WATER RESOURCE MANAGEMENT IN A SEMI-ARID REGION: A CASE OF ARAL SEA BASIN

Thesis submitted to the Jawaharlal Nehru University in [illegible] fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY

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Date: 28th July 2004

This is to certify that this thesis entitled **"Water Resource Management in a Semi Arid Region: A Case of Aral Sea Basin"** submitted by **Kishore Kumar Wankhade** in partial fulfilment of the requirement for the award of the degree Doctor of Philosophy and has not been previously submitted for any other degree of this University or any other University and is my original work.

We recommend that this thesis may be placed before examiners for evaluation

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Acknowledgements

Many people as well as several organizations have contributed to this Thesis in a variety of ways. I am happy to have the opportunity to record my sincere appreciation to all of them.

My deepest gratitude is to my Supervisor, Dr. Tahir Asghar, who inspired me with confidence about correctness of the chosen subject and supported me a lot at every stage of the research and writing. I benefited tremendously from his patient hearing and support, for my thoughts and his exceptional guidance.

Besides, I am grateful to Aryama, a very dear friend, for his 'genuine' interest in the subject and for providing valuable remarks and suggestions about my research. He also read the entire manuscript meticulously, and gave valuable inputs. To him I submit my sincere gratitude.

My special gratefulness is to my friends and mates, who have warmed my world with their friendship and support in good and difficult moments of my life here in JNU and I could hardly carry on during these years without daily warm words of encouragement and brief interludes of fun with them.

Finally, and probably most importantly, I am eternally indebted to all members of my family. In particular, I bend before my esteemed parents, who so recklessly believed in me and always supported me in my all undertakings, even the wildest ones.

(Kishore Kumar Wankhade)

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INTRODUCTION

BACKGROUND

In the past few decades, degradation of water resources, pollution, and other water-related environmental and ecological problems have increased with alarming rate in many parts of the world. Where water was once abundant, it is often now scare. More than a billion people lack access to adequate water. In the arid and semi-arid areas of the world, water availability is a major constraint to the development of economy.

According to Grigg, "The real crisis in water is a 'creeping crisis'—it comes on slowly but it demands a response right now."[1] Increasingly, researchers and policymakers are advocating sustainable development as the best approach to today's and future water problems.[2] Sustainable development—that is, development that meets the needs of the present without compromising the ability of future generations to meet their own needs—is a concept that has gained popularity since publication of the 1987 Brundtland Commission Report.[3]

Water has been a main issue on the international agenda for the last 30 years, starting with the 1st International Conference on Water (Mar de la Plata, 1977), and followed by the International Conference on Water and the Environment (Dublin, 1992) and the 1st World Water Forum (Marrakech, 1997). During the 2nd World Water Forum in The Hague in March 2000, the United Nations pledged to produce a periodic assessment of the state of the world's freshwater resources in the form of the World Water Development Report (WWDR).[4]

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1 Grigg, Neil S., Water Resources Management: Principles, Regulations, and Cases, McGraw-Hill, New York, 1996.
2 Loucks, D. P., "Sustainable water resources management" Water International, Vol. 25(1), 2000, p. 311
3 WCED (World Commission on Environment and Development), "Our common future" (The Brundtland Report), Oxford University Press, London, 1987.
4 FAO, "Review of World Water Resources by Country", Water Reports 23, Rome, 2003.

Water is a major component of biosphere, in which man occupies its central place. It is vital for the maintenance of all forms of life and helps in the movement, circulation and cycling of nutrients in the biosphere.

Apart from the need for drinking, production of food, water is also essential for power generation, navigation, manufacturing process of industries, etc. This great necessity for water has brought into focus both the fragility of environment and need to guard it. All the great civilizations have grown around water and many had perished with dwindling of water resources, perhaps not having realized the significance of water and its sustainable usage. It may be pointed out that only one per cent of the total amount of water in the hydrosphere is available to us and other biotic communities from various sources; ground water, precipitation, surface water, stratosphere etc.

Over the years, rising population, expanding agriculture, and growing industrialization have pushed up the demand for water and have degraded the water balance considerably. With the advancement of the cultural and technical levels of different societies, these foresaid activities have undergone drastic changes, which in turn had adversely affected the available water resources.[5]

Man has been dependent on the water resources for his very survival and always has been instrumental in disturbing the man-resources equilibrium. Human induced transformations of the continental water have already reached global scale, infringing natural regime of the largest lakes and rivers of the world.

Man started to violate water balance of separate regions by building hydro-technical construction (reservoirs, irrigation canals, systems of water transference), making irrigation of dry lands, polluting fresh waters, by industrial, municipal and domestic wastes.

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[5] TERI., "Looking Back to Think Ahead GREEN India 2047", New Delhi, 1998, pp. 43-59.

Water is an essential ingredient for human survival and a critical component for economic development and plays a critical role in a country's welfare, with pervasive linkages to many aspects of its economic development. Nevertheless, water has few characteristics that set it apart from other resources. Firstly, it is a limited resource with few substitutes, and for many purposes, no substitutes at all. Secondly, it is a unitary resource; intervention in one part of the hydrological cycle invariably has an impact on water quantity and quality elsewhere in the cycle. But as long as water is abundant, its particular characteristics may be of little consequences. As the demand increases, the limit to the quantity, quality and unitary nature of water, results in growing conflicts and externalities.[6]

Moreover, nature has not distributed water resources equitably. There is too much water where this much is not required and too little where it is needed most. In arid and semi-arid countries, growing population, pressing development needs, and increasing environmental awareness are rapidly accelerating water demands and at the same time; scarcity and mal-distribution of water are causing conflicts and impeding efficient development and management of available resources.[7]

Water is a finite natural resource, essential for the sustenance of life on earth. Agenda 21, a major outcome of the United Nations Conference on Environment and Development (UNCED), popularly referred to as the Earth Summit, held in Rio de Janeiro, Brazil, in June 1992, states that, "effective integrated management of water resources is important to all socio-economic sectors relying on water".[8] Rational allocation prevents conflict and enhances the social development of local communities, as well as economic planning and productivity.

In spite of considerable ability of water cycle for renewal and self-purification, intensive development of agriculture and industry affects water resources. Competition for water

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[6] Op cit, No. 5

[7] Kirmani, Syed & Guy Le Moigne., "Fostering Riparian Cooperation in International River Basins", World Bank technical paper No. 335, The World Bank, Washington, D.C. 1997.

[8] UNCED (United Nations Conference on Environment and Development). 1992. Report of the United Nations conference on environment and development, Chap. 5 and 18, Rio de Janeiro.

resources, particularly in the arid and semi-arid regions of the world, is bound to lead to conflicts in the near future among countries sharing international water bodies. Furthermore, environmental degradation resulting from intensive water development and usage, as well as from global change, plays an important role in the socio-economic and political processes both nationally and internationally.

Conflicts in river basins within countries are resolved within the domestic political processes and legal systems. Conflicts between riparian of international river basins, however, are difficult to address because international water laws are not enforceable. These conflicts can be resolved only through riparian cooperation.

For many developing countries, international rivers are the main source of water, but riparian cooperation in these river basins is rare. Smaller and weaker countries are suffering most because they have neither the political clout nor the economic strength to achieve their goals. Some riparian have tended to utilize as much water as possible to establish prior water rights while others who started late feel deprived of their fair share.

Historical factors, physical differences, political realities, and socio-economic variations are all part of the setting in which issues of efficiencies, distribution, equity and rights have to be considered in addressing riparian conflicts.

Over 246 separate river basins; comprising about 40 per cent of world's population and 50 per cent of the earth's land are shared by two or more continents. The adverse impacts of conflicts on economic development of riparian countries will sooner or later become too unbearable to sustain security and peace. The adverse effects of water conflicts will be particularly severe in the poor countries of Asia, the Middle East, and Africa, where major international rivers are shared. Their goals of economic development, poverty alleviation and sustainable environment cannot be effectively achieved without developing and utilizing their shared water resources.[9]

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[9] Op cit, No. 7

To ensure the best use of the water resources and to avoid disastrous interference in natural ecosystem, there is a pressing need for management. It is a challenge the world now faces to sustainably manage its water resources. To this end, the semi-arid and arid nations of the world have started adopting long-term strategies and this is reflected in their water resources management policy.

The strategy emphasizes the importance of taking a holistic approach to managing water, involving a vide variety of stakeholders in water resources management, and recognition of water as a scarce economic good.

Water also plays a key role in the development of world societies and a sustainable use of this resource is of utmost importance. Globally water resources are threatened by the increasing population with the resultant increase in water demand, the stresses of water use for various activities, desertification, global warming and climate change, and other interventions in the water cycle by man. These effects are more pronounced in the arid and semi-arid regions of the world and especially in Central Asia. It is therefore vitally important that the water resources in arid and semi-arid regions are developed and managed in a sustainable and integrated manner.

Integrated management of the water resources in the arid and semi-arid regions of Central Asia requires the whole spectrum of efforts from local and community stakeholders to national and trans-boundary river basin management.

There are no magic solutions in sustaining water supplies, as neither market forces, military might, mega-projects nor money alone are able to solve the world's water problems. Apart from the technical problems the social aspect of the problem should be integrated along with conservation and community initiatives to solve the root causes of water scarcity, which otherwise may incur immense human cost.

INTRODUCTION TO THE STUDY AREA

The Aral Sea basin extends over 690,000 km^2, including all or part of the five republics of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. The basin is formed by two of the largest rivers of Central Asia; the Amu Darya and the Syr Darya. The Amu Darya sources are mostly located in Tajikistan, with a few water courses originating in north-eastern Afghanistan. The Syr Darya originates mainly in Kyrgyzstan.

The Aral Sea basin has three distinct ecological zones: the mountains, the deserts, and the Aral Sea with its deltas. The Tien Shan and Pamir mountains in the south and south-west are characterized by high altitudes (peaks over 7,000 m) and by high moisture coefficients, with average annual precipitation ranging from 800 to 1,600 mm. The mountains host large forest reserves and some national parks. In the foothills and valleys, soil and temperature conditions are favourable for agriculture. The lowland deserts of Kara Kum and Kyzyl Kum cover most of the basin area, and are characterized by low precipitation (under 100 mm/year) and high evaporation rates. The present population of the basin is about 57 million people with growth rates averaging 2.54 per cent.

SCOPE OF THE STUDY

There have been considerable imbalances in the availability of water resources to the Central Asian population and their uses over the years, leading to the declining per capita availability of water, falling water tables, wasteful and inefficient use of water. While pressures have built up on water resources from wide range of ongoing economic and developmental activities, the policies and the institutional framework have failed to ensure equity and sustainability in the use of water. Water tension is growing with the growing population.

The demand for healthy and adequate food is among the most important sustainability indexes for sustainable development. In this context, water resource management plays a very important role. At the present time, most of the countries in the Middle East, Central Asia and North Africa are under water tension. For sustainable development, a sound management of water resources is crucial in the socio-economical development of countries in these regions.

Demand for water is on the rise everywhere in the world, particularly in arid and semi-arid countries including countries of Central Asia. A general increase in the standard of living over time has created a gap between access to and the need for water. Rapid population growth and expansion of irrigated farmlands during last four-five decades in Central Asia have imposed more pressure on the water resources.

Over two-third of the total area of Central Asia suffers from the lack of precipitation. Low recharge rates of underground resources lead to the negative balance of 5 km^3 per year for the aquifers and rapid drops in water tables. Therefore there is an urgent need for finding ways and means for solving the conflicting interests of urban, industrial and agricultural sectors in utilization of water. Since new resources of fresh water are very limited, proper water resources management plays a very important role. Concern about future food production and environmental degradation has increased awareness of sustainability. Although an abundant literature is now available, some fundamental questions have not yet received adequate answers.

In this background, the research examines the water resource management initiated in the Aral Sea basin in order to transform its current environmental scenario. The main focus is on the measures specific to water crisis in the Aral Sea basin.

This research focuses on the water resource and related problems and various aspects of management and planning in the Aral Sea basin. Hence a detailed and comprehensive understanding and analysis of the water resources and their linkages is needed. It comes with a systematic study of the water resources degradation, their causes in the Aral Sea basin. An attempt has also been made to highlight all the aspects related with the water resource problems and their complex interaction with socio-economic and political institutions.

The research provides insight about the change in human perception about the environment and its interaction with various institutions. This research also addresses some issues concerning the definition, assessment and implementation of the concept of sustainability, specifically in relation to water resource management for agricultural purposes.

As water demand surpasses water availability, the problem of who will have access to water and who will be rationed, is inevitable. This is already the case in arid and semi-arid regions or where the economic uses of water exceed water capability. This research contributes to the understanding and resolution of the problems in decision-making process. Several allocation mechanisms are discussed and an allocation model based on the opportunity cost of water for different users is presented.

In addition, this research also addresses the future water stress due to limited water resources, population growth, increasing demand and pollution and other related risks, resulting in insufficient water supply. It will also foster insights on issues of global sustainable development and set concrete targets to meet the need for drinking water and sanitation.

Water resource management in the semi-arid and arid regions of the world has always been identified as a key issue both in terms of development constraints and in terms of environmental impacts. The feedback between the physical hydrological system and the economic forces of development requires an interdisciplinary approach to properly evaluate plans for water resource development and management.

The management is required to view the water resource problem as a system. Consequently, a coherent and systematic study is needed to take careful account of the complex interactions involved. Attempts shall therefore be made to look in to policies and programmes to efficiently manage water resources within the Aral Sea basin.

Map 1: Aral Sea Basin

Source: http://www.icess.ucsb.edu/~aizen/centralasia.html

REVIEW OF LITERATURE

Research on the concept of water resource management, had been carried out extensively all over world, especially in context of arid and semi-arid regions of the world, where water resources has always been in short supply.

Aral Sea basin has been devoid of ample attention by the researchers during the Soviet period, though things have changed a lot since the disintegration of former Soviet Union. A number of extensive research works has been carried out especially by western scholars under the international development agencies about the various aspects of Aral Sea basin, focusing on the creeping environmental problem there.

The importance of literature to provide background to the present research is however, not denied. A review of some important work can provide a good insight into the current research trends and research gaps as well.

Philip, Micklin (2002), in the book ***"Managing Water in Central Asia"*** discusses the Aral Sea Basin's water resource geography along with other critical water issues includes irrigated agriculture, the Aral sea problem, water sharing among the basin states, their national water politics and the future of water management. As these complicated management issues are central to understanding and tackling the environmental and agricultural challenges confronting Central Asia, and in addition they also have the potential to prevent conflict both within and between states.

Michael, H. Glantz (2000), in multidisciplinary book ***"Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin"*** was the first to comprehensively describe the show onset, low grade but incremental changes, which affected the region. Over a dozen researchers explored every facet of this environmental disaster; changes in the landscapes, water level and salinity, river flow changes, desertification etc. The book presents a set of case studies on a region of worldwide environmental interests, and outlines marked lessons to be learned for other area undergoing such changes.

Enrha, Weinthal (2002), in the book ***"State Making & Environmental Cooperation Linking Domestic and International Politics in Central Asia"*** examines how the Central Asian States have tackled the Aral Sea basin crisis since 1991 collapse of the erstwhile Soviet Union. The Amu Darya now flows through three new nation – states and the Syr Darya through four. This shake up of political borders created a collective action problem for the successor states. She examines why there is need for cooperation over their land water resources. She also emphasizes the roles of non state actors (international organizations, NGO's and bilateral aid organizations) in the building of institutions for regional cooperation and for state formation, and shows how cooperation was nested within the state-building process when international third-party actors were involved, and highlights the dispensing of side payments by non state actors to aid both regional cooperation and state formation.

Philip, Micklin & William, D. Williams, in the book ***"The Aral Sea Basin (NATO Asi Series, Partnership Sub Series 2, Environment Vol. 12)"*** analyses the environmental, human and economic problems that has arisen and presents recommendation for future research needs. Primary focus is on the drying of the Aral Sea, but related issues of diminished river flow, land and water pollution and degradation, ecosystem deterioration, and adverse effects of human are also examined.

Iwao, Kobori and Michael, Glantz (1998) in the edited book ***"Central Eurasian Water Crisis: Caspian, Aral and Dead Sea, Water Resources Management and Policy"*** reflects the global awareness, that various regions increasingly face about problem of water quality and quantity. This work focuses on three such regions: the Dead Sea, the Aral Sea and the Caspian Sea. Researchers from various physical and social sciences disciplines identify water related problems and the prospects for resolving these in each region.

Heather, L. Beach & et al, in the book *"Trans Boundary Fresh Water Disputes Resolution: Theory, Practices and An noted References"* highlights and analyses various fresh water bodies spread over boundaries of more than one nation or state and the water sharing disputes faced by these nation in solving the problem to use the water resources judicially.

Max, Spoor (1998) in the article *"The Aral Sea Basin Crisis: Transition and Environment in Former Soviet Central Asia"* presents the picture of a disappearing Aral Sea, as a part of an overall environmental crisis in the Aral Sea Basin, where million of people are dependent on agriculture production around Amu Darya, and the Syr Darya rivers. The forced cotton cultivation in the former Soviet Union, the context of inefficient agricultural organization and production, caused water mismanagement, salinization, water and soil contamination, erosion and desiccation of the Aral Sea. The attempts to mitigate the impact of the crisis and contain its scope by the states and international agencies are also highlighted.

Patricia U. Carley (1989) in the article *"The Price of Plan Perception of Cotton & Health in Uzbekistan & Turkmenistan"* outlines the special problems concerning health and the environment, and the conditions that surround them – and describes the way in which these prevailing circumstances are explained rather than focusing on why this situation evolved and advanced, and doesn't attempt to 'prove' that it is somehow a result of Soviet system. She explains that there were other extreme factors in Central Asia and they were involved in aggravating the problem.

Rusi, Nasar (1988), in the *article "Reflections on the Aral Sea tragedy in the national literature of Turkmenistan"* examines the manner in which the Soviet Central Asian writers are treating the Aral problem. The disposition of the Aral problem and related issues, shall be resolved within the soviet system, the issues themselves may be seen as a nascent or submerged "natural" agenda. The publication of thousand, of articles in the native language press on Aral Sea reflects the depth of concern felt by Central Asians about the Aral problem. He attempts to show that the Central Asian writers, drawing across republic lines, are engaged in an effort to mobilize public opinion and press for positive resolution to the Aral problem.

Philip P. Micklin (1987), through the article ***"The Fate of 'Sibaral', Soviet Water Politics in the Gorbachev Era"*** raises the much discussed and hotly debated scheme to divert water from western Siberia to the Central Asia. However, time and again in a dramatic and unexpected policy reversal, the project lost momentum. He highlights the background and foreseeable future for this project. He offers a new perspective on some question regarding the project.

Boris, Rumer (1987), in the article ***"Central Asia's Cotton; the Picture now"*** discusses in detail about cotton cultivation scenario in Central Asia. Being the cotton base for the USSR, Central Asia and its development was always given highest priority. It produced 65 per cent of gross output and consumes 60 per cent of all resources and about 40 per cent of labour worked in this sector. But over the year; reduced exports, decline in production are being highlighted. The problem of irrigation and the development of Central Asian economy on the lines of agrarian – colonial model really show that the cotton was being supplied to Moscow rather than taking care of the development of the industry locally.

A. Nurushev (1999), in the article ***"Crisis of the Aral Sea"*** contends that the poor water management is responsible for the sorry state of the region. He showed the dynamics of the management of water, land in central Asia, and highlights the traditional economy and system of irrigation.

Igor, Lipovsky (1995), in the article ***"The Determination of the Ecological Situation in Central Asia: Causes and Possible Consequences"*** highlights the present critical ecological situation in Central Asia and contends that it is a product of several factors, and all these factors are the result of human activity. His emphasis is on saving the Aral Sea from desiccation by redirecting water from Siberia into the Central Asia. This will solve the Central Asian water deficit. The break up of the former USSR has also made execution of such a project more difficult.

N.F. Glazovsky (1991), in the article ***"Ideas on an escape from the 'Aral Crisis'"*** says that the current crisis is attributed to the errors in the formulation of regional economic policy in the 1950's and 1960's. In addition shortcomings of a number of proposals to ameliorate economic, social and environment aspects of the crisis are assessed. The inseparability of the Aral Sea and the problem of the surrounding are discussed while elaborating a plan of action for rehabilitating the Aral Sea in the article. He outlines a multifaceted approach for transforming the regions current economic profile, addressing demographic, social economic and environmental problems at a variety of level and scales.

Philips P. Micklin (1991), in the article ***"Touring the Aral: Visit to an Ecologic Disaster Zone"*** shares his experiences as a member of a United Nations working group charged with helping develop a plan of action for rehabilitation of the sea, and part of a Soviet research team studying hydrologic and biologic consequences of the decline in the water level. He describes his travels along the Aral's Northern & Southern shorelines in Kara kalpak SSR. Additional travels to sites along the lower Amu Darya basin also provide interesting insights into living conditions and economic adjustments of the population in response to changing environmental conditions.

David R. Smith (1994), in the paper ***"Change & Variability in Climate and Ecosystem Decline in Aral Sea Basin Deltas"*** concentrates on impacts that regional and global climatic changes may have on deltaic ecosystems using deltas in the Aral Sea Basin as an example. In addition to an assessment of regional climate change and variability and their relationship to environmental condition, within inland river deltas, this paper also examines the past developments due to human activities, climatic trends and ecosystem changes within them and the relationships among future climatic and ecosystem changes that may occur.

Philip R. Pryde (1994), in the paper ***"Observations on the mapping of critical environmental zones in the former Soviet Union"*** examines the evolution of a concept of critical environmental zones in the region and of programmers designed to identify and map them. Coverage focuses on persistent shortcomings of such maps – despite their potential to convey important environmental information in a form sufficiently standardized to permit spatial and temporal comparison – and their relationship to analogous section of the recent Russian environmental Law.

David R. Smith (1995), in the paper ***"Environmental Security and Shared Water Resources in Post Soviet Central Asia"*** examines the distribution of water and the location of physical and political boundaries in Central Asia. He identifies indicators of the susceptibility of its various regions to resources and water related conflict and then applies those indicators to predict the potential for future water-based regional conflict. The dimensions of the problem are addressed not only in terms of the physical availability of water, but also water quality and regional social unrest as a consequence of migration from regions of environmental deterioration.

OBJECTIVES

In this backdrop, any study regarding water management related problems especially in the given situation in the Aral Sea Basin, becomes an area of much interest for research. Hence the present study about the Water Resource Management in the Aral Sea Basin seems to be very fruitful and desirable.

In the light of the above discussion the broad objectives of the research are:

- To study the concept of sustainable development and its application to watei resource management.
- To look at the available water resources and their usage pattern in the Aral Sea basin;
- To examine the role of water resources in the socio-economic development in the Aral Sea basin;

- To identify the factors for and the impact of the depleting water resources and their socio-economic implications;
- To analyze the measures taken by the States and various National and International Organizations responsible for the environmental protection; and
- If possible to suggest certain alternative measures for efficient water resource management.

