of report between frames;
- frame for discussion (part 12), proposal and output.

I personally, as a specialist in drainage, who dedicated to this problem in Central Asia 45 years of my life and activity haven't objections on almost all principal statements in frames, but I can't agree with big part of his report between these frames.

Moreover, if we must account positions in frames as conclusion, we can accept them in the most of their part, but if it is not, then where are conclusions? Part 12 is authors' "negotiation" with him as probable conclusion, but no result of this exercise is correct.

Question 1 – no answer.

Question 2 – answer was given in our report, p. 6.1 and p. 6.2.1, where it was stated that the selection of volume and priority of rehabilitation inside province should be made on the basis of comparative analysis and modeling of different parts of provinces and different content of works. In particular, for Bukhara province it was recommended not to take the entire province but the territory of III groups (part of Bukhara and Peshkun districts) with an area of 52700 ha. So, our opinion is more or less identical.

Question 3 – answer is correct, but decision depends on the degree of social and demographic situation. Retirement of saline lands in Karakalpakstan is possible, in Ferghana Valley with high demographic pressure such decision will be fully rejected.

Questions 4, 5, 6, 7 – agree.
But one very strong disadvantage of conclusion (after questions): it ignores our scenarios of future development. We (chapter 6.1.5) proposed 5 scenarios, of which only the fifth one foresees full rehabilitation – others are oriented at different degree of network repair and maintenance but not capital works. Such proposal is based on the inability of states to make big investments in drainage.

The report also did not account other recommendations, which were done in our reports such as conclusions and recommendations of the International Conference held on March 10-13, 2004 with the participation of a big team of local and foreign participants of the project. So, our proposals (agreed with Mr. Harry Denecke) about future projects were oriented at most important of them: capacity building of local hydro-reclamation institutions and repair works. I support the need of the first project for Bukhara. Two others were not made in correct form.

Project proposal 2 – including drainage flows and increasing reuse of drainage water in Kyrgyzstan has sense with regard to local but not typical conditions of the Aral Sea basin. The proposed project will not impact river water quality.

Project proposal 3 should be discussed because we have some differences in approach: in our proposal we touched more broad scope of issues connected not only with the problem of Sarykamysh lake but also with organizing return water management in entire Amudarya basin. I think that joint work can merge our and Jacob's proposal.

One impression from all projects is that Jacob concentrated his attention on the data and vision of foreign specialists and rejected a huge scope of local reports. If he would do it, he can't avoid many mistakes, which he did in text based on his findings – Buckman and others. Comments of my team mostly related to the text of the report between frames, are given in the attachment. Some presentationsof the Jansen report, pp. 14-17, showed wrong understanding of the real situation in the Aral Sea basin, which is divided into several principal zones: zone of natural drainage, zone of natural drainage, which is not adequate for conditions of irrigation, and zone of salt accumulation existing even without irrigation.

Moreover, in those two zones we have different natural conditions: in Khorezm, for example, with sandy and light loam ground, drainage depth of 2.2 m is very big, but in Hunger Steppe with high capillary rise of loess ground, we need depth of no less than 3 m.

Our final proposal

1. The report of Jacob should be translated by FAO into Russian and disseminated among all the states for detailed negotiation at the level of stakeholders (as proposed by Geoff).

2. FAO would organize final negotiation in Central Asia with decision makers and donors, and the proposal for future investments should be corrected on the basis of this report.

3. We can recommend preliminary:
    - project proposal for Bukhara;
    - project proposal for capacity building of provincial reclamation services;
    - project proposal for transboundary return flow management.

Best regards,
Prof. Viktor Dukhovny

.S. lease, find attached Remarks to the I TRID Report

Remarks on the IPTRID report

In the report, there are a lot of (to put it mildly) uncertainties, for example, "transformation from communism", "density of the drainage network is low by international standards", "results of improved water management practices will be used for extension of the irrigated land", "the salt input from applied fertilizers". Not entering into controversy on clarifying these trivial things, we turn to principal remarks by each page.

Page ix, paragraph 2. The total irrigated area is not 9 million ha, but about 8 million ha, with only about 43% in the Syr Darya river basin.

Page x, paragraph 1. The density of the drainage network is low by international standards - where did the author find such standards?

Page 5. The estimated annual discharge of the Syr Darya and Amu Darya rivers combined is 116 km^3, not 110 km^3.

Page 6, paragraph 2. The percentage of GDP derived from agriculture ranges from 18-29% in Kazakhstan to 27-40% in Kyrgyzstan.

Page 6, Table 1. The irrigated area in the Syrdarya basin is 3300 th. ha (not 4649), and 4680 th.ha (not 4118) in the Amudarya basin.

Page 6, paragraph 2 after Table 2. The Syrdarya has 5 major reservoirs (not 2): 1 in Kyrgyzstan, 2 in Uzbekistan, 1 in Tajikistan and 1 in Kazakhstan.

Page 6, last paragraph. The rural population in Kyrgyzstan constitutes 64-65% of the total, and 72% in Tajikistan.

Page 7, section 1.3. Annual rainfall ranges between 250 and 300 mm in the Hunger Steppe (not 30 mm) and reaches 400-600 mm in the foothills (not 200 mm).

Page 12, paragraph 3. The area requiring artificial drainage is 5.7 million ha, and there is no traces of other estimates like 4.8 million ha.

Page 14, last paragraph. The Ferghana Valley is an intermountain depression, and here subsurface inflow is unavoidable as groundwater infiltration recharge, its pressure intensifies when surrounding submountain lands including adyr massifs are irrigated that cause growth in saline lands with non-functioning drainage.

Page 15, paragraph 4. In the area of Khorezm, groundwater desalination mainly occurs owing to forming, as a result of infiltration recharge in irrigated fields, of a so-called fresh pad that pushes aside saline groundwater into drainage network.