RESEARCH QUESTIONS

On the basis of these above objectives following research guiding questions have been formulated for the research:

- What is water resources management and why it is needed?
- How water resources have played vital role in socio-economic development in the Aral Sea basin?
- What are the factors stressing these water resources and their impact on the socio-economic development in the Aral Sea basin?
- What are the set of measures initiated by these States and various international organizations to solve these problems?
- How water problems can cause political and socio-economic instability among the Central Asian states?

METHODOLOGY

A suitable methodology is always required to process the available information to meet the objective of the study. To substantiate, efforts have been made to process and analyze the data gathered from various published and unpublished reports. As it is clear from the nature and scope of the study that the methodology will be both descriptive as well as analytical in nature, which will cover all spatial and temporal dimension of the subject systematically. Though use of statistical and cartographic techniques is always warranted, various methods have been used here. The remote sensing is also interpreted for precise water resource management.

SOURCE OF INFORMATION

Information required for successful completion of the present study is obtained from primary as well as secondary sources. To mention, primary source, includes various governmental and non-governmental documents, international documents published by UN, donor and development agencies such as World Bank, UNEP, UNESCO, FAO, UNDP, EU, USAID etc. and secondary source includes various books, journals and research articles, media reports, government and international reports, newspaper reports on the topic as well as on the area in general. The available data on various physical and socio-economic variables for the study area are also collected for in depth analyses of the problem.

ORGANIZATION OF THE STUDY

The study is organized in six chapters, along with introduction and conclusions:

Chapter One consists of the background information, a statement of the problem, objectives and research guiding questions, methodology and review of available literature.

Chapter Two represents theoretical part of the study, which introduces some conceptual issues necessary for understanding the peculiarity of water resource management with a focus on semi-arid region. This part of the study focuses on a concept of a water basin and on the problems in the basin. Besides, the chapter outlines basic principles of water management, concepts, methods, and sustainability analysis.

Chapter Three begins with a description of water resources in the Aral Sea basin in order to understand the logic behind available water resource with a focus on relief, location, climate etc. The chapter, then, introduces the water issue itself with the focus on those factors that have caused the disputes over the water of the Syr Darya River basin among Kyrgyzstan, Uzbekistan and Kazakhstan.

Chapter Four continues the analysis of the water issue in the Aral Sea basin by exploring consequences of the water degradation in the basin at large as well for each riparian state in particular. The chapter examines whether any of the parties involved gets benefit from a situation existing in the Aral Sea basin.

Chapter Five outlines the various attempts the organisations, government, have made in recent years in order to solve the water issue. In particular, it analyses water agreements, signed by co-riparian in different period of time. The chapter takes in to account the fact that the agreements have remained on paper and have never been put into practice in full measure. This is so because these agreements reflect a desire of the regional powers to pursue their unilateral interests rather than an aspiration for just cooperation. It forwards a number of proposals, which might be useful in solving water disputes between upstream and downstream co-riparian of the Aral Sea basin.

In the end the Chapter Six concludes by analyzing the current situation in the Aral Sea basin and suggests the measures appropriate for the water resource management the region.

WATER RESOURCE MANAGEMENT: CONCEPTS, METHODOLOGY, SUSTAINABILITY ANALYSIS AND ITS APPLICATION TO THE ARAL SEA REGION

INTRODUCTION

Water availability is an essential component of human welfare and productivity. Much of the world's agriculture, hydroelectric power production, and other water needs are dependent upon the hydrological cycle, and the natural re-charging of surface and groundwater resources. Changes in the natural water availability, as a result of global warming, would result in impacts, which are generally most detrimental in regions already under climatic stress. The ability to manage water resources effectively in these, as well as more benign climates, will receive increasing attention as climate change increases the level of competition between potential users for water.

Changes in surface water availability and run-off will influence the recharging of groundwater supplies and, in the longer term, aquifers. Water quality may also respond to changes in the amount and timing of precipitation. Rising seas could invade coastal freshwater supplies. Coastal aquifers may be damaged by saline intrusion as salty groundwater rises. Reduced water supplies would place additional stress on people, agriculture, and the environment. Regional water supplies, particularly in developing countries, will come under many stresses in the 21st century. Climate change will exacerbate the stresses caused by pollution and by growing populations and economies. The most vulnerable regions are arid and semi-arid areas, some low-lying coasts, deltas, and small islands.

As for impacts on the hydrological cycle, predicting where water resource problems due to climate change will occur is a tricky business, and can at present only be realized at a sub-continental scale. Uncertainties regarding future climate variability, water demand and the socio-economic and environmental effects of response measures all confound projections for future impacts on water resource management. Nevertheless, it is likely that demand for water will increase over the next few decades, particularly for municipal water supplies in rapidly urbanizing areas, for energy production, and for agriculture. Water resource management will consequently need to focus on demand management and the implementation of regulatory controls, and legal and economic instruments to minimize stresses resulting from the increased demand. In addition, new supplies must be developed and existing supplies used more efficiently. Long-term management strategies will also need to consider the construction of new reservoirs and pipelines to boost supplies.

Since the 1992 Dublin meeting; Integrated Water Resource Management (IWRM) has become universally accepted as the holistic, people and environment focussed paradigm by which water should be managed; a message that has been further reinforced by the recently concluded 2nd World Water Forum in The Hague. It seeks to break down sectoral, scalar, and disciplinary boundaries, to ensure that water is managed at the most appropriate level, by the most appropriate people, and in a manner that acknowledges the rights of other uses and users.

Although, water comprises three fourth of the earth's surface, only one per cent of the water supply in the world is available for human use. The rest is salty or locked in ice caps and glaciers. A mere one per cent of earth's water supply is utilized to support the world's agriculture, manufacturing, household needs and sanitation. Hence, water as a natural resource is being depleted at an alarming rate.

Its availability has serious repercussions on food security of nations and world peace in general. The International Water Management Institute recently warned that ***"the penalty of mismanagement of this valuable resource is now coming due, and it is no exaggeration to say that the results could be catastrophic for these countries, and given their importance, for the world as a whole."***

Sustainability, as used in the environmental policy and research arena is a complex and at times controversial concept. Sustainability attempts to address global issues, such as resource degradation, deforestation and ozone layer depletion etc. but also local issues, such as the maintenance of specific eco-socio systems or combination of these. In general, sustainability even on a local level has to address and relate to global issues.

The sustainability of the present state of utilization with the emphasis on the water resources is not tenable. In the Central Asia, for example, Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, and Tajikistan have a combined population of nearly 57 million. Among them approximately 60 per cent rely on trans-boundary river water resource and rest utilize other sources of water like ground water and precipitation. At this rate water supplies are being taxed to their limits, by these countries.

Water resource management should simultaneously achieve two objectives: sustaining irrigated agriculture for food security and preserving the associated natural environment. A stable relationship should be maintained between these two objectives now and in the future, meanwhile potential conflicts between these objectives should be mitigated through appropriate irrigation practices. Lessons learned from unsustainable water management practices around the world demonstrate the necessity—and growing urgency—of applying sustainability principles to water management in river basins where irrigation is a major factor.

This chapter presents the operational concepts and analytical framework for sustainability of water resource management in irrigation dominated river basins. These are applied to the Aral Sea region in Central Asia, a region famous for its conflict between the twin objectives of sustaining irrigated agriculture and preserving the environment. Maintaining current irrigation practices will lead to worsening environmental and economic consequences. Infrastructural improvements and changes in crop patterns will be necessary to sustain the irrigated agriculture and the associated environment in the region.

CONCEPTS AND DEFINITIONS

The concept of water as a resource is multidimensional. It is not limited only to its physical measure (hydrological and hydro-geological), the 'flows and stocks', but encompasses other more qualitative, environmental and socio-economic dimensions. However, this chapter focuses on the physical and quantitative assessment of the resource.

Concept of Water Resource Management

It has been recognized that degradation of the bio-physical environment is a process induced or accelerated by humans, but the term is one of the number of terms existing, that have been used in this context. The term management has also long been used, but in a broader rather than narrow context. References also exist about 'management or resources'. However, water resource management has emerged as a more formal, generalizing concept that covers the dynamics of agriculture, soil, vegetation and other perturbed natural systems which includes its related social impacts.

The drive for an integrated approach to water resource management contrasts with the traditions of many environmental and social scientists, whose perspectives have often been excessively blinkered. In a broader Third World context, we acknowledge a converse neglect of the environment by most social scientists. Bridging this gap is facilitated by the concept of water resource management, even though it creates theoretical and methodological problems, not least in terms of matching environmental or technical solutions to social or economic realities.

The concept of water resource management has emerged from what is widely perceived as an overpopulated or overexploited world. As such, it is a belated response to the global environmental movement that arose in the late 1960s and extended specifically to the semi arid tropics in the 1970s. Water resource management itself, however, is not a new phenomenon in the tropics or elsewhere. Its scale and intensity have greatly increased in recent decades, but, on a timescale of centuries, it is possible to identify a similar acceleration of destructive water exploitation that coincided with colonialism nor should exaggerated devotion to the idea of tribal adaptation to the environment obscure recurrent evidence of at least localized, pre-modern land degradation on a timescale of millennia.[10]

It is evident that in spite of increasing contemporary water degradation, paralleled by growing population densities and advancing technologies, water resource management is a complex phenomenon occurring under diverse social and environmental conditions. Its solution is also complex, lying as much with policy formulation and land management as with field experiment and laboratory analysis.

The Nature of Water Resource Management

Investigations of specific kinds of water resource degradation have long been undertaken in the tropics. They have involved both rural and urban-industrial environments and have focused on perturbed physical, chemical and biotic systems. Although discrete investigations of specific degradations, like soil nutrient depletion or savannisation have frequently occurred, linkages between bio-physical processes are apparent and some degradations overlap. This is particularly the case with desertification, which has been notable for its broad application. In the past, the term has been used in the humid tropics where deforestation has been seen as a potential precursor of desert like conditions, although its current usage is linked with arid to semi-arid areas like the Sahel. Even, there, it embraces the phenomena of drought, soil erosion and loss of vegetation cover as well as the degradation of human living conditions.[11]

Comprehensible reasons exist for discrete technical investigations of specific degradation, but, as recent desertification studies show, other benefits accrue from broader and more integrated treatments.[12] This equally applies at the level of land degradation itself, where, in spite of the multiple bio-physical processes involved, common underlying social causalities often exist whose comprehension is necessary for

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[10] Blaikie, P. M. and H. C. Brookfield., "*Land Degradation and Society*", Methuen, London, 1987.
[11] Eden, Michael J and John T Parry., "Land Degradation in the Tropics: Environment and Policy Issues", Pinter Press, London, 1996.
[12] Adams, W.M. 1996. "Irrigation, Erosion and Famine" In Leach, M. and Mearns R. (eds.) "*The lie of the land: challenging received wisdom on the African Environment*", James Currey, Oxford, 1996.

relevant policy intervention. Likewise, the bio-physical impacts of degradation not only create technical problems that need solution, but also affect the economic activity and social welfare of human populations. As Young and Ishwaran indicate, 'it's no accident that poverty and degraded environments are generally coincident'.[13]

In practice, this means that land-management policies must be appropriate in human as well as technical terms. Self-evident as this may be, it is often neglected in technically oriental studies of specific degradations. In purely bio-physical terms, benefits also accrue from an integrated approach to land degradation in that it encourages scrutiny of the linkages between specific degradations, reveals commonalities in degradation monitoring, and facilitates assessment of the relative criticality, and hence political significance, of particular degradations.

Social Aspects of Water Resource Management

Once we incorporate the fact that different water resource degradations have similar causes, relating for example to the chosen modes, intensities or technologies of water use, rapidly leads to consideration of more fundamental and controversial problems of human behaviour and their interaction with the environment. As indicated, water degradation in the arid and semi arid regions is an ancient phenomenon and, although its impact has increased over time with population growth are often emphasized, as in the Brundtwater Chapter 1987 and at the International Conference on Population and Development in Cairo in 1994. But water degradation is not uniquely associated with densely populated areas, and is nowadays as likely to derive from commercial water use that is anything but labour-intensive like cattle ranching in Amazonia or extractive logging in Southeast Asia.

In such instances, it is the mechanization of water exploitation, reflected in the arid and semi arid lands by historic progression from the using cattle's for water extraction, through the machines to pump water to the large dams and canal systems that is more directly responsible for water degradation than sheer numbers of people. As Ohlin claims,

[13] Young, M and N Ishwaran, "Human Investment and Resource Use: A New Research Orientation at the Environment/Economics Interface", Mab Digest 2, UNESCO, 1989, p. 10.

'it is not difficult to show that the bulk of environmental stress is due to technology rather than population growth'.[14] The case is arguable, although it must be recognized that ultimately technology is neutral and no more than the tool of the water user who employs it. Even so, a failure to come to terms with new technology, mechanical or chemical, commonly increases environmental degradation.

Equally critical, and very relevant in the tropics, is the issue of access to water and of property rights, which in turn affect de facto population densities, local water uses and hence the environmental impacts. In the tropical Andes, for example overcrowded small-holdings are widespread and commonly degraded; they are often unproductive and cultivated temporarily. Their existence reflects inequitable water distribution and the failure to achieve proper water reform in the region where more fertile tracts have long been held in large, under-used units. Structural factors of this kind also contribute to water degradation.

Other structural factors are influential in so far as commercial entities, including multinational companies, are widely involved in tropical water development and add to water degradation. Logging and ranching operations have been mentioned, while large-scale mining activities also induce bio-physical degradations that affect local populations. Economic benefits may accrue, but the attendant social costs are often high.

Broader developmental strategies pursued by international agencies or by developed world via aid programmes have also had serious environmental and social impacts that have been ignored or neglected in anticipation of economic benefits. Recurrent example exist in Brazilian Amazonia, not least in respect of transport and hydroelectric projects associated with the Programa Grande Carajas in Para or the Progama Integrado de Desenvolvimento do Noroseste do Brasil in Ronadonia. In the face of pressure from non-governmental organizations during the 1980s, institutions like the World Bank have sought to improve their environmental performance (World Bank Group, 1994), but enhanced policies based on sustainable development and low environmental impact are

[14] Ohlin, G., "The population Concern", *Ambio*, Vol. 21(1), 1992, pp. 6-9.

not easily implemented and criticism of such institutions has persisted, not least in respect of structural adjustment policies.

Water degradation in the tropics thus has diverse underlying causes that are broadly social in character and often far removed from the actual water user. Water degradation is as likely to arise from short-sighed policies or incompetent performance on the part of international agencies or national governments either from ignorance, neglect or misplaced priorities on the part of the actual water user. This pattern of causality driven human impact in its turn damages the water user and the broader society. In effect, parallel social degradation occurs. Irrespective of whether the initial water degradation involves, say, soil erosion or salinization or arises in the humid or semi-arid troops, recurrent patterns of human impoverishment occur that are expressed in terms of food shortage, ill-health, declining income, inadequate housing and the like. Such impoverishment is widespread in rural area, but also exists in towns and cities where the proximate causes range from industrial pollution to inadequate waste-disposal systems. Urban environmental degradations in the tropics have received less attention than their rural equivalent, but, in terms of human numbers, the potential impact is greater and increasing rapidly as the urban-industrial environment itself expands.

TYPES OF WATER RESOURCES

These are defined as the average manual flow of rivers and recharge of aquifers generated from precipitation. It distinguishes between the natural situation (natural renewable resources), which corresponds to a situation without human intervention, and the current or actual situation (Figure 1). The computation of the actual renewable water resources of a country takes account of possible reductions in flow resulting from the abstraction of water in upstream countries. The chapter also reviews available information on exploitable water resources, i.e. the part of the actual water resources available for beneficial use.[15]

[15] Op cit, No. 4

Renewable and non-renewable water resources

In computing water resources, a distinction is to be made between renewable and non-renewable water resources. Renewable water resources are computed on the basis of the water cycle. In this chapter, they represent the long-term average annual flow of rivers (surface water) and groundwater.

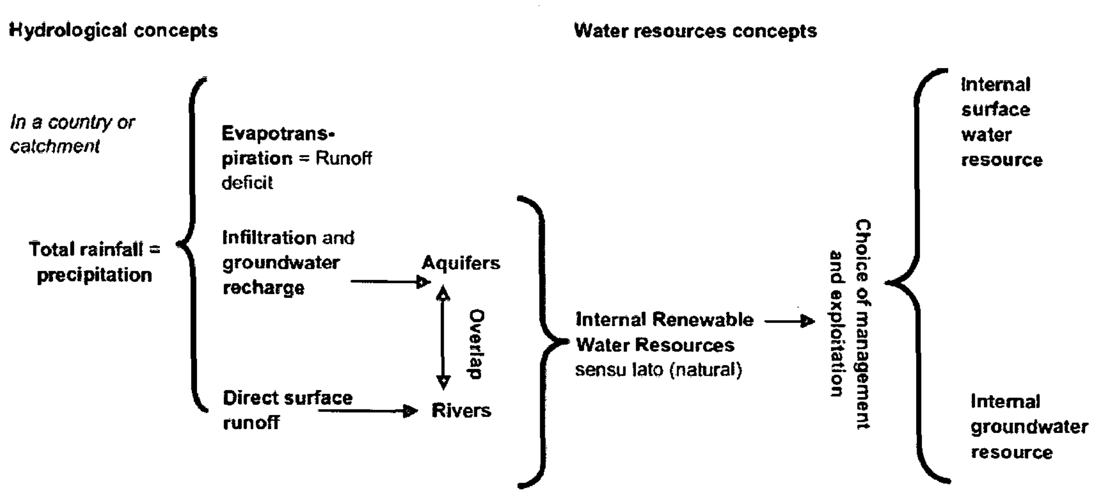
Non-renewable water resources are groundwater bodies (deep aquifers) that have a negligible rate of recharge on the human time-scale and thus can be considered non-renewable.

Natural and actual renewable water resources

Natural renewable water resources are the total amount of a country's water resources (internal and external resources), both surface water and groundwater, which is generated through the hydrological cycle.

This chapter also considers actual renewable water resources. These are defined as the sum of internal renewable resources (IRWR) and external renewable resources (ERWR), taking into consideration the quantity of flow reserved to upstream and downstream countries through formal or informal agreements or treaties and possible reduction of external flow due to upstream water abstraction. Unlike natural renewable water resources, actual renewable water resources vary with time and consumption patterns and, therefore, must be associated to a specific year.

Fig 1: From hydrological concepts to water resources concepts

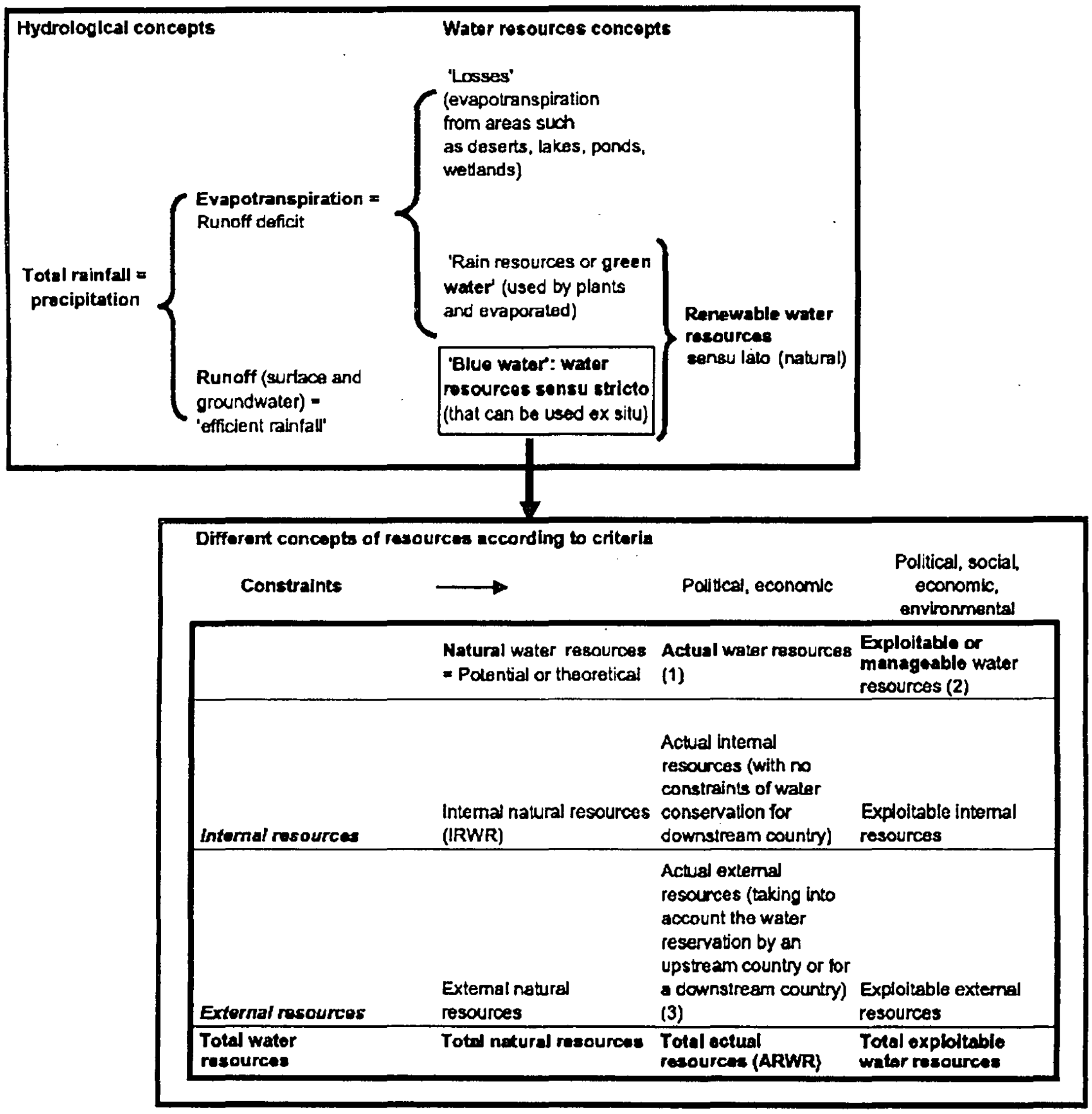


Source: FAO/BRGM, 1996.

Exploitable Water Resources

Not all natural freshwater, surface water or groundwater is accessible for use. In this chapter, exploitable water resources (manageable water resources or water development potential) considers factors such as: the economic and environmental feasibility of storing floodwater behind dams or extracting groundwater; the physical possibility of catching water which naturally flows out to the sea; and the minimum flow requirements for navigation, environmental services, aquatic life, etc. (Figure 2).

Fig 2: Water: natural resources and technically exploitable resources



Source: FAO/BRGM, 1996.

This concept varies according to:

- Natural conditions that may affect the development of water resources (regularity of the water regime, fragmentation of the hydro-graphic or hydro-geological systems, convenience of the sites for dams, and water quality);
- The importance of demand for water, which will determine the acceptability of internal and external costs of water development and management; it also involves arbitration for allocation between in situ use (reservation) and ex situ use or abstraction.

As it depends on the choice of a set of criteria (physical, socio-economic, environmental, etc.), this concept varies from country to country. It can also evolve according to demand pressures. However, it represents a realistic vision of the renewable resources available for use in a given situation and period.

In general, exploitable resources are significantly smaller than the natural resources. Preferably, national data on exploitable water resources should be provided with an indication of the set of criteria considered.[16]

Internal Renewable Water Resources, Surface Water and Groundwater

An internal renewable water resource (IRWR) is that part of the water resources (surface water and groundwater) generated from endogenous precipitation (Figure 3). The IRWR figures are the only water resources figures that can be added up for regional assessment and they are used for this purpose.

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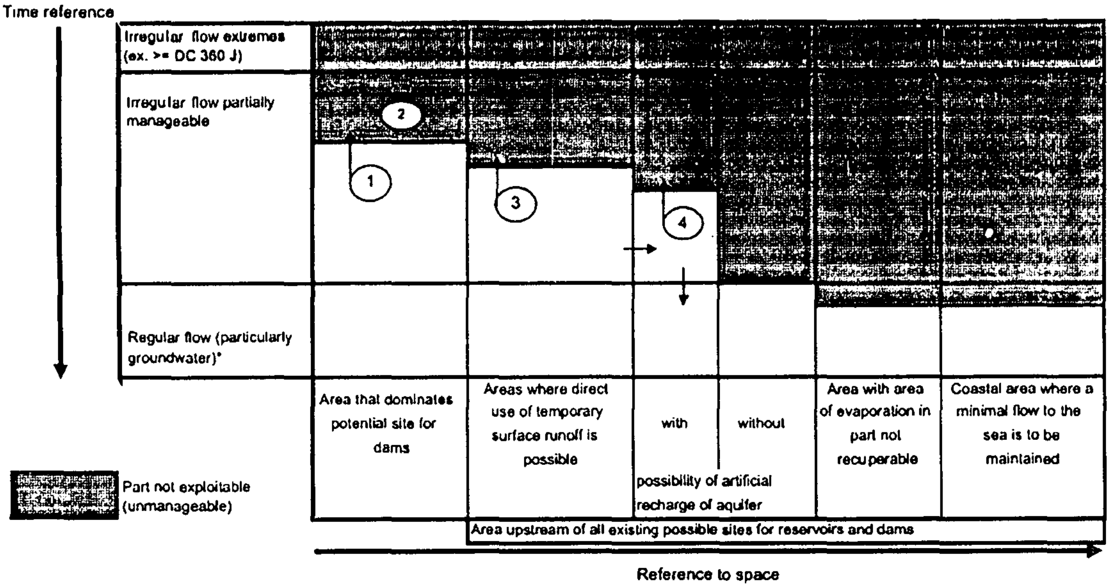
[16] Op Cit, No. 9

Fig 3: Surface water and groundwater concepts



Source: FAO/BRGM, 1996

Although the hydrological cycle links all waters, surface water and groundwater they are usually studied separately and represent different development opportunities. Surface water is the water of rivers and lakes; groundwater is the water captured in underground reservoirs.

Surface water flows can contribute to groundwater replenishment through seepage in the riverbed. Aquifers can discharge into rivers and contribute in their base flow, the sole source of river flow during dry periods. Therefore, the respective flows of both systems are not wholly additive. This chapter uses the concept of overlap to define the part of the country's water resources that is common to rivers and to aquifers.

External Water Resources

This study defines external water resources as the part of a country's renewable water resources that enter from upstream countries through rivers (external surface water) or aquifers (external groundwater resources). The total external resources are the inflow from neighbouring countries (trans-boundary flow) and a part of the resources of shared lakes or border rivers, defined for the purposes of this study through an arbitrary rule (unless defined by an agreement or treaty).

Most of the inflow consists of river runoff, but it can also consist of groundwater transfer between countries (e.g. between Belgium and France, Bulgaria and Romania, or Sudan and Egypt). However, groundwater transfers are rarely known and their assessment requires a good knowledge of the piezometry of the aquifers at the border. In arid areas, they are more important in comparison to surface flow.

In assessing the external flow of a country, this chapter distinguishes between natural incoming flow and actual incoming flow. Natural inflow is the average annual amount of water that would flow into the country in natural conditions, i.e. without human influence.

Actual inflow is the average annual quantity of water entering the country, taking into account that part of the flow which is secured through treaties or agreements and possible water abstraction in upstream countries.

Outflow

Outflow is the flow of water leaving a country to the sea or to neighbouring countries. Part of the outflow to neighbouring countries may be subject to reservation where a treaty or an agreement allocates a certain flow to a downstream country. This is reflected in the computation of actual water resources by subtracting the allocation for the country's water resources.

WATER QUALITY AND NON-CONVENTIONAL WATER SOURCES

Water quality

Differences in water quality may be significant locally but are difficult to aggregate in a meaningful way at national level. In addition, water quality must be expressed not only in terms of physical, biological and chemical variables, but also according to quality standards that vary according to use. Therefore, the evaluation of water quality requires the use of a water quality grid, defining quality classes according to several criteria and variables.

This chapter considers only inland freshwater and does not distinguish between categories according to water quality levels, owing to the unavailability of reliable information. In other words it assumes that the water resources it computes are of sufficient quality for beneficial use for agricultural, domestic or industrial purposes.

In countries where freshwater resources are scarce and under pressure, the assessment of freshwater resources is often complemented by an assessment of the available brackish water that can be used for specific purposes (desalination, some types of agricultural production).

Non-conventional Water Sources

With increasing pressure on natural freshwater in parts of the world, other sources of water are assuming importance. These non-conventional sources of water represent complementary supply sources that may be substantial in regions affected by extreme scarcity of renewable water resources. Such sources are accounted separately from natural renewable water resources. They include:

- The production of freshwater by desalination of brackish or saltwater (mostly for domestic purposes);
- The reuse of urban or industrial wastewaters (with or without treatment), which increases the overall efficiency of use of water (extracted from primary sources), mostly in agriculture, but increasingly in industrial and domestic sectors. This category also includes agricultural drainage water.

CONCEPTS OF SUSTAINABILITY: DEVELOPMENT V/S PRESERVATION

An integrated water resource management system comprises irrigation, crop production, and the environment. Irrigation sustains crop production systems. However, solely focussing on water resource development, without taking environmental preservation into consideration, is doomed to start with. Increased soil and water salinity resulting from extensive irrigation practices have already diminished opportunities to develop the crop production system. Although human society achieved a relatively stable balance between irrigation development and environmental preservation for several thousand years; during the last 30 to 50 years that relationship has been destroyed in some regions by inappropriate irrigation practices.

The purpose of sustainable water resources management is to sustain both the water supply capability and the environment, now and in the future. Water supply capability encompasses both the availability of water and the infrastructure to sustain water supply and use. The environment takes into account the water source, land and air systems that support human production activities. As water demands in agricultural, municipal, and industrial uses change over time—because of policy and technological changes, among others—the relationship between water use and the environment needs to be continually reviewed and adapted. In river basins where irrigation is the major water use, sustainable water management should ensure a long-term, stable, and flexible water supply to meet crop demands, as well as growing municipal and industrial demands, while at the same time mitigating or preventing negative environmental consequences from irrigation.

Sustainability reflects a systemic concept for irrigation water management that is, applying a set of elements that interact in interdependent fashion. Moreover, sustainability, by its nature, implies a dynamic system whose status is determined by a balance of opposing forces or trends.[17] When an accelerating flow of negative forces reaches a threshold beyond which it is impossible or inordinately costly to reverse the direction of the change and return to a more favourable equilibrium, the system becomes unsustainable. Another feature of the dynamic system, perhaps the most pervasive one for sustainability issues, is its association with inter-group and inter-temporal externalities.

[17] Svendsen, M., "Sustainability in irrigated agriculture", International Irrigation Management Institute (IIMI), Working Paper No. 4, Colombo, Sri Lanka, 1987.

The following section examines how sustainability can be measured and how it can be achieved in the context of irrigation water management.

Measuring Sustainability: Indicators

A set of manageable indicators of sustainability based on broad guidelines and principles are necessary to detect problems as they arise and to provide an early warning system for decision makers. The indicators should be monitored and measured on the basis of the performance of natural systems and anthropogenic interactions, and action should be taken once specified thresholds are passed. In particular, the indicators should be helpful in tracing long-term cumulative environmental changes due to irrigation practices, which can potentially create irreversible problems.

In the context of arid or semi-arid basins where irrigation is the dominant water use, sustainability in water resource management can be indicated by:

- Water supply system reliability, reversibility, and vulnerability,
- Environmental system integrity,
- Equity in water sharing, and
- Economic acceptability.

These indicators, defined at the basin scale, are supposed to be used by basin authorities or related national administrative agencies, instead of individual farmers. An example of indicators designed for farmers can be found in MAF (1997). Moreover, definitions of these indicators should be analytically sound and measurable in a modelling framework, which will be illustrated in the following section.

RELIABILITY, REVERSIBILITY, AND VULNERABILITY OF THE WATER SUPPLY SYSTEM

Water supply systems are subject to substantial risk because of inherent stochastic variability and a fundamental lack of knowledge. Sustainable water resources management requires a stable water supply system with enough flexibility to deal with various extreme conditions. Risk has been identified as one of the key sustainability issues in water resources management.[18] The traditional measures of system performance (mean value or variance of some variables) are insufficient to capture risk behaviour, and additional criteria must be used to quantify recurrence, duration, severity, and other consequences of unsatisfactory system performance. These criteria include reliability, reversibility, and vulnerability.[19]

Reliability represents the probability of a system's success state and is complementary to risk, which represents the frequency of system failure. Reliability, as used in water resources management, comprises three terms: *occurrence reliability* (the ratio of the number of periods of system success to the number of periods of operation), *temporal reliability* (the ratio of the time the system is in a success state to the total time of operation), and *volumetric reliability* (the ratio of the volume of water supplied to the total volume demanded).

Reversibility or ***resilience*** is the probability that the system can recover from failure to some acceptable state within a specified time interval. Fiering (1982) proposed several alternative indices of resilience, including how long the system remains in the satisfactory state and the steady state probability of the system being in the satisfactory state.[20]

Vulnerability represents the severity or magnitude of a system failure. Hashimoto, Stedinger, and Loucks developed a matrix for overall system vulnerability as the expected maximum severity of a sojourn into the set of unsatisfactory states. They emphasized the maximum severity (how bad things are) for each unsatisfactory state and the probability that the failure with the maximum severity would occur. These risk indicators can be used for various aspects such as water quantity and quality, crop area,

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[18] Simonovic, S. P. "Risk in sustainable water resources management", In *Sustainability of water resources under increasing uncertainties*. IAHS Pub. No. 240, 1997.
[19] Kundzewicz, Z. W and J. Kindler., "Multiple criteria for evaluation of reliability aspects of water resource systems", *Proceedings of a Boulder Symposium*, International Association of Hydrologic Sciences (IAHS) Pub. No. 231, 1995.
[20] Fiering, M. B., "Alternative indices of resilience", *Water Resources Res*earch, Vol. 18(1), 1987, p. 3339.

yield or production, and flow requirement for environmental and ecological purposes. The selection depends on the specific analytical objectives. The threshold for "system failure" (for example, water supply is 25 per cent below water demand), which is a managerial assumption, has to be considered in the quantification of the risk indicators discussed above.[21]

ENVIRONMENTAL SYSTEM INTEGRITY

A guiding criterion for sustainable water resource management is to minimize the interference of the irrigation system with the associated environmental system, including the effects on the water bodies that receive irrigation water through wind-drift, surface runoff, or drainage to groundwater. In addition, to sustain irrigation over the long term, water resource management must meet legislative requirements with respect to the environment.

Indicators for environmental system integrity fall into three categories:

(1) Health of aquatic and floodplain ecosystems: Extensive irrigation can affect drinking water health as indicated by bacteria, nutrients, and toxic contaminants, and soil health as indicated by the soil's water-holding capacity, total organic Nitrogen and Carbon, PH value, and the conditions of surface aggregates.
(2) Water quality: Irrigated agriculture affects water quality in several ways, including higher chemical use rates associated with irrigated crop production, increased field salinity resulting from applied water, accelerated pollutant transport with drainage flows, groundwater degradation due to increased deep percolation to saline formations, and greater in stream pollutant concentrations due to flow depletion.
(3) Soil degradation: Irrigation is responsible for soil water logging and salinization in many regions where drainage systems are poor; irrigation with traditional furrow systems also causes soil erosion that can be measured by the extent of topsoil losses.

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[21] Hashimoto, T., J. R. Stedinger, and D. P. Loucks., "Reliability, resiliency, and vulnerability criteria for water resources system performance evaluation", *Water Resources Research*, Vol. 18(1), 1982, p. 1420.

Thus, the adverse environmental effects of irrigation (such as water logging and salinization, groundwater pollution, and soil erosion) are often cumulative and may develop to an irreversible state because of long-term poor water resource management. The measure of these indicators should be connected to both the short-term irrigation practices and performances and the long-term dynamic transmissions through some physical processes.

Equity

Equity is one of the basic concepts of sustainable development. Water is not just an economic resource; it is also a community resource with deep emotional and symbolic value. Experience has shown that plentiful and clean water flows toward the rich and powerful and away from the poor and powerless.[22] Another emerging issue is the relationship between the environment and equity, which needs to better qualify the water needs of ecosystems and the economic, social, and cultural values, functions, and services that aquatic ecosystems provide.

Thus, equity in water resources management involves complex natural, political, and socioeconomic factors. The ASCE view of equity in sustainable water resources systems would allow people, "now and then" and "here and there" to share the water use right (both benefit and cost) in such a way that no one should be disadvantaged or inadequately compensated.[23]

Factors affecting temporal equity and spatial equity in water resources development can be either anthropogenic or natural, or both. Temporal equity is associated with resource depletion and long-term cumulative consequences that may lead to damages or even disasters in the future. Spatial equity often concerns the conflict between upstream and downstream areas in a river basin and the conflict between various water users. As mentioned in chapter one, the continued availability of water for irrigation will be

[22] Ingram, H., "Water and equity: A direction for research", *The Common Property Resources (CPR) Forum* No. 43, 1997.

[23] ASCE (American Society of Civil Engineers) and UN/IHP (United Nations International Hydrologic Program), Committee on Sustainability Criteria, Water Resources Planning, and Management Division 1998. *Sustainability criteria for water resources systems*. IV Project M-4.3.

threatened in many regions by rapidly increasing non-agricultural water uses (in industry, households, and the environment), which normally have a higher marginal return than irrigation. The same conflict exists between farmers who plant high-valued crops and those who plant low- valued crops. Continued research is needed to measure the social value, or the public welfare component, of water to ensure that, when water is transferred, the area of origin will retain sufficient water to protect social value and to adequately compensate losses that cannot be prevented.[24]

Moreover, water quality is also an equity issue. For example, conflicts arise when upstream users release excessive pollutants into the river and downstream users suffer damage resulting from the poor water quality. The measure of equity can be descriptive and normative. Descriptive measures simply evaluate the dispersion of the benefit using some descriptive statistics. Normative measures are derived from some underlying social welfare function.[25]

Economic Acceptability

Besides food self-sufficiency, achieving net profit over the long term is the motivating factor that sustains irrigated agriculture. Economically acceptable irrigation systems provide lifestyle and social options for farmers and also contribute to the wider economy and community.

From the perspective of using water more economically, the great challenge in irrigated agriculture is to include the opportunity costs of irrigation water supply, which are often an order of magnitude higher than current charges.[26] Another challenge is to include the costs of long-term economic damage to the environment due to irrigation. To maintain and improve economic acceptability, some regions will require investments both to enhance water supply capacity and to increase water use efficiency.

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[24] Op cit, No. 17

[25] Tsur, Y., and A. Dinar., "*Efficiency and equity considerations in pricing and allocating irrigation water*", Policy Research Working Paper 1460. 1995, Washington, D.C.: World Bank.

[26] Briscoe, J., "The Financing of Hydropower, Irrigation and Water Supply Infrastructure in Developing Countries", *Journal of International Water Resources Development*, Vol. 15(4), 1999, pp. 459-491.

Given all these considerations, the marginal benefit and marginal cost associated with irrigation development and management can be assessed. When the marginal benefit is less than the marginal cost, the irrigation practice loses its economic acceptability, which implies an unsustainable state.

ACHIEVING SUSTAINABILITY: AN ANALYTICAL FRAMEWORK

The indicators outlined above provide information for decision making in water resource management. They are not an end in themselves but rather the means to influence the decision making process. How can sustainability be achieved? It can be done through decisions on national or regional agricultural policy, basin/sub-basin water allocation, and water resource management at the field level. The following section describes an analytical framework to support these decisions at various levels.

A river basin forms a natural boundary for water resource planning and management, in which water interacts with and, to a large degree, controls the extent of other natural components in the landscape such as soils, vegetation, and wildlife. Human activities can also be organized and coordinated within the river basin unit. Physical processes, such as flow and constituent balances are governed by natural laws and are also affected by human actions, including impoundment, diversion, irrigation, drainage, and discharges from urban areas. Therefore, decision making in water resources management should be based on physical processes and should also take into account artificial "hardware" (infrastructure) and "software" (management policies). A modelling framework can help identify and analyze the issues in the context of the river basin.

Water can be used for in-stream purposes, including hydropower generation, recreation, and waste dilution, and for off-stream purposes that are differentiated into agricultural, municipal, and industrial water uses. The rapid increase in municipal and industrial water demand in many regions of the world will not only require increasing transfers of water out of agriculture but also lower the quality of downstream irrigation water if municipal and industrial wastewater discharge is not appropriately controlled.

Taking into account in-stream water requirements for hydropower generation, recreation, and ecological uses involves setting aside sufficient water over space, time, and distribution between in-stream and off-stream water uses.

The social benefit of water uses should be an important component of a basin water management strategy. That means both the positive contribution from the economic value of irrigated agriculture and the environmental damage from salinity and water logging, soil erosion, and water quality degradation resulting from irrigation is taken into account. The social benefit also relates to the benefits and costs of municipal and industrial (M&I) water uses.

The water resource management system should be governed by national or regional agricultural policies, including trade and macroeconomic policies, agricultural input and output prices, government investments in technology and infrastructure, and institutional resource management policies, such as market quotas, water allocation policies, and soil conservation programs.

Policy instruments applied directly to water resource management could include a mix of water prices, penalty taxes on waste discharge and irrigation drainage, and water rights. The impact of these policies on agricultural sector growth and on environmental sustainability in the region should be analyzed along with decisions on water management at the basin/sub-basin and farm levels.

Decisions at the basin/sub-basin and farm levels may be considered separately. Decisions at the basin/sub-basin level should promote an appropriate expansion of infrastructure capacity and optimal operation of existing reservoir, aquifer, and stream systems. They should also take into account water allocation among different sectors and users, especially in trans-boundary situations, as well as the interaction between those sectors and users. While keeping in mind water rights within a basin, decision makers should consider the efficiency with which water is used at different places in the basin by different users and the degree to which different uses degrade the water quality.[27]

Efficiency at the river basin level can be improved by (1) increasing output per unit of evaporated water, (2) reducing losses of usable water to sinks, (3) reducing water pollution, and (4) reallocating water from lower valued to higher valued uses.[28]

Batchelor suggested several ways to improve physical and economic efficiency at the farm level:

- Agronomic (for example, improving crop husbandry and cropping strategies);
- Technical (for example, installing an advanced irrigation system);
- Managerial (for example, adopting demand-based irrigation scheduling systems and better maintaining equipment); and
- Institutional (for example, introducing water pricing and improving the legal environment).[29]

Supply and demand management policies may also affect decision making. A portion of the growing demand for water can be met by investing in water supply and utilization systems, and some potential exists for expanding non-traditional sources of water supply (for example, desalinization). However, in many arid or semi-arid areas, water is no longer abundant, and the high economic and environmental costs of developing new water resources limit how much supply can expand. Demand management aims to better utilize existing water resources by curbing inessential or low-value uses through price or non-price measures. The modelling framework should provide information to analyze tradeoffs between the decisions for the two categories. In most cases, new sources and improved demand management are both necessary and joint decisions for supply and demand should be made for sustainable water resources management.

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[27] Batchelor, C. "Improving water use efficiency as part of integrated catchment management", *Agricultural Water Management*, Vol. 40(2), 1999, pp 249-263.
[28] Seckler, D. "*The new era of water resources management: From "dry" to "wet" water savings*", Research Chapter, No 1. International Water Management Institute (IWMI), 1996, Colombo, Sri Lanka.
[29] Ibid.

These water management issues, policies, and decisions are complex and integrated with the social, economic, and environmental development and sustainability of the basin. The process of achieving sustainable water management requires a framework for decision making. This framework should be a dynamic system that includes modelling components capable of analyzing the effects of the proposed policies and strategies over periods of time long enough to see the cumulative, long-term effects on the system.

IMPLEMENTATION OF THE ANALYTICAL FRAMEWORK

The modelling framework for sustainability analysis combines traditional water resources management models with indicators that are based on newly developed sustainability criteria. Specifically, the modelling framework needs to simulate the performance of short-term decisions so the sustainability indicator can be quantified by some prescribed mathematical forms. Moreover, the indicators, embedded in the modelling framework, should be used to evaluate rules, and thus form a managerial control to the short-term decisions so as to ensure long-term sustainability. The following section discusses some issues related to implementing this kind of analytical framework.

Integrated Short-Term and Long-Term Objectives

Irrigation water planning and management should balance short-term and long-term objectives. They are neither totally consistent nor totally in conflict with each other.

Short-term objectives focus on current benefits, while long-term objectives aim to sustain current and expected benefits into the future. Long-term decisions must account for the long-term consequences of short-term decisions in a way that avoids possible negative future effects of current decisions. Put another way, the long-term situation improves when short-term decisions balance current and future benefits.

Integrated Hydrologic-Agronomic-Economic Modelling Components

The interdisciplinary nature of water resource problems require the integration of technical, economic, environmental, social, and legal aspects into a coherent analytical framework, so that both economic and environmental consequences of policy choices can be examined. Hydrologic relationships provide a physical basis to evaluate water availability and water quality conditions. Accurate estimates of deep percolation, return flows, and their contaminant concentrations, as well as groundwater levels, are essential to evaluate the environmental effects of irrigation. Assessing the damage resulting from the depletion of water over time is also critical to evaluating the environmental effects of irrigation. Long-term simulations of these processes are necessary to trace the cumulative consequences such as water logging, soil salinization, and groundwater quality reduction.