Page 21, Table 4. Many data are wrong: in row 3, it should be written as "with pumped water"

drained land – 5.3 million ha, not 4.8 million ha
surface drainage – 3.5 million ha, not 2.6 million ha
horizontal sub-surface drainage – 0.6 million ha, not 1.3 million ha
vertical drainage - 0.6 million ha, not 0.9 million ha
collector drains – 200 th. km
on-farm collectors -155 th. km, not 145
off-farm collectors – 45 th. km

Page 24, paragraph 1. The total loss sum has been estimated US$1.7 billion by consultant from the Haskoning within the GEF project. Losses of yield are 1.3-2.3 th./ha. Where were these data taken from? If it is correct, actual losses should not be $10/ha/year, but $230-350/ha/year!!!

Page 32, paragraph 3. The highest level of loss in land productivity is expected to be in Kazakhstan and Turkmenistan, if repair and restoration of drainage and leaching of saline lands are not carried out.

Page 35, last paragraph. It is obligatory to take socio-economic aspect into account comparing the cost of system rehabilitation with the cost of subsidizing farmers.

Page 38, last paragraph. In Uzbekistan, use of groundwater for irrigation is too limited.

Page 39, last paragraph. It is necessary to take into consideration that rehabilitation of irrigation and drainage infrastructure is necessary and economically sound for conditions of the region. These measures will provide conservation of water, which is presently released to rivers polluting their flows and partially wasted in evaporation ponds. At that, the main effect of these measures is formed by improving the productivity of irrigated lands and living standards of the poorest rural population.

Especially, we need underline two aspects: mobilization of salts and remote sensing monitoring of salinity.

Salt mobilization (pages 12 to 14)

We consider that the controversy over the mobilization of salt mass and active water and salt exchange zone in different types (vertical, horizontal) and parameters (deep and shallow drainage) is groundless.

In artificial land drainage the characteristic of water-bearing complex and parameters of drainage predetermine formation of an active water and salt exchange zone. The main factors influencing the formation of water exchange zone are aquifer thickness, ground stratification and underlying bed position. The formation of an active water and salt exchange zone of drainage is mainly influenced by drain spacing in horizontal drainage and well spacing in vertical drainage, not by drainage depth. In theoretical solutions on operation of systematic drainage with alternation of field drains and collectors at drain spacing $B \geq 3$ T (T is aquifer thickness) entire thickness of aquifer participates in drainage flow formation regardless of drain depth. As drain spacing decreases, the impact of drainage on water and salt exchange zone depth comes down. However, in this case too, entire thickness of aquifer takes part in drainage flow formation, because field drains alternate with collectors. In case of shallow underlying bed, all the thickness of water-bearing complex participates in drainage flow formation in systematic drainage. At the same time, the intensity of drainage module (flow) formation depends on drainage depth, which creates head gradient, i.e. water exchange in the system between aeration zone and groundwater.

Based on the results of model and field observations, hydrogeologists and reclamation specialists of Central Asia give the following values of horizontal drainage active zone with regard to mostly frequent soils:

- in light soils (dusty and loamy sands $C_f = 0.5\text{-}2.0$ m/day) h = 50-100 m;
- in medium soils (light and medium loam $C_f = 0.5\text{-}0.1$ m/day) h = 30-50 m;
- in heavy soils with the permeability factor $C_f = < 0.1$ m/day, h = 10-30 m.

In the pilot projects presented in the IPTRID register active water and salt exchange zone against subsurface horizontal drainage changes:

- in the Amudarya lower reaches presented by stratified soils at a big depth (100-150 m) with fine-grained soil coverage of 3-3.5 m deep with sub-artesian groundwater against subsurface drainage 2.5-3.0 m deep and drain spacing of 250-300 m; according to data from piezometric observations, *h* varies from 35 to 50 m;

- for the midstream of the Amudarya, according to Turkmen scientists, under the conditions of limited aquifer thickness against subsurface drainage 3.0 m deep with zero slope at L = 250-300 m, active water exchange zone is 20-35 m;
- at rice drainage system located in the Amudarya lower reaches under the conditions of laminated soils with a thickness of more than 150200 m against subsurface drainage 2.5-3.0 m deep, active water and salt exchange zone varies within 2.0-2.5 m.

Similar picture of active water exchange zone formation is observed against systematic vertical drainage and it depends on well spacing, on one hand, and groundwater head, on the other hand. In any case, under systematic vertical drainage impact of pumping applies to all thickness of water-bearing complex and more active first aquifer, where well screens are laid. At that, the more is the coverage area of systematic vertical drainage, the less is the share of external inflow, for instance in the area of the Hunger Steppe, Ferghana Valley and Bukhara province, i.e. practically the whole drainage flow is formed by surface waters supplied to irrigated massifs. In this context, according to SANIIRI, the entire thickness of the first aquifer participates to depth of 1.5 m of well depth in formation of filtration flow to drainage wells.

In principle, from the position of flow dynamics, types of drainage have an identical impact on the formation of active water and salt exchange zone.

Land salinization monitoring (page 16)

The SEBAL method (for remote sensing) gives only status of surviving plants, but it is unknown whether the stress occurred owing to salinization, or any other factors, or synergetic impact of the whole set of factors.

Plant development delay and low crop density can be explained by a number of reasons: low quality of seeds, mishandling of farming techniques in sowing and further treatment, infrequent irrigation, poor field leveling, uneven soil cover structure.

Our attempts together with the authors of SEBAL (IWMI report, 2001) to apply this method to identify salinization did not give positive result. SEBAL gives practical LAI – leaf area index, which is not single-factor one.

SEBAL requires large work aimed at identifying RS picture results through ground-based observations for different crops, slopes, stress sources and salt composition.