Crop production functions connect water, soil, and other inputs with crop production, which is the fundamental building block for estimating the demand for and value of water in irrigation. An ideal crop-water production model should be flexible enough to address issues at the crop, farm, and basin levels. The production function should allow the assessment of policy-related problems and, in particular, be sufficiently comprehensive to allow the estimation of externality effects. Moreover, the modelling framework should generally include the valuation of non-agricultural uses of water, such as values for domestic demand; commercial, industrial, and mining demand; recreational demand; and environmental demands such as maintenance of in-stream river flows and flushing of pollutants.[30]

Only by considering all interactive components that benefit from or damage the resource can the optimal use be established from a social standpoint. Thus, with the growing scarcity of water and increasing competition for water across sectors, the economic aspects of water allocation are increasingly important in river basin management. Important economic issues that need to be examined through integrated economic-hydrologic river basin modelling include transaction costs, the effects of allocation mechanisms on agricultural productivity, inter-sectoral water allocation, the

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[30] McKinney, D. C., et. al., "*Modelling water resources management at the basin level: Review and future directions*", SWIM Paper No. 6. International Water Management Institute, 1999, Colombo, Sri Lanka.

environmental effects of allocations, and property rights for different allocation mechanisms.[31]

Moreover, institutional relationships present directives aimed at achieving equity in water resources management. An integrated system should be able to explore the interdependence between economic development and environmental consequences, and between short-term decisions and potential long-term problems. The outcome of water use can then be examined in terms of efficiency, equity, and environmental impact. Over time, these outcomes change the environment through processes such as salinization and water logging, siltation, industrial water pollution, technological change, crop diversification, and legislative and institutional change. These processes are critical for understanding the dynamic changes occurring in the environment associated with water use systems, and for implementing appropriate controls on the actions that drive the system to sustainability thresholds.

A Prototype Modelling Framework for Sustainability Analysis

A long-term dynamic modelling framework following the concepts and methodology discussed above was developed in the dissertation of Cai.[32]

The core of the modelling framework is an Inter-Year Control Program (*IYCP*) and a sequence of Yearly Models (*YMs*). The yearly model for year *y*, *y YM,* is a short-term (annual) optimization model developed at the river basin scale. The objective function of the model is to maximize total water use net benefit in a river basin for that year.

The model includes essential integrated hydrologic, agronomic, and economic components such as (1) flow and pollutant (salt) transport and balance in the river basin network, including the crop root zone; (2) irrigation and drainage processes; (3) crop production functions, including the effects of both water stress and soil salinity; (4)

[31] Rosegrant, M. W., and R. S. Meinzen-Dick., "Multi-country research program: Water resource allocation: Productivity and environmental impacts (MP-10) Program statement and methodology", International Food Policy Research Institute, 1996, Washington, D.C.

[32] Cai, X., "Modelling framework for sustainable water resources management", Unpublished Ph.D. dissertation, University of Texas at Austin, 1999.

benefit functions for both in-stream and off-stream uses, accounting for economic incentives for salinity control and water conservation; (5) tax and subsidy systems to induce efficient water allocation, improved irrigation-related capacities, and protection of the environment; and (6) institutional rules and policies that govern water allocation.

The model is based on a node- link network with source nodes—such as rivers, reservoirs, and groundwater aquifers—and demand site nodes—such as agricultural, municipal and industrial (M&I), and ecological demand sites, and hydropower stations.

Detailed agricultural water demand, in-stream water uses (including flow release for environmental and ecological use), and hydropower generation are modelled. Details of the yearly model can be found in Cai.[33] In addition, McKinney et al. provides a comprehensive review of integrated, hydrologic-agronomic-economic models at the basin scale;[34] and Rosegrant et al. illustrates the application of such a model to the Maipo basin in Chile.[35]

The *IYCP* is a long-term model which uses some prescribed indicators based on sustainability criteria to control relations between short-term irrigation practices and their long-term socioeconomic and environmental consequences. The long-term decisions include the regulation of inter-year reservoir storage, irrigation and drainage infrastructure improvements, changes in irrigated area and crop patterns, and economic incentives (for example, salt penalty taxes.) The thesis of this framework is that short-term (intra-year) decisions should be controlled by long-term (multi- year) sustainability criteria to reach sustainable planning and management decisions.

The long-term optimization/simulation model of the basin incorporates specific indicators of sustainability, taking into account risk minimization in water supply, environmental

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[33] Op cit, No. 26
[34] Op cit, No. 24
[35] Rosegrant, et al., "Integrated economic-hydrologic water modelling at the basin scale: the Maipo river basin", *Agricultural Economics*, Vol. 24 (1), 2000, pp 33-46.

conservation, equity in water allocation, and economic efficiency in water infrastructure development. These indicators are measured by certain approximate methods.

Risk is represented by reliability, reversibility, and vulnerability in terms of sustained irrigated area and flow for ecological use, reflecting how much irrigated area/ecological flow can be sustained, how often irrigated area/ecological flow drops below an assumed target, and how serious the deficits are in a long-term time horizon (30 years).

Environmental indicators are identified as worst water and soil salinity conditions in the basin over the long run. Temporal equity ("now and then") is defined as the standard deviation of the rate of change of total water use benefit in the basin over all years; and spatial equity ("here and there") is defined as the standard deviation of the average rate of change of water use benefit over all demand sites. Economic indicators are represented by the ratio of the marginal benefits to the marginal costs of additional water infrastructure improvements. Mathematical representations of these indicators are given in Cai, McKinney, and Lasdon.[36]

The results of the sequence of yearly models (y *YM)*, over a long time horizon under a particular selection of the inter-year decision variables, are used to calculate the indicators, which are then used to evaluate the long-term performance of some policy options represented by the long-term decision variables. To find optimal long-term policies, these modelling processes are implemented in an iterative form. The solution approach to the modelling framework is presented in Cai, McKinney, and Lasdon.[37]

In many countries (including central Asia), environmental degradation is a by-product of development, along with water deterioration from conventional agricultural practices. In contrast, sustainable water and water resources carry a strong commitment to environmental quality. In conclusion, one has to take into consideration the choice of sustainability indicators and the determination of threshold values with the spatial

[36] Cai, X., D. C. McKinney, and L. Lasdon., "Solving non linear water management models using a combined genetic algorithm and linear programming approach", *Advances in Water Resources*, Vol. 24(6), 2001, pp. 667-676.
[37] Ibid.

variability of the natural and human conditions controlling sustainability. A crucial question is how to evaluate the time component of sustainability and estimate the longevity of a water system under specific management practices. Lal et al. proposed periods of 5-10 years for agronomic productivity and 5-10 decades for soil and environmental features.[38] Fresco and Kroonenberg suggest the time scale of both internal and external processes acting on the system should be considered for agro-ecosystems at local and regional levels.[39]

In Iran, for example, traditional water management practices (Qanats, Bands, Pot irrigation, etc.) that evolved over a long time into a socially and ecologically integrated system quickly collapsed when agriculture underwent modernization.[40] The author argues that we should consider ancient integrated systems as sustainable ones. Sometimes we forget that our ancestors formed frameworks for our present knowledge. Priority should be accorded to water use evaluation as the main and primary decision-making factor. If one were to evaluate these systems it would take a long time, and is beyond the scope of this thesis.

WATER RESOURCES: AN EMERGING CRISIS

The problem of water shortages in the arid and semi arid regions of the world is a developmental issue, since water limitations are seriously impeding the economic growth and development of countries in these regions. Even countries that are quite advanced technologically are experiencing restraints on their future development. Water scarcity in the arid and semi-arid region is rapidly becoming part of a widespread environmental concern for the region. The twin phenomena of depletion of existing water resources together with pollution of these resources are causing unbearable hardships in the area. Land deprived of its scarce water resources, either by natural phenomena or human activities, produces devastating consequences as the recent occurrence in the Aral Sea Basin in Central Asia demonstrates. At the very least, water scarcity creates an environment where sustainable development is severely limited in the Aral Sea Basin

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[38] Lal, D., et al, "Polar ice ablation rates measured using *in situ* cosmogenic ^{14}C", *Nature,* Vol. 346, 1990, pp 350-352.
[39] Fresco, L O. and S. B. Kroonenberg., "Time and spatial scales in ecological sustainability", *Land Use Policy 9,* 1992, pp. 155-168.
[40] Farshad, A. and Zinck, J. A., "Seeking Agricultural Sustainability", *Agriculture, Ecosystems and Environment*, Vol. 47, 1993, pp. 1-12.

(Kazakhstan, Uzbekistan, Turkmenistan) and in the worst case, extreme water shortages can create an environmental climate that exacerbate serious conflicts, as evidenced by water-related conflicts in the Central Asian region.[41]

POLICY IMPLICATIONS

Whether the impact of water degradation are short-term or long-term, reversible or irreversible, human populations incur damage to their economic activity and social welfare. Factors other than water degradation may be involved, but, irrespective of the precise location and source of the problem, the damage constitutes a political issue and requires an appropriate policy response.

Hitherto, environmental scientists have commonly investigated specific water degradations and sought to formulate appropriate preventative or mitigatory measures. Such measures aim to provide a rational basis for water-management decisions by politicians and planners. At times, the tendency has existed, especially on the part of mid-latitude scientists, to formulate technical options that are over-elaborate or otherwise unsuited to local water conditions or that poorly fit with the social realities of the areas in question. In this respect, local soil conditions, property relations or cultural traditions can equally undermine a supposed technical solution to a specific degradation.

As far as the immediate water user is concerned, however, factors other than the availability of an appropriate technical solution affect the management of water degradation. Small farmers in the tropics may be so preoccupied with meeting subsistence needs that they cannot attend to long-term measures that would protect or restore the quality of their water. Likewise, corporate water users, even if well aware of the long-term benefits of minimizing water degradation as a basis for sustainable exploitation, often opt for short-term profits at the expense of the environment in the course of, say, logging operations in Southeast Asia or cattle ranching in Amazonia.[42]

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[41] Redclift, Michael., "*Sustainable Development: Exploring the Contradiction*", Methuen, London, 1987.
[42] Op cit, No. 35

Where individual or corporate behaviour degrades the environment, more effective government involvement in water management is required. However, at individual or corporate levels, governments have multiple and often conflicting priorities, which, in the tropical as much as elsewhere, commonly result in neglect of the environment. In recent decades, governments in the tropics have become more aware of the need for environmental protection.

Indeed, detailed legislative framework and dedicated government agencies are often in place which, if used effectively, would go a long way in resolving many of the environmental problems in both rural and urban-industrial areas. On occasions, governments are constrained by inadequate or misleading technical information, but more often they are deflected from, or simply ignore, their formal environmental obligations. Explicit priority may at times have to be given to resolving short-term economic or social crisis at the expense of environmental resources. However, more culpable behaviour is often evident on the part of governments whose performance are characterized by inept or corrupt management that has little or no concern with water degradation or related issues.

Meanwhile, global awareness of the environment has increased in recent decades. External bodies ranging from international funding agencies and developed world governments to non-governmental organizations and the world media have variously proceeded to monitor, advise, criticize and even coerce governments in the tropics in respect of their environmental performance. The governments in question rarely appreciate such attentions, which they see as infringing their authority or threatening national sovereignty. Even, so the reality of contemporary global politics, particularly since the United Nations Conference on Environment and Development in 1992, is that environmental issues are increasingly global issues that transcend national boundaries. Intrusive as this may appear and incompatible as it often is with the ambitions of individual's states, it is increasingly the context in which water degradation, and other environmental issues, are, for better or worse, being approached.[43]

CONCLUSION

Although water degradation has traditionally been an environmental or technical issue, its causes and effects are linked to socio-economic conditions and its prospects related to political frameworks. Even assuming that suitable technical options exist for managing water degradation, there is no guarantee that such options will be adopted, even if longer-term national or global interests are served thereby. In other words, neither individuals, corporate nor governmental responsibility for the environment can be assumed, nor any policies aimed at managing water degradation can de recognized.

In these circumstances to start with, the primary objective should be to ensure that any technical options for managing water degradation are the best that current scientific knowledge allows. Some degradation, like soil nutrient depletion, is relatively uncomplicated and locally manageable in technical terms. Others, like deforestation, are less straightforward on account of their broad bio-physical feedbacks and overall technical complexity. At times, exaggerated impact and 'worst-case scenarios' have been proffered for these and other degradations, and have latterly been justified in terms of sounding the alarm about environmental deterioration, or of 'advocacy, with respect to the environment'. Additional authority has been conferred thereon by resorting to the 'precautionary principle' which expresses the desirability of risk taking too much action rather than too little in the face of perceived threats. The principles are a valid response to technical uncertainty, but, in practice, needs to amount to more than a spurious cover for environmental propaganda. Its most useful function would be to provoke sufficient research on water degradation and other environmental issues. Some progress is being made, but the technical basis for understanding and managing water degradation is still inadequate.[44]

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[43] Anon, "Lithuania's environment: status, processes, trends", Environmental Protection Ministry, 1994, Vilnius.

[44] Op cit, No. 35

Secondly, it needs to be recognized that managing water degradation, critical as it is, is but one of a number of priorities in tropical countries. Government often accord higher priority to developing commercial agriculture or mining operations, implementing water colonization or urban housing schemes, or establishing strategic road-building projects. In spite of periodic pressure from radical environmental groups for severe constraints on tropical water development, the political problems involved are immense, and, in most cases, the best that can be hoped for is a compromise between developmental objectives and environmental protection. In practice, this means the promotion of sustainable exploitation systems and proper conservation programmes and the rigorous adoption of environmental impact analysis wherever significant developments are proposed. The aim must be to ensure that the linkages between development and degradation are acknowledged by politicians and planners in the tropics, and that conflicting economic, social and environmental priorities become explicit political issues.[45]

Thirdly, it has to be recognized that, even where environmental issues are part of the political process, it is often difficult for governments to implement environmental policies, even if they wish to. This is particularly so in tropical countries where severe economic constraints already exist, over which the government has little immediate control. The constraints may be massive overseas debs that absorb much of the national revenue or adverse terms of trade that limit generation of income in the first place. Externally applied policies, like the structural adjustment programmes of the World Bank, also severally constrain a government's scope for action, even if those policies are narrowly beneficial. Likewise, internal structural factors limit the scope for action. Designated agencies for environmental management may be in place, but, if trained staff are unavailable or a shortage of vehicles or roads exists, there is little, prospect of implementing existing environmental polices. In other cases, government performance is limited by security problems involving civil disturbance, guerrilla activity or drug trafficking. In such as scenario the scope for effective water management is limited.

[45] Op cit, No. 35

Finally, it must be recognized that the quality of government in the tropical world, as elsewhere, is imperfect that rational environmental, as well as economic and social, objective are often compromised by individuals or collective ignorance, incompetence or corruption. The conventional wisdom of the west is that an educated and informed population and a more open, democratic system of government is a solution of such ills in the long run. There is an understandable disinclination in parts of the tropics to adopt a Western political model, but in such circumstances an alternative system is required that adequately handles environmental as well as other issues. Authoritarian political systems, whether of the left or the right, have a poor record in this respect. Thus, the quality of governance in the tropics is of critical importance to water degradation and as important as any technical factor. Making governments more accountable for their environmental policies and actions via internal or external feedbacks, is part of the way forward, and one is which the role of electorates, non-governmental organization and the media is critical.

Given these constrains what are the prospects for managing water degradation in the tropics? Some grounds for optimism exist, but the situation is uncertain as it depends ultimately on the political response. Thus far, chapters in this thesis testify, that response has often been inadequate. Nevertheless, some progress has been made in translating water degradation into political issues, which is a prerequisite to its management. The progress has not been fast enough to alleviate the fears over water degradation, but in comparison to the neglect of tropical environmental issues that existed prior to the 1970s, momentum of environmental concern has been generated that offers some hope for the future. The momentum has developed over the years from local attention to specific degradations to broader concerns with more general issues, some of which have lately been addressed at the global political level, notably at the United Nations Conference on Environment and Development in Rio de Janeiro.

It is difficult to envisage other ways forward that offer a lasting prospect of managing water degradation in the tropics. Meanwhile, the performance of relevant institutions, whether funding agencies or non-governmental organizations, needs constantly to be monitored by individuals and groups of individuals at all levels in order to ensure that appropriate environmental policies are adopted and that the momentum of concern about environment is sustained.

WATER RESOURCES IN THE ARAL SEA BASIN: THEIR ACCESS AND AVAILABILITY

INTRODUCTION

The water resources in the Aral Sea basin are limited by both distribution and amount. Their distribution involves the location of population and their access to water supplies as well as the availability of water supplies by season thus they are also limited by total amount available and amount available per person.

Interestingly, it has always been said that Aral Sea basin had enough available water resource to support a population of 57 million people approximately, but water is so unevenly distributed as to be effectively in short supply. Whatever the case, in traditionally rural Central Asia, rapid increases in urban areas have brought new demands on the region's limited water resources. Various attempts are being made to address the problems arising from this situation. In some cases like Turkmenistan, investments are being made in reverse osmosis systems. Water-saving measures are being emphasized more than looking for new water resources; for example, in agriculture, drip irrigation systems are being used.

The availability of water resource in any region depends on the geography of the region.

GEOGRAPHY OF THE ARAL SEA BASIN

The Aral Sea Basin is located in the heart of the Asian continent, and covers the whole territory of present Tajikistan, Turkmenistan, Uzbekistan, Kyrgyzstan, and the southern part of Kazakhstan (see Figure 1). Some parts of the basin are located in the northern part of Afghanistan and Iran (about 8 per cent), and some in China (less than 0.1 per cent).[46]

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[46] Dukhovny, Viktor and Vadim Sokolov., "Lessons on cooperation building to manage water conflicts in the Aral Sea basin", UNESCO, 2003.

Hydro-geographical Characteristics

The total area of the basin is about 158.5 million hectares (see Table 1). This territory extends between longitudes 56° and 78° east, and latitudes 33° and 52° north, which represent almost 18 per cent of the area of the former Soviet Union. Kazakhstan alone covers 68 per cent of this area. The relief in this region is extremely varied. In the east are the Tien Shan and Pamir mountain ranges. The highest mountain of the former Soviet Union, the Peak of Communism at 7,495 m. above sea level, is located in the northern Pamirs in Tajikistan. Much of the mountain region is permanently covered with ice and snow and there are many glaciers. Mountain ranges in the south of the region include the Kopet Dag range along the border with Afghanistan.[47]

Table 1: Territory of the Aral Sea Basin in the Central Asian States

Country	**Area of the country (in hectares)**
Kazakhstan*	34 440 000
Kyrgyzstan*	12 490 000
Tajikistan	14 310 000
Turkmenistan	48 810 000
Uzbekistan	44 884 000
Afghanistan*	3 600 000
The Aral Sea Basin	158 534 000

* Only provinces within the Aral Sea Basin are included.

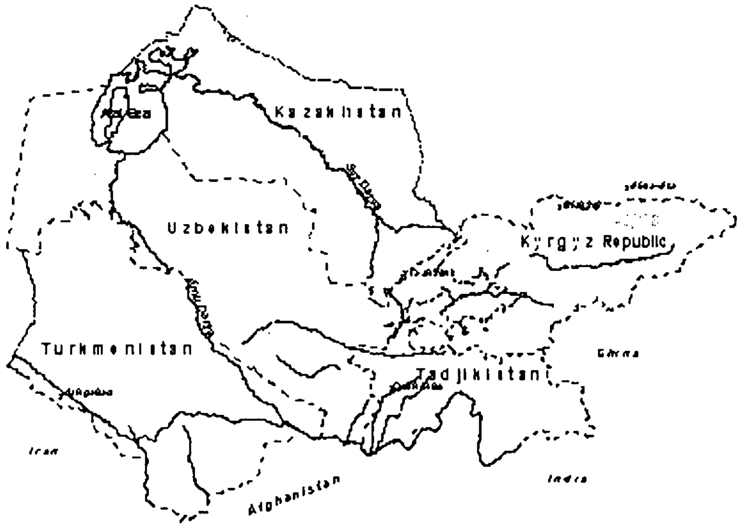
In the north-east of the region lies the second largest Crater Lake in the world, the Issyk-Kul in the Kyrgyzstan. On the border between the Kyrgyzstan, Tajikistan and Uzbekistan is the Fergana valley, which is a major agricultural area in this region. In the south-west lies the Kara-Kum or Black Sand desert, this is one of the largest sand deserts in the world and which covers over 80 per cent of Turkmenistan. Another large desert, the Kyzyl-Kum or Red Sand desert, extends over Kazakhstan and the north of Uzbekistan. The west of the region is dominated by the depressions of the Caspian Sea. The Aral Sea, in the central western part, is located on the border between Kazakhstan and Uzbekistan.

[47] Op cit, No. 46

Location and Geomorphology

The Aral Sea basin (Figure 1) coincides with almost the entire area of Central Asia. It is located in the heart of the Euro-Asian continent. The basin covers the whole territory of Tajikistan, Uzbekistan, the majority of Turkmenistan, three provinces of the Kyrgyzstan (Osh, Jalalabad and Naryn), the southern part of Kazakhstan (the Kyzyl-Orda and South Kazakh provinces) and the northern parts of Afghanistan and Iran.

Fig 4: The Aral Sea Basin



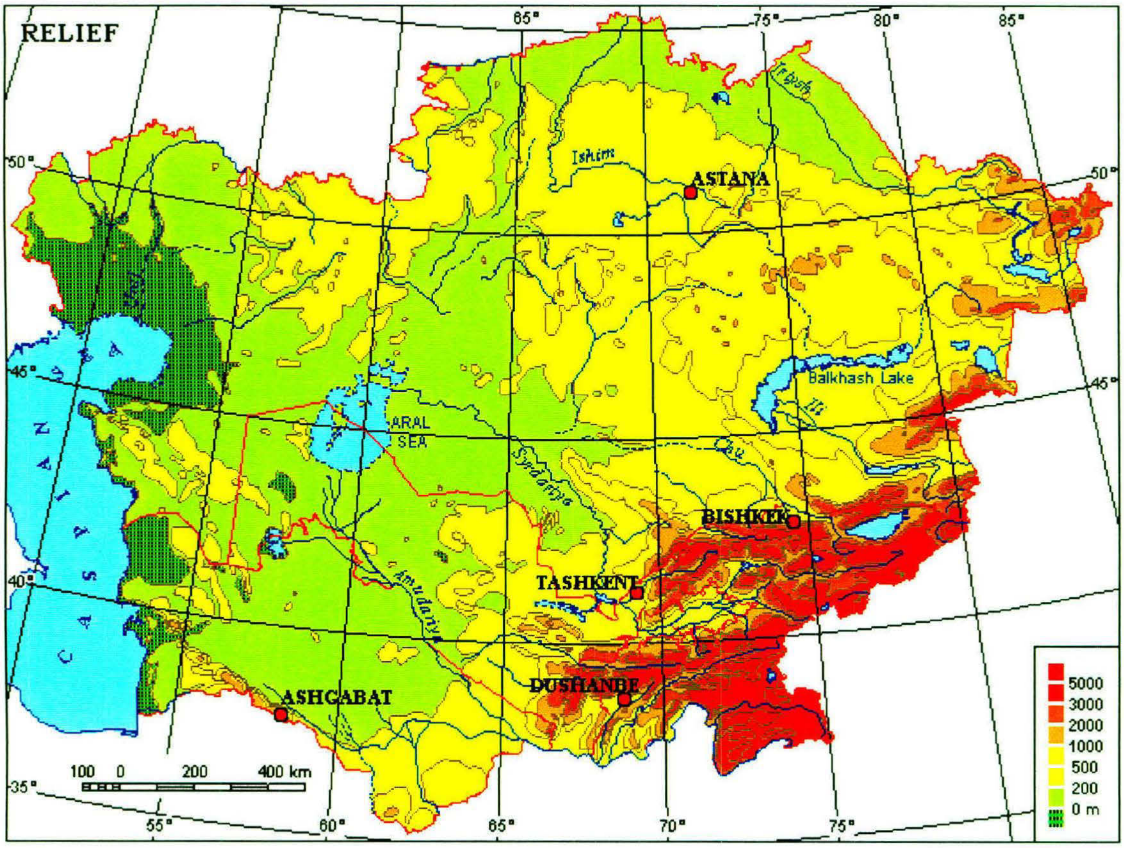
The basin is named after the Aral Sea, one of the largest inland seas in the world, which lies in the west of the basin and receives the waters from the two main rivers, namely the Syr Darya and Amu Darya. This Chapter will discuss generic aspects of the basin and subsequently will review the Syr Darya, and the Amu Darya.

The basin comprises two main zones:

i) The Turan plain

ii) The mountain zone.

Map 2: Relief of Central Asia



Source: http://www.icess.ucsb.edu/~aizen/centralasia.html

The Kara Kum zone covers the western and the north-western parts of the basin within the Turan plain and the Kyzyl Kum deserts. The eastern and south-eastern parts are situated in the high Tien Shan and Pamir mountains ranges. The remaining part of the basin is composed of various types of alluvial and inter-mountain valleys and dry and semi-dry steppes. The mountainous Kyrgyzstan and Tajikistan are upstream riparian having a "monopoly" on the formation of the water, but they also have a deficit of cultivable lands. An important feature of the region is the number of large wet oasis areas (Fergana Valley, Khoresm, Tashaus, Mary, Zerafshan, Tashkent–Chimkent) which cover a small part of the overall area, but since ancient times have been the focus of human activity and population.[48]

The majority of the territory of Kazakhstan, Turkmenistan and Uzbekistan is covered by desert and less than 10 per cent by mountains. Such a scenario requires irrigated agriculture, however, they demand more water resources than those countries have available with them. This disparity of water and land was seen in Soviet times as an opportunity to re-allocate the water resources for the development of irrigated agriculture in the downstream Republics. However, in the current scenario these circumstances are a source of potential conflicts.

Climate

The land locked position of Central Asia determines its continental climate, with low and irregular precipitation. Large daily and seasonal temperature differences are characteristic features, with high solar radiation and relatively low humidity. Although this area is often struck by humid winds, the mountains in the east and south-east trap most of the moisture, leaving little precipitation for the other areas of the Aral Sea basin. The climate in the region is continental, mostly arid and semi-arid, but varies considerably according to altitude. Average winter temperatures vary between -3°C and -20°C, but can fall below -45°C in the mountain regions in Tajikistan. Average summer temperatures vary between 19°C and 32°C, but often reach 50°C in the south-eastern Kara-Kum in Turkmenistan.[49]

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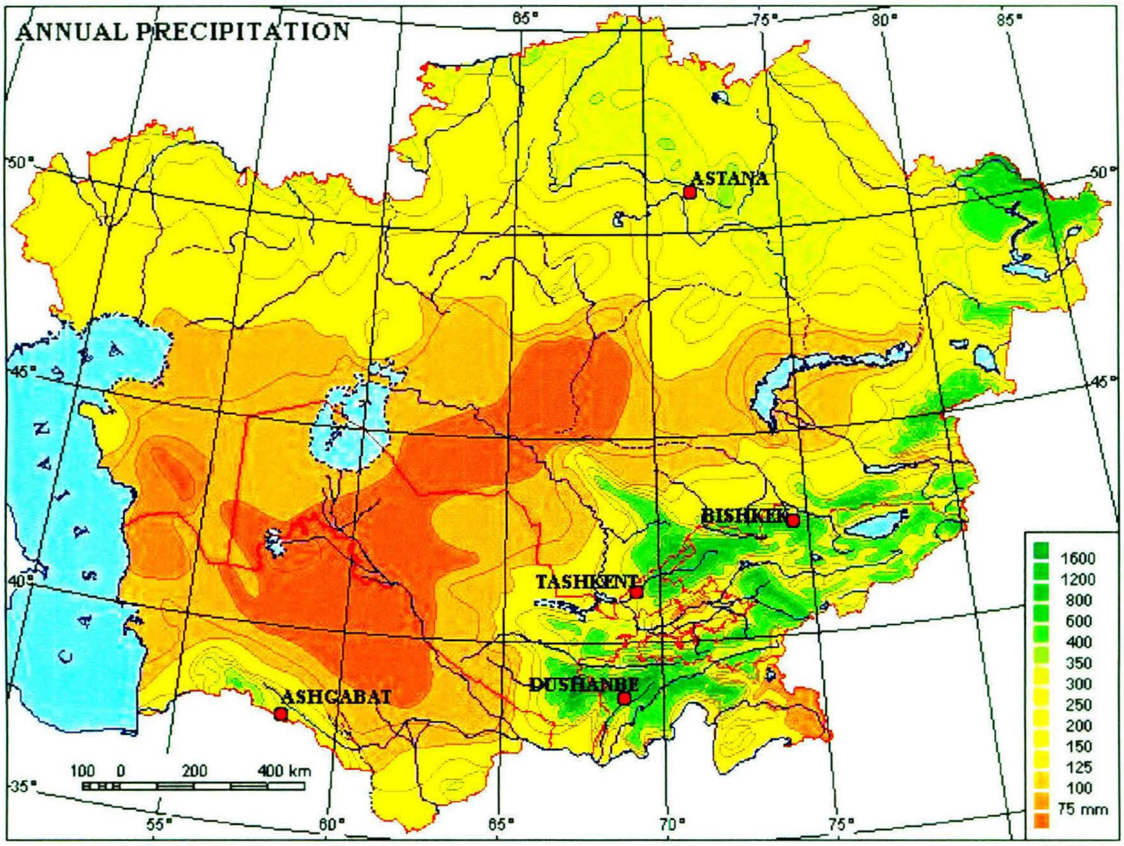
[48] Op cit, No. 8
[49] Ibid.

Map 3: Annual Precipitation



Source: http://www.icess.ucsb.edu/~aizen/centralasia.html

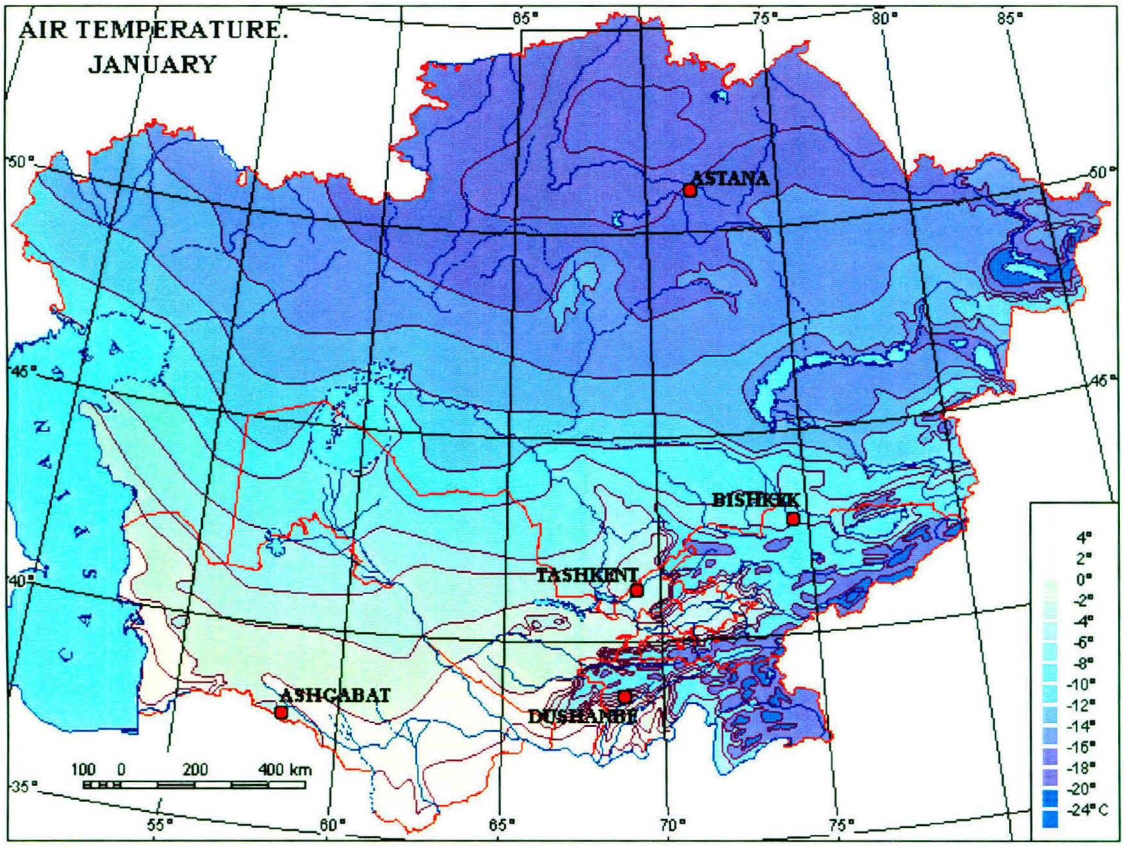
The average annual precipitation in this region is 338 mm, concentrated in the winter and spring, varying from less than 70 mm in the plains and deserts to 2,400 mm in the mountains of central Tajikistan. One half of the total irrigated area of the Former Soviet Union is located in Central Asia. The region has very different climatic zones with distinct water demands for irrigation. Large differences in air humidity in summer time between the old oasis and the newly irrigated areas (50-60 per cent and 20-30 per cent, respectively) cause water demands to be significantly larger in the former desert that are now under irrigation.

In addition, the two major land quality problems related to irrigation in the region are the interrelated issues of salinity and water logging caused by high groundwater levels. This makes drainage important in this region. The main features of the climate of countries in the Central Asia region are a great variability from country to country and also within countries (Table 2).

Table 2: Climate Variability in the Central Asia Region

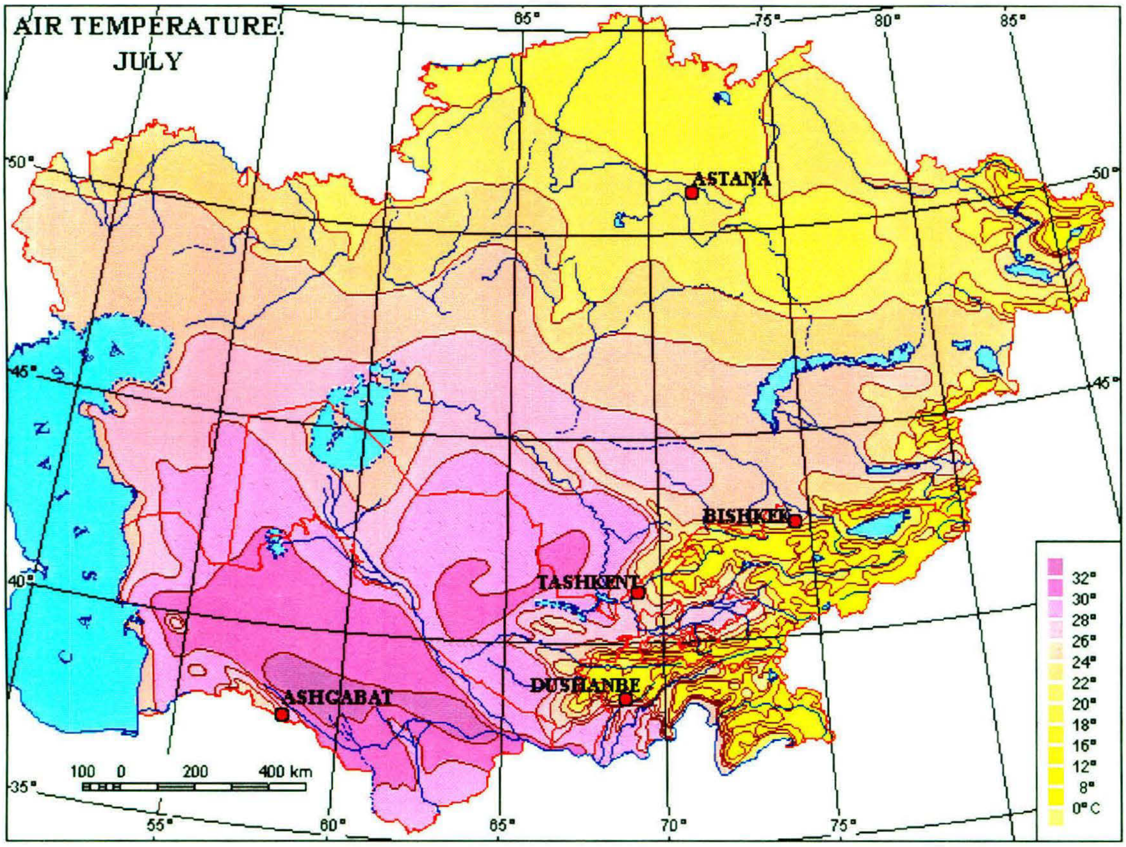
COUNTRY	TYPE OF CLIMATE	ANNUAL PRECIPITATION (mm)	
		Average	Range
Kazakhstan	Continental	344	100-1 600
Kyrgyzstan	Continental	533	150-1 300
Tajikistan	Continental	691	100-2 400
Turkmenistan	Semi arid	191	80-300
Uzbekistan	Continental, Semi arid to arid	287	97-878

Map 4: Air Temperature in January



Source: http://www.icess.ucsb.edu/~aizen/centralasia.html

Map 5: Air Temperature in July



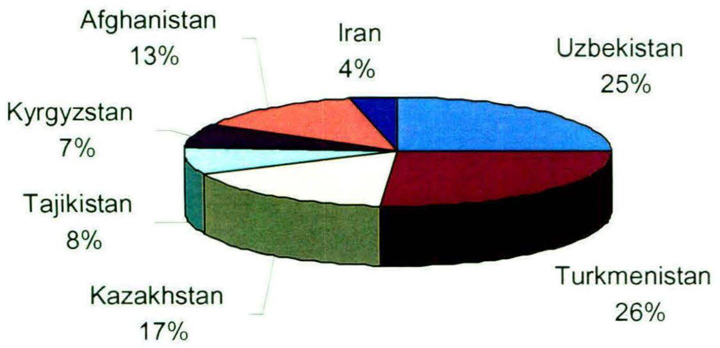
Source: http://www.icess.ucsb.edu/~aizen/centralasia.html

THE ARAL SEA

The Aral Sea, located in a depression in the Turan Plain, is fed by two major rivers: the Amu Darya in the south, and the Syr Darya in the north. These rivers originate in the south-western Pamir and Tien Shan mountain ranges respectively. The combined basin of these two rivers has a total area of about 1.9 million km^2 and spreads over six countries. In Kazakhstan, the flow of the Turgay, Sarysu, Chu and Talas rivers is lost in the desert or is directed to natural depressions. It can be considered that these rivers are not part of the Aral Sea Basin.

Most of the Aral Sea Basin lies within Uzbekistan, Turkmenistan, Kazakhstan, and Afghanistan. The figure below illustrates division of basin more clearly:

Fig 5: Percent of Aral Sea Basin in Each Country



The assessment of natural flow in the basin is hampered by the large amount of water withdrawn from the rivers since the 1950s for irrigation purposes. Reconstructing long-term time series, the average annual renewable surface water resources in the Aral Sea Basin are estimated at 116 km^3, of which 78 km^3 in the Amu Darya Basin and 37 km^3 in the Syr Darya Basin. For a 20-year return period, the values are 47 km^3 for the Amu Darya and 21 km^3 for the Syr Darya.

Before 1960, the level of the Aral Sea was more or less stable. Its surface area was about 66,000 km^2 and its volume about 1,060 km^3. The Aral Sea received water from the following sources: surface water (the total average discharge of the Amu Darya and Syr Darya to the Aral Sea was about 47-50 km^3/year), groundwater inflow (5-6 km^3/year), and precipitation over the Aral Sea (5.5-6.5 km^3/year). The total volume of 57.5-62.5 km^3/year compensated the evaporation from the lake, estimated at about 60 km^3/year. The level of the Aral Sea was then fluctuating about 50-53 m above the average level of the oceans. The difference between the renewable surface water resources of the Aral Sea Basin, estimated at 115.6 km^3/year, and the necessary discharge to the Aral Sea for a stable water balance, estimated at 47-50 km^3/year, could have been available for use in the basin, i.e. about 65.6-68.6 km^3/year. The average mineral content of the seawater was estimated at 10 g/litre in 1960.[50]

THE AVAILABLE WATER RESOURCES

The distribution of water resources in an area is shaped by the region's geography. Although the Central Asia region covers 3.5 per cent of the world's total land area and contains 1.3 per cent of its population, its water resources are only about 0.7 per cent of the world's Total Renewable Water Resource (TRWR). However, the region is reasonably endowed with water (3,320.5 m^3 per persons per year). The figures in the column external resources (Table 3) correspond to either actual inflow affected by upstream consumption or to inflow secured through treaties. Therefore, the actual inflow may be higher than the inflow secured through treaties indicated in the table for certain countries (e.g. Uzbekistan). Another difficulty related to the inflows or outflows secured by treaties relates to the fact that in most cases the treaties fix the exchanges between countries in terms of per centage of basin water resources, which vary from year to year.

[50] Op cit, No. 8

Table 3: Water resources in the Central Asian Region

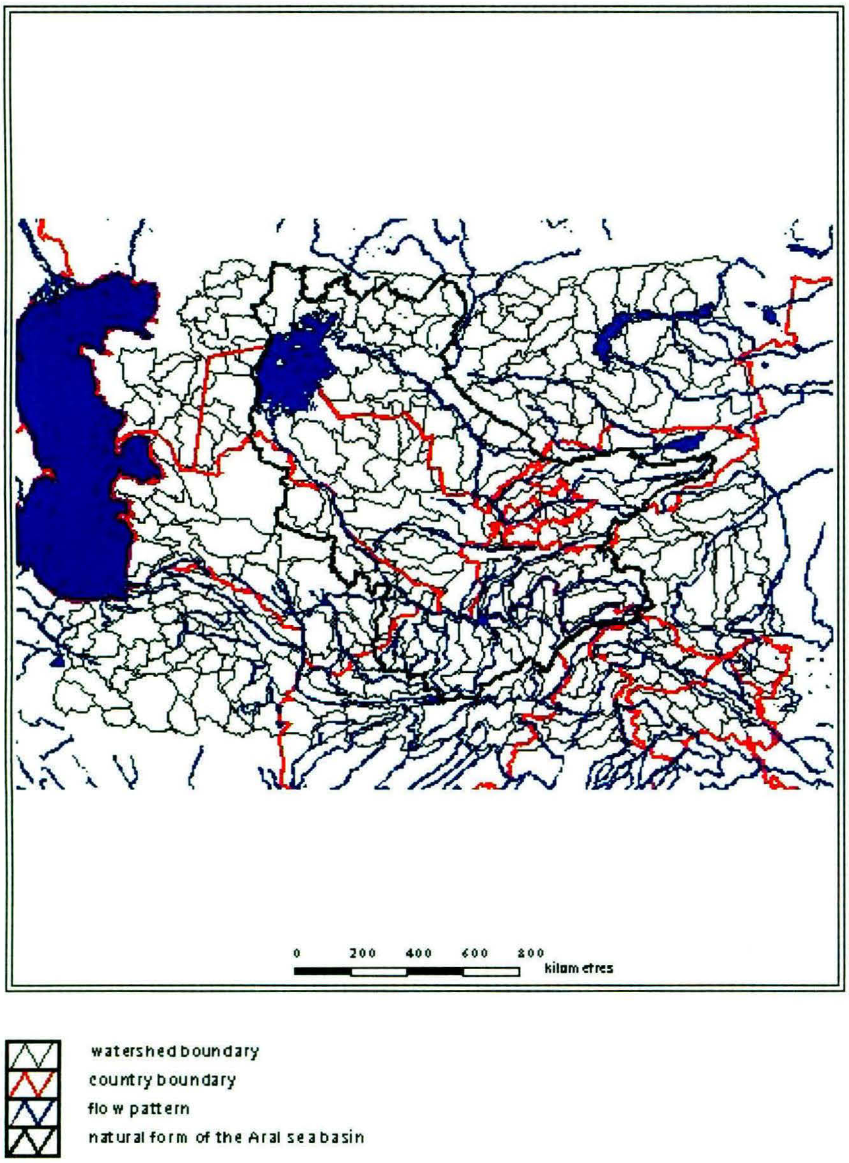
Water resource region	Internal resources : total (km^3/year)	External resources : actual (km^3/year)	Total resources: actual (km^3/year)	% of internal water resources of the region	IRWR/ persons (m^3/year)	TRWR (actual)/ persons (m^3/year)
Aral sea basin	91.8	37.8	129.6	35.17	2235.2	3155.9
Central Asia	260.9	28.3	289.2	100	3320.5	3680.5
Central Asia as % of world	0.6		0.7			

Two main rivers cross the Aral Sea Basin from the south-east to the north-west are the Amu Darya and the Syr Darya. They lead into the Aral Sea, which until 1960 was the world's fourth largest lake in area, but has since declined precipitously. The Amu Darya is the biggest river in the region in terms of water availability, and the Syr Darya is the longest. The Zerafshan River, once a tributary of the Amu Darya, is located between them. The total available surface water resources in the basin are estimated as 116.5 km^3 per year (see Table 4).

The Amu Darya, which rises in Tajikistan, is the region's largest river draining a catchment of 692,300 km^2. From its headwaters in the Hindu Kush it flows 2,540 km across Tajikistan through Uzbekistan (where it forms the border with Afghanistan) and Turkmenistan, and finally back into Uzbekistan before discharging into the Aral Sea. Its mean annual flow varies from 46.9 to 108.4 km^3 per annum with an average of 78.5 km^3.[51] The Syr Darya rises in Kyrgyzstan and crosses Tajikistan, Uzbekistan and Kazakhstan where it also discharges into the Aral Sea. Although similar in length to the Amu Darya (2,200 km) its discharge is considerably smaller ranging from 21.4 to 54.1 km^3 per annum with the average being 37.2 km^3.[52]

[51] WARMAP., "Water Resources Management and Agricultural Production in the Central Asian Republics, 7 Volumes, copies held at the EU-TACIS office Ashgabad, 1995.
[52] Ibid.

Map 6: Aral Sea Basin and Delineated Watersheds



http://www.ce.utexas.edu/prof/maidment/grad/akmansoy/aral/master_sa.pdf

Taken together these two rivers account for nearly 90 per cent of the total water resources of the Aral Sea basin, which on average is 125 km^3 per annum. Tajikistan forms the main flow generation zone in the Aral Sea Basin accounting for more than 55.4 per cent of total discharge. A further 25.3 per cent of all flow falls on the territory of Kyrgyzstan, which means that today, these two republics account for more than 80 per cent of all water resources available for use in Central Asia. The actual amount of water used by these republics, however, is relatively small, totalling less than 15 per cent. In contrast, Uzbekistan and Turkmenistan who have little in the way of indigenous water resources are the main consumers using 71 per cent of available water resources mainly for irrigation.

Table 4: Total natural river flow in the Aral Sea Basin (multiyear flow, km^3/year)

State	River basin		Aral Sea Basin	
	Syr-Darya	Amu-Darya	Km^3	%
Kazakhstan	2.426	--	2.426	2.1
Kyrgyzstan	26.850	1.604	28.454	24.4
Tajikistan	1.005	55.73	56.735	48.6
Turkmenistan	--	1.53	1.530	1.3
Uzbekistan	6.167	5.056	11.223	9.6
Afghanistan	--	14.50	14.500	12.4
Iran	--	0.86	0.860	0.9
China	0.755	--	0.755	0.7
Total Aral Sea Basin	37.203	79.280	116.483	100.0

It is important to emphasize that most of the former tributaries no longer flow into the main rivers (Amu Darya and Syr Darya). Among them are the Chu, Talas, Assa, Bugun, in the Syr Darya basin, and the Ab, Tedjen, Zerafshan, Kashka Darya in the Amu Darya basin.

Renewable resources of groundwater are located in 339 aquifers with total reserves of 43.49 km^3, of which 25.09 km^3 are in the Amu Darya basin and 18.4 km^3 in the Darya basin. The actual (year 2000) water abstraction from aquifers is 11.04 km^3/year, though in 1990 it exceeded 14.0 km^3.

Recycled water is an additional source of water but, due to high mineralization, it is also a source of pollution. About 95 per cent of this water comes from collector drainage and the rest is municipal and industrial wastewater. The recycling rate increased with the development of irrigation and reached its peak between 1975 and 1990. Since then it has stabilized, and in the period 1990–9 it varied between 28.0 and 33.5 km^3/year (13.5–15.5 km^3 in the Syr Darya basin and 16–19 km^3 in the Amu Darya basin). More than 51 per cent of this water is released back to the rivers and 33 per cent into natural depressions. Due to its polluted state, only 16 per cent of this water is used for irrigation.[53]

Hydrological data on the basin is made available to the basic users. Hydrometric monitoring, as well as meteorological data collection at basic weather stations, was organized at the beginning of twentieth century, and reached its most advanced level in the mid-1980s. However, in the 1990s, because of widespread economic destabilization, this system declined; there are now only 384 climatic stations and 273 hydrometric posts, whereas in 1985 there were more than 800 posts. The water quality is registered only at 154 points.

[53] Op cit, No. 8

Table 5: Renewable Surface Water resources of the Aral Sea basin

Country	Renewable surface water resources					
	Amu Darya basin		Syr Darya basin		Aral sea basin	
	km^3/year	% of basin	km^3/year	% of basin	km^3/year	% of basin
Kazakhstan	-	0.0	4.50	12.1	4.5	3.9
Turkmenistan	0.98	1.2	-	0.0	0.98	0.8
Uzbekistan	4.70	6.0	4.84	13	9.54	8.3
Afghanistan	6.18	7.9	-	0.0	6.18	5.3
Tajikistan	62.90	80.2	0.40	1.1	63.30	54.8
Kyrgyzstan	1.93	2.5	27.25	73.4	29.18	25.2
Total	76.69	97.7	36.99	99.6	113.68	98.3
Basin	78.46	100	37.14	100	115.60	100

Formation of the Surface Flow

The region has three distinct zones of surface runoff:

(a) The zone of flow formation (upper watersheds in the mountain areas)

(b) The zone of flow transit and dissipation

(c) The deltaic zones near the Aral Sea.

Generally, there are few anthropogenic influences in the upper zone, but large dams and water reservoirs on the border of this zone alter the downstream run-off regime significantly. Within the zone of flow transit intensive interaction with land use occurs characterized by water withdrawal to the irrigated areas and the return flow to the river carrying salt and agricultural chemicals.

The Amu Darya is the largest river. Its length from the headwaters of the Pyandzh to the Aral Sea is 2540 km, with a catchment of 309,000 km^2. Three large right tributaries (Kafirnigan, Surhan Darya and Sherabad) and one left (Kunduz) flow into the Amu Darya River within the middle reach. It is fed largely by water from melted snow, thus, maximum discharges occur in summer and minimum ones in January-February, which is very favourable for irrigation. While crossing the plain, from Kerky to Nukus, the Amu Darya loses the majority of its flow through evaporation, infiltration and withdrawal for irrigation. In terms of sediment the Amu Darya carries the highest load of all the rivers in Central Asia and one of the highest in the world. The main flow of the Amu Darya River originates on the territory of Tajikistan (about 74 per cent). The river then flows along the border between Afghanistan and Uzbekistan, across Turkmenistan territory and then again returns to Uzbekistan where it discharges into the Aral Sea.

The total mean annual flow of all rivers in the basin is about 116 km^3. At flow probabilities of 5 per cent (wet years) and 95 per cent (dry years), the annual flow ranges from 109.9 to 58.6 km^3 for the Amu Darya, and from 51.1 to 23.6 km^3 for the Syr Darya.

In terms of water availability the Syr Darya is the second most important river in Central Asia but the largest in terms of length. From the Naryn headwaters its length is 3019 km, with a catchment area of 219,000 km^2.

The river is glacier and snow-fed. The regime is characterized by a spring-summer flood, which begins in April, and largest discharge in June. About 75.2 per cent of the Syr Darya run-off originates in the Kyrgyzstan. The Syr Darya then flows across Uzbekistan and Tajikistan and discharges into the Aral Sea in Kazakhstan.

Groundwater

The groundwater resources in the basin originate from either the natural flow from mountainous and water catchment areas, or from infiltration from reservoirs and irrigated land. Three hundred thirty nine aquifers were approved as sources for extraction. The regional reserves are about 31.17 km^3, of which 14.7 km^3 are located in the Amu Darya basin and 16.4 km^3 in Syr Darya basin. To control impact on surface water flows, the extractable reserves are estimated at13.1 km^3/year (Table 6).

Total actual groundwater extraction in the basin was about 10.0 km^3. The groundwater quality in the region varies by salt content from 1 to 3g/l, and in effect almost half of the groundwater is adequate for domestic consumption, and approximately 70 per cent for agricultural use. About 30 per cent of the groundwater has a Tran's boundary nature, and its usage requires inter-state regulation.

Table 6: Groundwater Reserves and Use in the Aral Sea Basin (million m^3/year)

Country	Estimated regional reserves	Confirmed for extraction	Actual extraction for	Users and purposes
Kazakhstan	1846	1224	420	420
Kyrgyzstan	862	670	407	407
Tajikistan	6650	2200	990	990
Turkmenistan	3360	1220	457	457.15
Uzbekistan	18455	7796	7749	7749
Aral Sea Basin	31173	13110	10023	10023

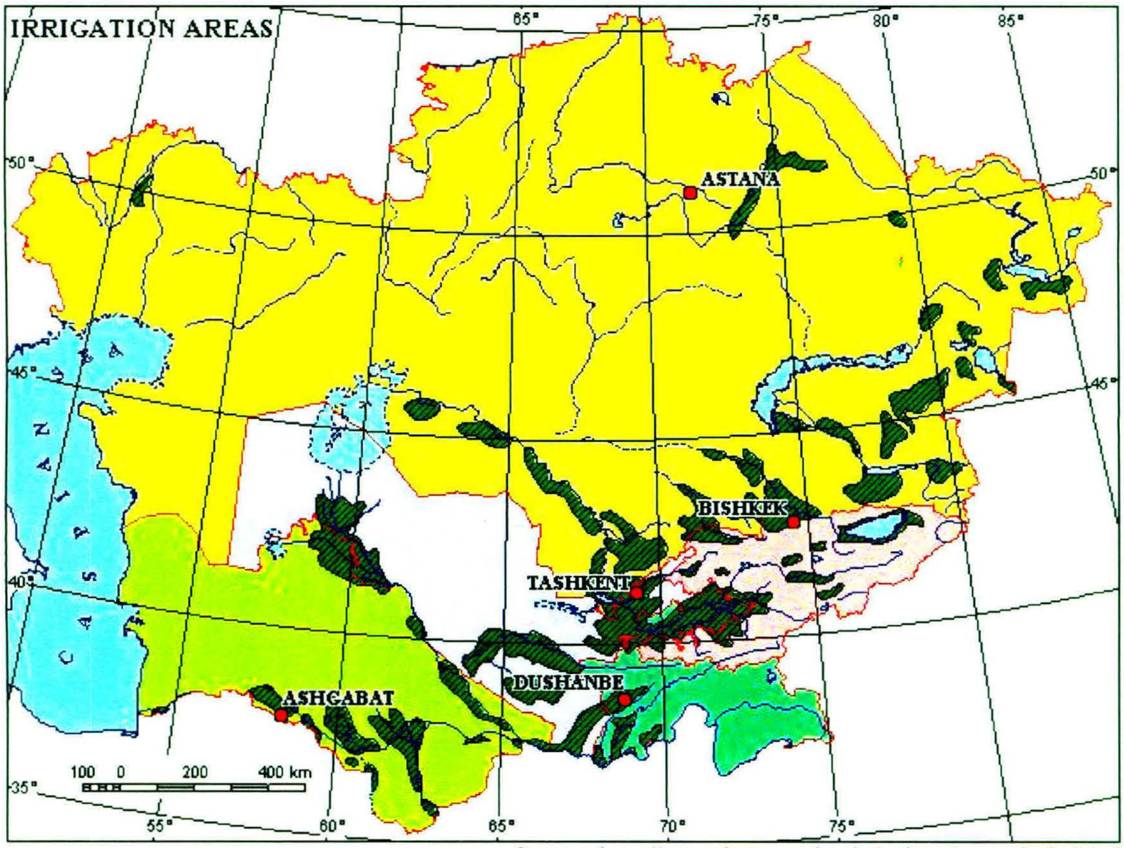
Source: Dukhovny & V I Sokolov., "Integrated Water Resources Management in the Aral Sea Basin", Scientific Information Centre for the Inter-state Commission for Water Coordination in the Aral Sea Basin, 2000.

IRRIGATION AND WATER MANAGEMENT IN CENTRAL ASIA

Despite its aridity Central Asia has a long history of agriculture and settlements boasting some of the oldest known sites of irrigation in the world.[54] Since initiation 7,000-8,000 years ago irrigation spread gradually across the region with the development of a series of extensive oases and by 2000 years ago large tracts of land were irrigated in the region's better-watered locales. As irrigation networks expanded, methods to control and manage them developed and it is likely that sophisticated organisational structures were in place at a very early stage, although relatively little is known about them. It is evident, however, that the administration of scarce water resources was central to the way in which the social and political hierarchy of the settlements operated.

[54] Dukhovny, V. *et al.*, "Drainage and water strategy for the Aral Sea basin", paper presented at the 6th Workshop on Drainage and the Environment, ICID, Ljubljane, Slovenia, 1996.

Map 7: Irrigated Areas of Central Asia



Source: http://www.icess.ucsb.edu/~aizen/centralasia.html

Water was viewed as a 'Gift from God' which could not be owned or controlled by an individual.[55] Distribution of water at a village level was overseen by a water controller, the Mirab, who in turn, was supervised by a village elder who was elected by the people. It was the responsibility of the Mirab to ensure that every one linked into the irrigation system received their fair share of water. Within the central government the most important government official was the chief Mirab who had considerable power being responsible for the highly important and often contentious decisions of water allocation and distribution. Indeed the success of political officials often hinged on their skill at managing local water resources. The first detailed descriptions of traditional water management strategies date to the Islamic period and describe practices that had probably existed for some considerable time. Yakut, writing in the 13th century, for example, provided an excellent insight as to how water was managed at Merv, which at its zenith in the 11th-13th centuries was one of the largest cities of the medieval world.[56]

The Mirab determined the amount of land to be cultivated in the oasis each year based on the level of the river in spring. Moreover, hourly reports on the level of water in the main canal were passed to his office to enable decisions on which off-takes were to be opened and closed. The system was so large that over 12,000 people were employed by the Mirab to maintain and manage the system. Moreover, all water users were obligated to take part in communal maintenance as well as pay for the water they used.

Given the importance of water to Central Asian society it is not surprising that conflicts occurred. Disputes occurred at a number of levels. Most tended to be localised and were mainly concerned with gaining control over irrigated lands rather than water per se. But gaining control over water was of considerable importance not only because of its economic implications, but also because water could be used to control and subjugate people. The ancient Greek historian Herodotus, for example, wrote how the Persian King had dammed one of the rivers and that 'from that time the five nations which were

[55] Sarah L. O'Hara., "Water and Conflict in Central Asia", Environmental Politics in Central Asia, University of Nottingham, UK.
[56] Ibid.

formally to have the use of the stream, losing the accustomed supply of water have been in great distress' and it was only after the people had grovelled to the king and 'paid him a large sum of money over and above the tribute' that the water would be allowed to flow to their lands.[57]

Later, in the early 13th century the Mongols took advantage of the fact that many large cities were reliant on a single water source to aid in their conquest of the region. Time after time they forced cities to capitulate by disrupting water supplies and damaging irrigation structures. At Merv, for example, all they need to do was to destroy the main dam that controlled water in the oasis to bring about its surrender. There were, however, many examples where water-sharing arrangements existed. The cities of Samakhand and Bukhara, located on the Zeravshan River, for instance, had long established agreements on water distribution whereby Samakhand (the upstream river) would close some or all of its off-takes to increase flow to Bukhara at certain times during the main growing season.[58]

Agreements were also made at a more local level about the amount of water given to individual users determined by a variety of factors. In general, however, each settlement had its own set of rules and regulations on water use and allocation based on their own personal circumstances, and as these changed so would water entitlements. In the early 1800s, for example, settlements in southern Turkmenistan adopted a system know as Sanashyk where all men able to defend the community from the enemy and to take part in the construction and maintenance of the irrigation system had a right to water. As the population grew, however, it was necessary to change entitlements so that by the latter part of the 18th century only those men that were married were eligible to take water in their own right.[59]

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[57] Op cit, No. 55
[58] Ibid.
[59] Yazliev C., "Turkmenshaya celshaya obshina", Ashgabad, 1992.

LAND USE

The prosperity of Central Asia, an agrarian region since ancient times, has always been very closely interrelated with land use. The fertile soils were the basis of the prosperity of the rural population. Out of the total land resources of about 154.9 million hectares some 59.4 million hectares are considered to be cultivable, of which only about 10.1 million hectares (see Table 7) were actually used. Half of the actually cultivated lands are located in the oases (which are naturally drained, with fertile soils). The other half of the land requires a complicated and expensive set of reclaimative measures, including not only drainage and levelling, but also improvement of soil structure. The total irrigated area is about 7.9 million hectares in former NIS states and close to 0.5 million hectares in the Afghan part of the Aral Sea Basin.

Table 7: Land use in the Aral Sea Basin

Country	Cultivable Area	Cultivated Area	Actually Irrigated Area
	000 hectares	000 hectares	000 hectares
Kazakhstan	23,872	1659	786
Kyrgyzstan	1,257	595	422
Tajikistan	1,571	770	719
Turkmenistan	7,013	1805	1735
Uzbekistan	25,448	5208	4233
Total	59,162	10,037	7896

Source: Dukhovny & V I Sokolov., "Integrated Water Resources Management in the Aral Sea Basin", Scientific Information Centre for the Inter-state Commission for Water Coordination in the Aral Sea Basin, 2000.

ECOSYSTEM DYNAMICS

The large-scale development of water resources, mostly for irrigation, has changed the hydrological cycle in the region and caused serious environmental problems in the Aral Sea Basin. The most dramatic effect has been the shrinking of the Aral Sea and disruption of its ecosystem.

Other impacts are:

- Losses of biological productivity, especially of fish species in the sea, due to increasing salinity and toxic contamination
- Degradation of river deltas
- Deforestation of tugay forests
- Transfer of dust and salts from the dried-out seabed
- lowering of groundwater levels
- Desertification of the Aral Sea shores.

In other parts of basin we can see: (1) soil degradation as a result of water logging and salinization of irrigated land in the catchment areas of the Aral Sea Basin; (2) crop diseases and insect infestation, due particularly to the cotton mono-culture agricultural development, (3) adverse health effects due to poor water quality and wind-blown chemicals from the exposed seabed, (4) erosion of land in the upper watershed, and (5) local climate changes.

The riparian states have agreed that the Aral Sea coastal region (the deltas of the Amu-Darya and Syr-Darya) will be considered as an independent water user whose requirements will be specified jointly by all the states. These requirements are to be defined on the basis of an approved strategy to improve the environmental situation in the coastal region, taking into account the year-to-year variability of river flows. At the same time, all the riparian states recognize the importance of environmental water requirements concerning both water quality and the preservation of biodiversity and bio-productivity of natural rivers and reservoirs.

SOME HISTORICAL BACKGROUND TO CURRENT CHALLENGES

Generations of peoples living for centuries and even millennia in the harsh arid and semi-arid climate across vast territories of the Turan lowlands, as well as in adjoining surrounding mountain and sub-mountain ranges, associated their existence, development, and welfare with water. The expression “water means life” is more than just a slogan for the peoples of Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan, as well as Afghanistan, Sinthziang, and Iran. For them it is the reality that determines whether people can survive and prosper or are doomed to hunger and misery, or even death.

It is no accident that the development of irrigation in the region has been closely related to the progress of civilization, as this had been the case with ancient cultures that emerged at the same time (sixth to seventh millennia B.C.) in Egypt, China, Mesopotamia, India, and Central America. Central Asia was the motherland of many scientific discoveries connected with the need for water flow forecast, management, and use (algebra – Alkhorezmi; astronomy – Abu Ali ibn Sino, Ulugbek, and others). The relationships among Central Asian nations are rooted in deep traditions and a mutual, interrelated historical background that unites Central Asian nations into one family, heavily dependent on water use.

Agriculture, for the most part irrigated, cattle breeding, fishery, household and industrial water use have always been crucial for the livelihood of the 70–80 per cent of population who live in rural areas. From time immemorial, a way of life that was determined by the water factor stimulated the elaboration and strict observance of key principles of oriental and later Islamic water law (sharia) norms which reflected legal regulations of Zaroostrism (the code of law known as videvdat) as well as centuries-old traditions and behaviour patterns.

This legal and customary framework included such provisions as communal ownership of irrigated land, and particularly of water; compensation for damage caused by water use or by actions affecting water; prohibitions on pollution of natural water sources; water law linked to irrigated lands; and common participation in all activities connected with maintenance of water systems, as well as flood control and managing other water related disasters.

Before the nineteenth century this region saw the rise and fall of independent states such as Ariana, Baktria, Merv, Sogdiana, Bokhara, Khorezm and others, which never had problems relating to the allocation of water.

The colonization of Turkistan by Tsarist Russia left local water law unchanged, especially as it applied to communal participation in works related to the operation, maintenance, renovation, and rehabilitation of irrigation nets. The institution of "aryk aksakals" and "mirabs" – water managers elected by communities – was put on a sound basis.

Seventy years of Soviet power changed these principles by creating a strict and rigidly controlled system of centralized water management that worked in a top-down manner. Some of the systems that were managed according to hydro-graphic boundaries included:

- Water management of the Zarafshan river valley
- Administration of the Amu-Darya downstream canals
- Administration of the Kirov main canal

This system made it possible to deliver and allocate water successfully by means of a huge water infrastructure with vast operational costs, covered at the expense of the federal government at inter-farm and up to on-farm levels, and which also included drainage. But this water system suffered from mainly two shortcomings. First, the opinions of water users and consumers were not taken into consideration; as a result, the transition of agriculture and the Central Asian economy in general to market principles showed many water users to be insolvent and not self-sufficient. Second, environment considerations were largely ignored in favour of the needs of water users; hence ecological and sanitary requirements, along with the environmental needs of deltas, Priaralye, and the Aral Sea itself, were ignored and the scale of the problems was understated.

Some aspects of Soviet heritage, however, have had positive influences on current and future development of the region:

- In the period from 1960 to 1980 the so-called "integrated development of the Hunger Steppe deserted lands" was initiated, followed by other schemes, including the Karshy, Djizak, Syrkhan-Sherabad, Kyzylkum, and Yavan-obik projects, among others. These projects increased water demands enormously. Drainage systems were developed concurrently with irrigation; large numbers of settlements, productive enterprises, roads, and communication systems were constructed. Long before the worldwide campaign for integrated water resources management was launched, these works had given regional water specialists and economists the opportunity to understand the advantages of this advanced technology, and to gain experience in a type of operation and management that is nowadays spreading across the world.
- High levels of water education, science, and skills combined to provide a secure basis on which to develop significant potential among specialists engaged in water management.
- The teamwork of water specialists of the former Soviet Union republics – working under a single leadership in one system that followed similar standards, rules, methods, and approaches – created the right conditions for sustainable work by future generations: their aspiration has been to keep the coordinated approach that took shape in Soviet times.
- For six to eight years before the USSR's collapse, the Soviet government paid more attention to plans for improving the situation in the Aral Sea Basin, and this led to approval of the "State Program on Priaralye" in 1986, the creation of Basin Water Organizations (BWOs), and allocation of huge investments into various projects, particularly into water supply and social improvements.

These provisions had an immense inertial effect, ensuring smooth operation and transition of water management from the former political formation to a different one – from imperfect socialism to other forms of primary accumulation of capital with various degrees of transition accomplished in different countries.

REGIONAL WATER SITUATION

As mentioned earlier, Central Asia obtains their water mainly from surface diversions. Although a few supplement surface diversions with some groundwater development, and from streams flowing out of the Kopet Dag Mountains forming the border with Iran to the south and from the Kara Kum Canal system, after the water has travelled hundreds of miles from its diversion point along the middle Amu Darya near the Turkmenistan-Afghanistan border are also the sources of water supply.

Most groundwater that is used in Central Asia is pumped from fresh water lenses that form as water seeps down through the sandy banks of the many unlined canal systems are found throughout the region. Most of the cities and towns found along the lower reaches of the Amu Darya on its way to the Aral Sea obtain their water in this way.

The territory in the basin of the Aral Sea itself involves the area of 400,743 thousand hectares of Central Asia, and in the basin of the Aral Sea it is 154,934 thousand hectares. The basin of the Aral Sea includes the area of two southern oblasts (region) of Kazakhstan (Kyzyl Orda and Southern Kazakhstan), three oblasts of the Kyrgyz Republic, the whole territory of Tajikistan and Uzbekistan and four velayats (regions) of Turkmenistan. The area of agricultural land in the basin of the Aral Sea is 591,615 thousand hectares, 491,247 thousand hectares of hay mowing and pastures, ploughing land is 100,368 thousand hectares including 78,956 thousand hectares of irrigated land. Forest area and other lands used in agriculture are 9,577 thousand hectares.

Water resources for Central Asia are strategic, vital natural resources, having interstate significance. Natural existence and national economy functions, especially agriculture, completely dependent on water supply of these territories. Characteristic features of the climate: sharply continental, high evaporation (up to 1,700 mm per year), small and very non-uniform seasonal precipitation (on average 150-200 mm), high summer temperature (up to 40 degrees C) determines the conditions when and where agriculture is not possible without irrigation. As a result salt is intensively accumulated in the soil, so water is used both for watering plants and washing lands.

Table 8: Indicators of water-land resource use dynamics in the basin of the Aral Sea

Years	Population (millions)	Irrigated land area (000 hectares)	Water intake (km^3 per year)	GDP (million $)
1960	14.1	4510	64.7	16.1
1970	20	5150	83.5	32.4
1980	26.8	6920	120.7	48.1
1990	33.6	7600	118.1	74
1999	39.9	7900	107.6	54.5

Source: Dukhovny & V I Sokolov., "Integrated Water Resources Management in the Aral Sea Basin", Scientific Information Centre for the Inter-state Commission for Water Coordination in the Aral Sea Basin, 2000.

Irrigated agriculture in the Aral Sea basin started many centuries ago. During the last 50 years it has intensified rapidly. The area brought under irrigation was increased from about 5 million hectares in 1950 to some 8 million hectares in 1999. Parallel to this development, the population in the Republics of Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan has also increased from about 11 million in 1950 to some 55 million in 1995. To irrigate the 8 million hectares, water was taken from the two main rivers, the Amu Darya and Syr Darya. Both discharge into the Aral Sea, an inland sea with no outlet.

Table 9: Average long-term resources of G W in the basin, (km^3 per year)

State	Basin of the river		Total in the basin of the Aral Sea
	Syr Darya	**Amu Darya**	
Kazakhstan	2.426	0	2.426
Kyrgyz Republic	27.605	1.604	29.209
Tajikistan	1.005	59.898	60.903
Turkmenistan	0	1.549	1.549
Uzbekistan	6.167	4.736	10.903
Total	37.203	79.28	116.483

Source: Dukhovny & V I Sokolov., "Integrated Water Resources Management in the Aral Sea Basin", Scientific Information Centre for the Inter-state Commission for Water Coordination in the Aral Sea Basin, 2000.

The surface water supply in the Amu Darya river basin is about 80 km^3. In the Syr Darya river basin this is about 40 km^3. The Syr Darya no longer reaches the Aral Sea. All of its discharge is now being used for irrigation and other purposes. Only about 10 per cent of the Amu Darya surface water supply reaches the Aral Sea. As virtually all of the water is now being used, no major expansion of the irrigated area is possible.

Table 10: Use of water resources (million m^3)

River basins	Surface flow from			Ground water	Repeated use of CDW	Available water resource
	The main riverbed	Tributary	Total			
Syr Darya	10.49	9.42	19.91	1.865	2.325	24.1
Amu Darya	22.08	10.41	32.49	0.785	1.835	35.1

Source: Dukhovny & V I Sokolov., "Integrated Water Resources Management in the Aral Sea Basin", Scientific Information Centre for the Inter-state Commission for Water Coordination in the Aral Sea Basin, 2000.

Deficit of water resources is observed in the whole region except Kyrgyzstan and Tajikistan stipulated by arid climate and water losses especially in irrigation systems of agricultural territories. The reason behind deficit of water is unsatisfactory technical condition of irrigation and water distribution systems, equipment wear out, poor methods of watering, lack of water save technologies and a system of water supply without discharge.

Underground water is spread everywhere but the distribution is uneven. Kyrgyzstan and Tajikistan have enough reserves of underground water of high quality, Turkmenistan has low quality of underground water and Turkmenistan occupies the intermediate position between Kazakhstan and Uzbekistan.

ECONOMY OF THE REGION

Use of water resources in Central Asia, mainly for irrigation, began more than 6,000 years ago. In pre-revolution times Turkestan, and in the Soviet era Central Asia, were developed mainly as sources of raw materials and as agricultural appendices of the federal state. This was reflected in low levels of processing industry in the region, and a concentration of industries to support agriculture, with a strong dependence on the metropolis. Intensive use of water resources started in the twentieth century, especially after 1960, driven by fast population growth and intensive development of industry and, in particular, irrigation. Such one-sided development, with no processing of agricultural production into final products taking place within the region, caused a rapid increase in water delivery from rivers. Total water diversion in the Aral Sea Basin in 1960 was 60.6 billion m^3, and by 1990 it had risen to 116.271 million m^3 (that is, by 1.8 times).

Over the same period the population in the territory had grown by 2.7 times, the irrigation area had increased by 1.7 times, agricultural production by three times, and gross national product by almost six times (see Table 11). Understanding of the negative ecological consequences in the 1980s, together with the general economic depression that followed the disintegration of the Soviet Union in 1991, led to a fall in total use of water in the region. After 1994, as a result of the coordinated water saving policy accepted by Interstate Coordination Water Commission (ICWC) of the states of Central Asia, the target policy was to decrease the common water intake.

Table 11: The basic parameters of water-land resources development in the Aral Sea Basin (on the territory of CIS)

Indicator	Unit	1960	1970	1980	1990	2000
Population	Million	14.6	20.3	26.8	33.6	41.8
Irrigated area	1 000 ha	4 510	5 150	6 920	7 600	7 896
Irrigated area per capita	Ha	0.31	0.27	0.26	0.23	0.19
Total water diversion	km^3/year	60.61	94.56	120.69	116.27	105.0
Incl. irrigation	km^3/year	56.15	86.84	106.79	106.4	94.66
Specific diversion per ha	M^3 /ha	12 450	16 860	15 430	14 000	11 850
Specific diversion per capita	M^3 /capita	4 270	4 730	4 500	3 460	2 530
GNP	Bln. US$	16.1	32.4	48.1	74.0	55.3
Including agricultural production	Bln. US$	5.8	8.9	18.3	22.0	15.0

In 2000 general water intake was 11.2 km^3 less as compared to 1990 and stood at 105 km^3. During the last three decades of the Soviet era (1960–90), irrigated agriculture and the sectors of economy related to water management (preparation and initial processing of agricultural products, hydropower, construction and some others), contributed more than 50 per cent to the GNP. The collapse of the former USSR and the unified currency (Russian Rouble) zone caused shocks to the economies of Central Asian countries as well as of all other NIS states. The severe disruption of production, trade and financial relations were the main reasons for the drop in general output, and agricultural output especially.

Uzbekistan experienced the smallest output decline among the Central Asian countries, as well as the shortest period of contraction: five years, compared to six years in the Kyrgyz Republic, seven years in Tajikistan and Turkmenistan, and eight years in Kazakhstan in the ten years of market reforms that followed (1991–2001). During this period, Uzbekistan's GDP fell back to the level of the early 1980s, while in Tajikistan and Turkmenistan it slumped to that of the beginning of 1960s or even earlier, in Kazakhstan to the late 1960s, and in Kyrgyz Republic to levels seen at the beginning of the 1970s. Corresponding to the general decline, the overall contribution of agricultural production to the GDP now ranges between 10 per cent (Kazakhstan) and 46 per cent (Kyrgyzstan) (see Table 12).

It should be emphasized that in all countries agricultural output fell less than GDP and much less than industrial output. As a whole, in Central Asia, changes in agricultural production related to an increased share of food crop output (again, except in Kazakhstan). Further reforms, with more price incentives to the farmers and a better legal framework for land and water use, are important to promote labour productivity and better living standards for farmers and the rural population in general, who make up the majority of the population (63 per cent) in all countries within the Aral Sea Basin. Despite the relative decline of agriculture's share, it still plays a significant role in the

Aral Sea Basin, especially in the Kyrgyz Republic, Tajikistan, and Uzbekistan. It is also important in Turkmenistan (cotton and wheat) and Kazakhstan (grain). Independence after the Soviet Union's collapse (August– September 1991) was accompanied by a serious social threat to the majority of the population in the region. Thus, Central Asia, despite a high level of human development and social services, now has poverty levels comparable to some African countries and is on the same level as in Pakistan and India.

Table 12: Changes in the economic situation during the transition period

Country	GNP per capita (US$)		By Sectors of Economy, %					
			Industry and construction		Agriculture, forestry and fishery		Service sector	
	1990	2000	1990	2000	1990	2000	1990	2000
Kazakhstan	2 310	1 493	36.1	34.2	28.0	21.3	35.9	44.5
Kyrgyzstan	1 240	365	35.9	30.4	34.6	34.1	29.5	35.5
Tajikistan	910	321	33.7	27.9	27.1	23.8	39.2	48.3
Turkmenistan	1 490	820	33.6	35.1	28.6	17.9	37.8	47.0
Uzbekistan	1 700	985	32.5	19.9	31.3	34.0	36.2	46.1

Since the rural population was heavily dependent on irrigation, the water deficit had a severe impact on the social situation in some parts of the region. The last two years of water scarcity (2000–2001) caused social tensions and the migration of parts of the rural population from the lowlands of the Amu Darya.

STATE OF WATER RESOURCES

Central Asia has been consuming water at an unsustainable rate for decades, but since independence in 1991 water use has soared further. Although the region has sufficient water to meet its needs, crumbling infrastructure and poor management mean the countries are now consuming 1.5 times more than what they should. Demographic pressures and expanding agriculture have meant that more water is being used every year.

Since the 19th Century, the focus of agricultural policy in Central Asia has been on increasing the output of cotton and rice so that Russia, and later the Soviet Union, could reduce reliance on imports. Investment in farming and irrigation was aimed at expanding the cotton area, disregarding the environmental or social impact. Likewise, rice was expanded even though Central Asia is on the edge of the crop's ecological limit. The cash starved new nations; stripped of their subsidies from Moscow after independence, have increased production further. In Turkmenistan and Uzbekistan, cotton is at the heart of a system of political and social control that operates in a manner almost unchanged from Soviet days. As cotton is vital for foreign exchange and political patronage, the sorts of reforms needed to reduce water use – particularly privatisation of farming and realistic pricing of water to encourage conservation – have never got off the ground.

With the expansion of agriculture, the two major rivers in Central Asia have become a focus for growing competition among the five nations. The Syr Darya, which rises in the mountains of Kyrgyzstan and flows through Tajikistan, Uzbekistan and Kazakhstan to the Aral Sea, has been a particular focus of tensions. The Amu Darya, which flows from Tajikistan through Uzbekistan and Turkmenistan also to the Aral Sea, is likely to become a locus of disputes as governments compete for its water, and Afghanistan starts to claim its share.

The agricultural sectors of downstream countries Uzbekistan and Turkmenistan are almost completely dependent on water from the Syr Darya and the Amu Darya. Southern Kazakhstan also depends on the Syr Darya. A majority of the population in all the Central Asian countries except Kazakhstan live in the countryside.[60] In Uzbekistan agriculture accounts for 28 per cent of GDP,[61] and irrigation is used in the production of 95 per cent of crops.[62] More significantly, in Uzbekistan, Turkmenistan and Tajikistan, one major export crop, cotton, accounts for a large proportion of hard currency earnings. Thus, for

[60] Tsentralnaia Azia: novye tendentsii v ekonomike, RAN (Moskva, 1998). [Central Asia: New Economic Tendencies, Russian Academy of Sciences], p. 21.
[61] Human Development Report, UNDP, Tashkent, 2000, p.15.
[62] Philip Micklin., "Managing Water in Central Asia", p. 55.

both Uzbekistan and Turkmenistan, water supply is at the heart of their perceived national security interests.

Between 1995 and 2000 irrigated land increased by 7 per cent throughout Central Asia,[63] and all the countries have plans to expand this area further. Turkmenistan intends to add 450,000 hectares in the coming years,[64] Kyrgyzstan to increase land under irrigation by 230,000 hectares by 2005,[65] and Tajikistan to add 500,000 hectares of irrigated land by 2005. If projects like this are implemented, pressure on limited water resources will increase massively. The ground water table is also likely to rise as a result of irrigation, making land unfit for agriculture elsewhere. Rapid population growth has raised demand for land, and the problem has been compounded by the collapse in industry that has forced many people back to farming. Although Uzbekistan and other downstream countries have emphasised food self-sufficiency in agricultural programs, the pressure to grow cotton remains high. It is a key foreign currency earner but is also a particularly thirsty crop that requires heavy irrigation.[66] Turkmenistan plans to triple cotton production by 2010. Other countries are also expected to expand cultivation, meaning an enormous rise in water use and wastage.[67]

Kazakhstan

Deficit of fresh water prevent sustainable development of Kazakhstan and is the most important ecological problem. Total water resources in terms of average volume water make up 100.5 kmi annually, and available to use: 46 kmi. Comparison of water resources both in the republic and in separate regions showed that deficit of water resources in average long-term water volume reach 6.6 kmi and takes place in all the

[63] Iskandar, Abdullayev., "Water Management and Prospects of Water Division in Central Asia", The Times of Central Asia, 3 November 2000. http://www.times.kg

[64] Diushen Mamatkanov, Director, Institute of Water Problems and Hydropower of the Kyrgyz Academy of Sciences, Bishkek, 20 February 2002.

[65] Kadyrbek Beshekeev, First Deputy General Director, Department of Water Management, Ministry of Agriculture and Water Management. Bishkek, 21 February 2002.

[66] Karl Wegerich., "Not a Simple Path: A Sustainable Future for Central Asia", Occasional Paper No.28, Water Issues Study Group, School of Oriental and African Studies (London. February 2001), p. 2.

[67] National Development Plan 2010, quoted in Human Development Report, UNDP (Tashkent. 2000), p. 9.

basins. In dry years level of water supply is 60 per cent and in some regions (Central Kazakhstan) only 5-10 per cent and then great deficit is observed in irrigated agriculture. The most dramatic situation is in the basins of the Tran Boundary Rivers the Syr Darya (1.2-3.4 kmi), Ural (up to 1.7 kmi), Ili, Shu, Talas.[68]

Table 13: Dynamics of water resources use in Kazakhstan (million metres^3)

Years	Sources	Farming drinking	Agricultural water supply	Industrial technical	Fishery	Irrigation	Others	Total
1990	Total	214	147	276	111	10136	437	11320
	From surface (Tran boundary)	20	20	0	61	8500	0	8601
	From surface (local)	19	11	154	50	1636	0	1870
	From ground	175	116	122	0	0	14	427
	Re use of CDW	0	0	0	0	90	423	513
1995	Total	140	130	180	150	10100	60	11300
	From surface (Tran boundary)	0	20	0	100	7960	185	8265
	From surface (local)	0	10	60	50	2040	100	2260
	From ground	140	100	120	0	0	15	375
	Re use of CDW	0	0	0	0	100	300	400

The reasons for water resource deficit are: natural conditions (90 per cent of river discharge in spring period), formation of half discharge in neighbouring states, over-exploitation, extreme water consumption on irrigation without return and losses of water.

[68] Sokolov V.I., "Definition of boundaries of water collection basins of Trans bordering, local and mixed types of surface water resources in the basin of the Aral Sea and quantitative assessment", Collection of scientific works of SRC ICWC, p.35-53 Tashkent, Issue 2, 2000.

Besides, surface water resources on the territory of the republic are distributed unequally and water volume changes according to years and within a year.

The important problem is water decrease and deterioration of quality in lake systems that are natural regulators of water balance. In Northern Kazakhstan the territories of lakes have reduced by 12 per cent.

As a result of underground water over-exploitation by large water intake and mine water withdrawal, regional level of ground water declines. Territories of large depression funnels in some cases reach more than 1,000 kmi, and level lowering in the centre of depression is 100 m (South-Kazakhstan, Karaganda, Kostanai, Kokshetau, Eastern-Kazakhstan oblasts).

The great part of ground water volume is discharged without use. It is the result of self-pouring artesian wells in the Pre-Aral area, mine and quarry water runoff and water losses while transporting. Ground water withdrawal is 0.54 million mi per day or 10.2 per cent of total water supply.

Providing the population with high-quality drinking water is becoming increasingly difficult republic every year. In general about 25 per cent of population or more than 4 million people don't get water-pipe water, and 16.5 per cent use water from open reservoirs and 3.2 per cent use water taken from other places, quality of which is not guaranteed. Specific weight of water discrepancy to sanitary standard according to decentralized sources of drinking water supply is 12.4 per cent.[69]

[69] UNESCO., "Water related vision for the Aral Sea basin for the year 2025", 2000, p. 237.

Kyrgyzstan

Kyrgyzstan has considerable reserves of water resources. Annual average volume water of total water resources makes up 2,458 kmi including 50 kmi of surface river runoff, 13 kmi of potential reserves of ground water, 1,745 kmi of lake water, 650 kmi of glaciers.

Table 14: Dynamics of water resources (million mi)

Years	Sources	Farming drinking	Agricultural water supply	Industrial technical	Fishery	Irrigation	Others	Total
1990	Total	90	70	68	13	4910	0	5155
	From surface (Tran boundary)	0	0	0	0	370	0	370
	From surface (local)	53	0	14	13	4182	0	4262
	From ground	41	70	54	0	0	290	455
	Re use of CDW	0	0	0	0	68	0	68
1995	Total	91	85	56	5	4730	0	4966
	From surface (Tran boundary)	0	0	0	0	350	0	350
	From surface (local)	48	20	6	5	4120	0	4199
	From ground	43	65	50	0	176	0	334
	Re use of CDW	0	0	0	0	84	0	84

The republic uses only 12-17 per cent of the resources and greater part (about 23 per cent) of the water is lost while using. About 75 per cent of the river runoff goes out from the republic - to Uzbekistan, Kazakhstan, Sintzyan-Uigur region of China. More than 10 large reservoirs for irrigation were built to regulate runoff of trans-national rivers the Chui, Talas, Naryn, Ak-Bura, Kara Darya. Damage from agricultural yield shortage on the territories occupied by reservoirs is estimated of 11.3 million US dollars. Exploitation of these interstate reservoirs is made at the expense of the Kyrgyz budget. Because of hard economic situation in the republic, financing of these reservoirs maintenance is not sufficient, and threat of ecological accident appears as a result of possible reservoir breakthrough.[70]

Trend of climate warming leads to stable intensive reduction of glacier surfaces. According to forecast, by 2025 the territories of glaciers will be reduced by 30-40 per cent resulting in water volume diminish by 25-35 per cent.[71] Stable tendency of non-industrial water loss growth was marked last years and 90 per cent of these losses were in irrigation.

Economic development strategy and indicative plan till 2005 foresees increase of water consumption (from 8.0 to 11.1 billion mi), so volume of sewage will be increased respectively (approximately by 40 per cent), but refining constructions power will be increased only by 12 per cent. In such a situation according to the forecast assessment, economic damage to natural environment will be increased 1.5 times.[72]

Tajikistan

Tajikistan is rich in water resources. It should be noted that about 50 per cent of annual discharge of the Aral Sea is formed on its territory. Most of the rivers are steep and together with broad river net and large water volume provide the first place on hydro resource supply in Central Asia and generate over 95 per cent of electric energy.

River net may be divided into 4 main systems: the Syr Darya in the north, Zeravshan in the centre, Amu Darya in the south, and the basin of Western Pamir lakes without runoff. Total length of 947 rivers with lengths more than 10 km is more than 28,500 km. Most Tajik lakes (90 per cent) have squares less than 1 kmi. Total number of lakes exceeds

[70] Op cit, No. 67
[71] Op cit, No. 68
[72] Ibid, No. 70

1300, most of them (80 per cent) are concentrated at altitude of 3000-5000 m. 30 lakes having total square 2.4 kmi are situated in plains and at the foot of the mountains. The biggest natural lake is Karakul with salty water, square is about 380 kmi. The deepest fresh water lake is Sarezskoye, its volume is 18.9 kmi, depth exceeds 450 m. 9 water reservoirs for irrigation, fishery and electric power production are created in Tajikistan. Their volumes are from 0.03 to 10.5 kmi. The largest reservoir is Kaira Kum, square is 520 kmi, average volume is 3.5 kmi.[73]

Main reserves of water are accumulated in glaciers and eternal snow that are situated in mountainous part of the republic. Icing square of the Pamir is 8,471 kmi (6 per cent of the whole territory of the republic). Up to the present time the largest continental glacier (Fedchenko glacier) is kept in Tajikistan. Its square is 900 kmi, total length is 70 km. Ice reserves in glaciers of the republic is 7.5 times more than annual runoff of all rivers. Total number of glaciers with length over 1.5 km is 1,085 km, including 7 big glaciers which stretch over 20 km.[74]

Mineral water is widely spread in Tajikistan. Great quantity of the water has medium degree of mineralization, but in the south, mineral water has extremely high indices of mineralization. This is so-called solution; the mineralization of the water is over 200 g/litre. Ground water of the republic makes up 7 per cent of the total reserves.

[73] Op cit, No. 67
[74] Ibid

Table 15: Dynamics of water resources (million mi)

Years	Sources	Farming, drinking	Agricultural water supply	Industrial technical	Fishery	Irrigation	Others	Total
1990	Total	485	696	594	459	10239	374	12847
	from surface (Tran boundary)	0	36	201	200	8270	340	9047
	from surface (local)	165	200	143	259	392	0	1159
	From ground	320	460	400	0	1080	34	2294
	Re use of CDW	0	0	0	0	347	0	347
1995	Total	475	585	449	140	10400	40	12089
	from surface (Tran boundary)	0	102	150	30	9198	20	9500
	from surface (local)	175	333	199	110	232	0	1049
	From ground	300	150	100	0	600	20	1170
	Re use of CDW	0	0	0	0	370	0	370

Turkmenistan

Total average long-range volume of water resources from permanent water resources makes up 30.4 kmi per year, and guaranteed water resources providing reliable water supply for the branches of national economy are equal to 26.1 kmi per year. While total consumption of water reach 27.2 kmi per year, for irrigation 25 kmi, or 92 per cent, is used annually. Such level of water consumption is available only in the years of abundant water, as water resources are practically exhausted.[75]

Water resources are distinguished by extremely unequal location on the territory of the country: 95 per cent of them are given by the Amu Darya and the rest 5 per cent are given by small and big rivers, streams, wells, revealed reserves of ground water of the south and south-west of Turkmenistan. Discharge of southern rivers (Murgab, Tedjen, Sumbara and small rivers of the foothills of the Kopet Dag) has already entirely taken for irrigation, so the Kara Kum River was put into operation to meet water needs of western and south-western regions of the country. Inter-basin run-off transference has changed greatly the territorial re-distribution of water resources in Turkmenistan due to the Kara Kum River. It eliminated discrepancy between location of large fertile lands in one part of the country, and water resources in another part.

Thus, about 80 per cent of ploughing land is in the south and south-east of the country, while water resources 95 per cent of which consist of the Amu Darya run-off are located in the east of Turkmenistan. The main source of water supply is the Amu Darya which, in its turn, serves as source for the Garatum canal stretching over 1,100 km on the territory of the southern Turkmenistan. The canal provides water to all big cities including the capital of the republic - Ashgabad.

River network is ill developed. The biggest river of Turkmenistan is the Amu Darya. Murgab, Tedjen and Sumbar are smaller. The rivers of the country play an important part in irrigation. However, they are not equally distributed on the territory and it stipulates scarcity of water resources for irrigated agriculture especially in the south and west of the country. There are 15 lakes and 16 artificial reservoirs in Turkmenistan. The largest natural reservoir is the Caspian Sea washing the western boarders of the country.

Acceleration of work in putting into operation new water intake of ground water is foreseen to provide qualitative drinking water. Potential reserves of ground water are

[75] Op cit, No. 67

estimated as 3.3 kmi per year, exploitation reserves - 1.12 kmi, but in fact over 60 per cent is used.[76] Over 90 per cent of the consumed water is used for irrigation, 8 per cent is for industrial needs, and 1.5 per cent is for domestic needs.

Table 16: Dynamics of water resources (million mi)

Years	Sources	Farming drinking	Agricultural water supply	Industrial technical	Fishery	Irrigation	Others	Total
1990	Total	187	42	11	35	22963	0	23338
	From surface (Tran boundary)	0	15	75	35	22776	0	29901
	From surface (local)	0	0	0	0	0	0	0
	From ground	187	27	36	0	140	0	390
	Re use of CDW	0	0	0	0	47	0	47
1995	Total	330	70	325	35	22470	0	23230
	From surface (Tran boundary)	145	40	289	35	22274	0	22783
	From surface (local)	0	0	0	0	0	0	0
	From ground	185	30	36	0	151	0	402
	Re use of CDW	0	0	0	0	45	0	45

Deficit of water resources is increased by great consumption by irrigation, considerable losses, surface and ground water pollution by sewage, collecting and drainage waste, pesticides and oil products.

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[76] Op, cit, No. 67

Uzbekistan

Uzbekistan has the largest territory of irrigated agriculture in the world. Favourable climatic conditions, land and labour resources stipulated development of cotton, rice, vegetable growing, gardening, vine growing, which are characteristic for dry subtropical zone and require essential water consumption. Scarce water resources are limiting factors for the republic.

The main sources of water resources are: the Amu Darya with average long-term withdrawal 2,500 mi/s, the Syr Darya (1,200 mi/s), the Zeravshan (164 mi/s), the Kashka Darya (50 mi/s), the Surhan Darya (52 mi/s), the Ahangaran (23 mi/s), the Chirchik (22 mi/s).[77]

The Amu Darya has the largest drainage basin, covering 227 thousand kmi in the mountain region, with a water volume of 78 kmi per year (average long-term index, stretch - 1,440 km). The Syr Darya with a water collecting area of 150 thousand kmi, 2 times less in water volume (36 kmi per year) but it exceeds in stretch (2,140 km).[78]

Discharges of the both rivers are formed in contiguous countries - Kyrgyzstan and Tajikistan. Annual discharge, formed within the republic, makes up 9 per cent of the total water resources being used for needs of national economy. Forecast supply of ground water is 19 kmi per year. Over 50 per cent is used as a reliable source of drinking water for population; industrial needs, pasture watering and land irrigation.

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[77] Op cit, No. 68

[78] Antonov V.N. "Water resources of Uzbekistan, their use in modern conditions and in the future", Collection of scientific articles: Water resources, the Aral problem and environment, Tashkent University, 2000.

Table 17: Dynamics of water resources (million mi)

Years	Sources	Farming drinking	Agricultural water supply	Industrial technical	Fishery	Irrigation	Others	Total
1990	Total	2354	723	1298	1080	58156	0	63611
	From surface (trans boundary)	0	0	555	427	42939	0	43921
	From surface (local)	0	0	0	653	7097	0	7750
	From ground	2354	723	743	0	3220	0	7040
	Re use of CDW	0	0	0	0	4900	0	4900
1995	Total	2030	1090	1200	880	49020	0	54220
	From surface (trans boundary)	0	0	450	350	35440	0	36240
	From surface (local)	0	0	0	530	7280	0	7810
	From ground	2030	1090	750	0	2500	0	6370
	Re use of CDW	0	0	0	0	3800	0	3800

Table 18: Dynamics of use of land and water resources

Years	Dynamics of irrigated lands (thousand hectares)	Use of water resources (kmi)	Specific water consumption (mi per person)	Specific water consumption per capita (mi per person)
1960	2.571		11200	3690
1970	2.674	47.29	15690	3950
1980	3.407	65.76	18120	4120
1990	4.155	63.6	1520	3510
1996	4.223	60.6	11720	2400

Trans boundary Rivers of the region are affected by pollution of cattle-breeding, domestic, municipal, industrial sewage and collecting, drainage waters. Polluted sewage from more than 5 thousand water using objects go into surface waterways and make up approximately 20 per cent of total water withdrawal in open reservoirs.

CONCLUSION

The available water resources at the disposal of the people of Central Asia are adequate. The figures given in the chapter shows that both surface and ground water resources are enough to support the Central Asian population. The problem lies in the way the available water resources were not used in a sustainable manner, and extracting the water to the last limit for rampant irrigation, just to promote a water intensive monoculture of cotton, which eventually disturbed the water cycle and the whole ecosystem.

THE ARAL SEA BASIN: POLICY DECISIONS, ECONOMIC DEVELOPMENT AND ENVIRONMENTAL DEGRADATION

INTRODUCTION

The Aral Sea Basin is one of the oldest regions of irrigated agriculture in the world where the favourable climatic conditions and natural fertility of the soil favoured the development of agriculture. The basin has undergone many changes in the last two to three decades. Aral Sea, the world's fourth largest lake before 1960s has been progressively drying up. With the end of the Soviet era, the international community has become aware of this problem and focussed on what is considered one of the major anthropogenic environmental degradations in the world.

These problems, mostly started in the early 1960s, head the list of global environmental problems in terms of their size and the difficulty of solving them as they are unparalleled in the world. Many people, including leaders of the states, however, are more concerned about "business" than about sustainable development that meets the needs not only of the present generations but also of future ones. The transition to a market-oriented economy will take many years, but the victims of the environmental disruption are dying day by day and people continue to suffer.

Until the 1950s, irrigation water demands were relatively low with the major water supplying rivers, i.e. Amu Darya and Syr Darya regularly discharging into the terminal lake, the Aral Sea. The assessment of natural flow in the basin was hampered by the large amounts of water withdrawn from the rivers since the 1950s.

The Aral Sea Basin crisis now represents one of the world's major environmental problem areas. The dimensions of this environmental crisis are as follows:

First, the Aral Sea, one of the largest inland water reservoirs of the planet is in danger of disappearing. It has dramatically decreased in size and water volume since the early 1960s, as a result of inadequate water supply from its two arteries, in its turn caused by the increasing diversion of water to agricultural irrigation in combination with high rates of evaporation in the semi arid climate of most of Central Asia.[79]

Second, salinization of the Aral Sea and the mid and downstream reaches of the rivers is an additional problem. Most of the irrigated lands in the basin are affected by processes of primary and secondary salinization. Furthermore, winds blow enormous quantities of salt and contaminated dust from the exposed bed of the Aral Sea in to the basin causing soil to deteriorate further.[80]

Third, water and soil pollution are having a dramatic and negative impact on the human ecology of the region in particular in the downstream areas and deltas of the main rivers, such as in the region of Karakalpakstan of western Uzbekistan and Kzyl Orda in south west Kazakhstan; here, the health of the native population have deteriorated at an alarming rate.[81]

This chapter seeks to identify what kind of political and economic structure caused the environmental disruptions, and how these disruptions affected the environment and health in the region.

THE ARAL SEA BASIN

The ecological situation in the Aral Sea basin is most complex in Central Asia. The situation is aggravated by the fact that environmental degradation is accompanied by deterioration in economic and social conditions. Many of the problems of the Aral basin, however, are typical of many other arid and semi-arid regions of the world.

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[79] Micklin, Philip P., "The Aral Sea Crisis: Introduction to the Special Issue", *Post Soviet* Geography, Vol. 33 (5), 1992; pp. 269-82.
[80] Precoda, Norman., "Requiem for the Aral Sea", *Ambio*, Vol. 20 (3-4), 1991; pp. 109-14,
[81] Carley, Patricia., "The price of the plan: Perceptions of Cotton and Health in Uzbekistan and Turkmenistan", *Central Asian Survey*, Vol. 8 (4), 1989; pp. 1-38,

The Aral Sea basin includes the basins of the Syr Darya and Amu Darya rivers, which flow into the sea, and also the Tedzhen and Murgabi Rivers, the Kara Kum canal, and shallow rivers flowing from Kopet Dag and western Tien-Shan, as well as the areas with no runoff among these rivers and around the Aral Sea. The area of the whole basin amounts to about 2 million km^2.

Landscapes of arid and semi-arid regions are known to be very sensitive to global climatic changes and to tectonic events and other physical processes. The Aral region is one of the centres of origin of civilizations and farming, and primitive forms of artificial irrigation have existed here for more than 2,000 years.

Natural variations and human activity led to significant ecological changes in the Aral basin during historical time. The sea itself often rose and fell considerably. During the Quaternary period, variations in the level of the Aral Sea evidently reached 36 metres. But in spite of such important earlier variations in the level of the sea, fluctuations during the first half of the twentieth century did not exceed one metre, and the ecological situation was quite stable up to the end of the 1950s. Substantial variations have taken place during the last 30 years, however, and this chapter focuses on this time-period.

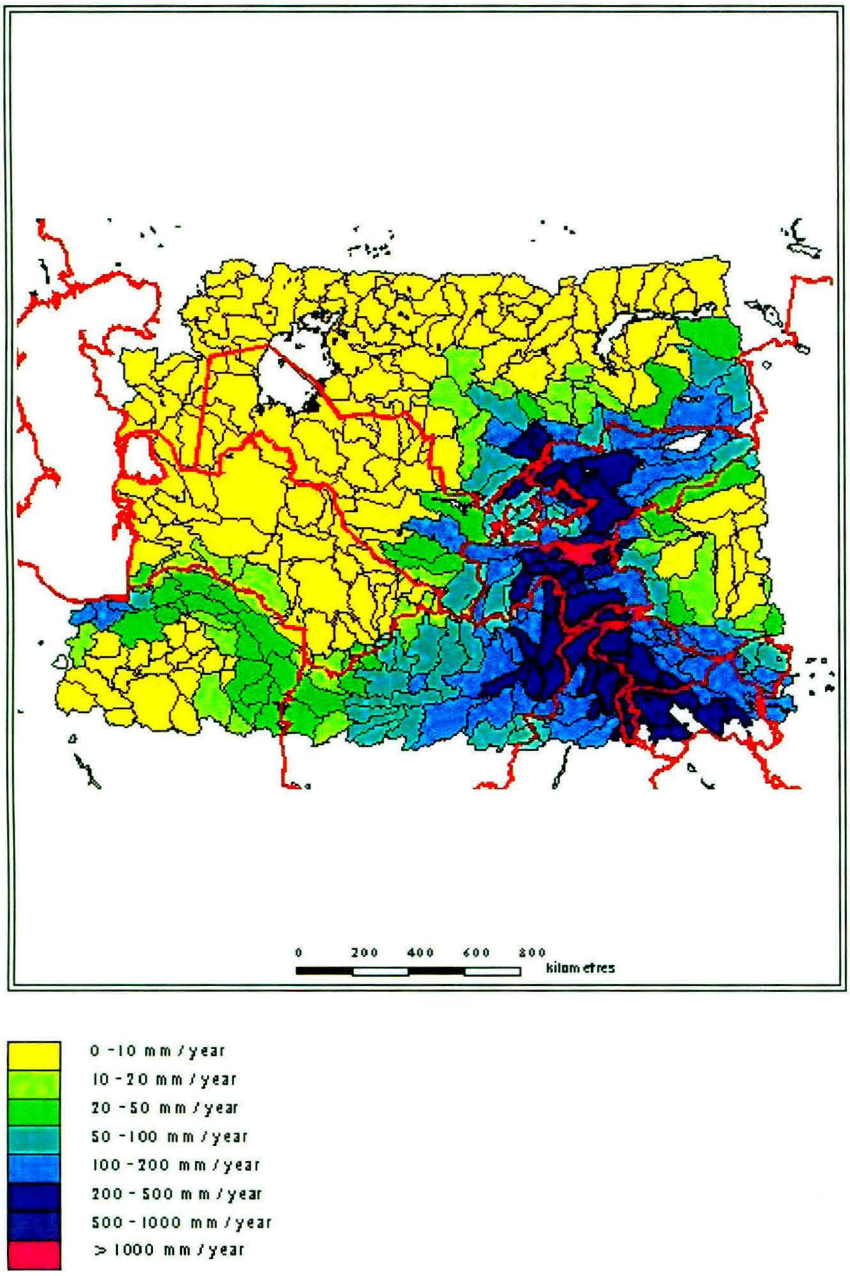
ENVIRONMENTAL CHANGES

Important changes have occurred in practically all of the components of the environment in the Aral basin over the past 30 years. The following discussion treats the most important of these changes.

River runoff

The mean perennial runoff from source areas in the mountainous regions of Central Asia and Kazakhstan during 1911-1960 amounted to 116 km^3 per year. Of this, 60 km^3 was diverted for irrigation and lost in the deserts, whereas 6 km^3 reached the Aral Sea, thus keeping its level relatively stable.

Map 8: Mean Run off per watershed



http://www.ce.utexas.edu/prof/maidment/grad/akmansoy/aral/master_sa.pdf

Beginning with the 1960s, the runoff to the Aral, in spite of some peaks in wet years, began to fall and decreased to 4 km^3/year approximately. In some years the runoff to the Aral did not exceed 1-2 km^3. Available data suggest that only 10-15 per cent of the runoff decline was associated with climatic variations and that the main factor was the development of irrigation.

Hydrographic Changes

By our calculations, the total length of the drainage network in the arid zone of the former USSR stretches to 150,000-200,000 km, which is 10-15 times longer than the main rivers in this region. As a result of the discharge of drainage waters to the desert, vast new water basins without outflow have been formed, of which the Sarykamysh and Arnasai lakes are the largest.

The Sarykamysh Lake in the south eastern portion of the Usturt plateaux was formed as a result of discharging the drainage runoff from the left-bank irrigated massifs to the lower reaches of the Amu Darya River. These discharges started early in the 1960s. Currently, the lake covers an area of about 3,000 km^2 and has a volume of 26 km^3. Mineralization of the lake waters is continuously increasing: from 3-4 grams/litre (g/l) in the early 1960s to 12-13 g/l in 1987.[82] Annual increases in mineralization amount to 0.5-0.6 g/l.

The Arnasai lake (and, more precisely, the Arnasai lacustrine system) was formed on the site of the Aidar solonchak northward of the Nuratau ridge as a result of the diversion of discharge waters from irrigated massifs on the left bank of the middle reaches of the Syr Darya river. The area of this water basin has varied from 2,330 km^2 to 1,750 km^2, the water volume from 20 km^3 to 12.5 km^3, and mineralization in different parts of the lacustrine system from 4 g/l to 13 g/l.[83] As a result of a discharge of drainage waters into

[82] Shaporenko, S. I., "Vliyaniy gidrologicheskogo rezhima na ryboropoduktivnost' osolonyayushikhsya vodoyemov (na primere Aralskogo morya, ozer Arsanajskoi sistemy i Sarykamysh) [The effect of hydrological regime on fish productivity of salinized water bodies (using the example of the Aral Sea, lakes of the Arnasai system and Sarykamysh)]". *Avtoref na soisk uch. step.k.g.n.* 1987, (Moscow)
[83] Nikitin, A. M., and Yu N. Lesnik., "Otsenka dinamiki ravninnykh ozer Srednei Azii po materialam kosmofotosnimkov [Utilizing remote sensing in an analysis of the dynamics of lowland lakes in Central Asia]", In *Gidrometeorologiya ozer i vo dokhranilishch*, (eds.), 1982.

Kara Kum, swamps emerged that cover an area of over 200,000 (and perhaps 250,000) ha.[84]

Reduction in runoff has led to changes in the number and area of lakes in the Amu Darya and Syr Darya deltas. The area of natural lakes has continuously shrunk while the number of lakes during the first period of water-basin drying increased owing to the fragmentation of large lakes (Table 19).

Table 19: Changes in the number and area of natural lakes in the Amu Darya and Syr Darya deltas, 1936-1980

Region	Period	No. of lakes	Area of lakes (km^2)
Amu Darya delta	1936	346	2,330
	1950-1960	490	840
	1972		630
	1980		76.3
Syr Darya delta	1936	558	1,490
	1950-1960	2,080	833
	1967		789
	1976		400

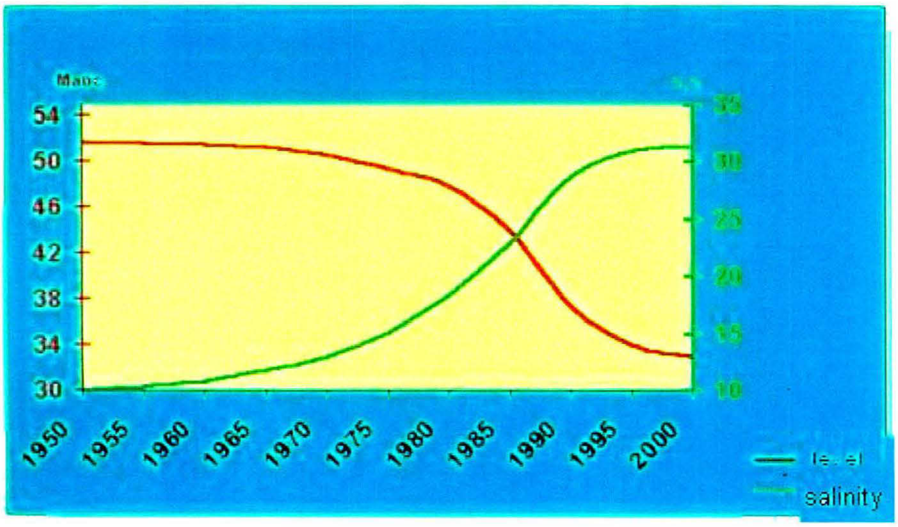
Sources: Nikitin (1977) and Chebanov (1989)

Variations in the Aral Sea

Prior to the 1960s, the Aral Sea area amounted to 68,300 km^2, comprising a water surface area of 66,100 km^2 and islands of 2,200 km^2. The volume of the sea water amounted to 1,066 km^3.[85] The maximum sea depth was 69 m, but depths of less than 30 m were common over much of the sea. The sea level, meanwhile, fluctuated in the 52-53 m range.

[84] Rozanov, Boris G., "Zemelnye resursy aridnogo poyasa SSSR, ikh ratsional'-noye ispozovaniye i okhrana [Lands of the arid belt of the USSR, their rational use, and protection]". *Problemy osvoyeniya paistyn 5*, 1986, pp. 22-28.
[85] Nikolayeva, R. V., "*Osnovnoye morfologicheskoye kharakteristiki aral'-skogo morya. Problemy Aral'skogo morya* [The main morphological characteristics of the Aral Sea: The problems of the Aral Sea]", 1969, Moscow: Nauka, pp. 25-38.

Fig 6: Level and Salinity Speed of Aral Sea



Mineralization of the Aral waters during the past 100 years of instrumental observations has varied within a range of 10-12 g/l, and constant salinity has been sustained owing to two main processes, sedimentation of poorly soluble components owing to water evaporation and salt accumulation in narrow bays often connected only periodically with the Aral Sea (especially in the south-eastern part of the sea) and in depressions without outflow near the seashore.

Table 20: Water Budgets of the Aral Sea prior to the 1960s (km³/year)

Inflow		Outflow	
River runoff	56	Evaporation	58-65
Groundwater runoff	0.7-0.3	Filtration to the banks and diversion to the lagoons	1-2
Atmospheric precipitation	5-8		

River runoff and evaporation were key factors in the water budget (Table 20). Two rivers - the Amu Darya and Syr Darya - maintain river runoff. Some 20 fish species (including commercial ones), 266 species of invertebrates, and 94 species of superior and inferior plants existed in the sea.

With decreased river inflow beginning about the early 1960s, the water budget of the sea changed. The sea area decreased to 34,800 km² and the volume to 304 km³ by 1990. Over the same period, the level of the sea fell to 37.8 m, a drop of more than 15 m from the preceding period. A significant part (about 33,000 km²) of the sea floor dried up, the configuration of the shoreline changed, and water mineralization increased to 33 g/l. As water mineralization increased, the spawning sites of fish disappeared and a deterioration in the forage reserve led to a decline in fish, with only five species remaining. Nearly all limno-plankton and numerous halo-plankton became extinct.[86]

Climate Change

Owing to the recession of the sea, the climate in the Aral area has changed.[87] Summer and winter air temperatures at stations near the shore increased by 1.5 to 2.5°C, whereas diurnal temperatures increased by 0.5 to 3.3°C. At coastal stations the mean annual relative air humidity decreased by 23 per cent, reaching 9 per cent in spring and summer.

Recurrence of drought days increased by 300 per cent. Spring comes 7 days later and autumn 12-13 days later (the date on which the mean diurnal temperature passes the zero value) than previously. The last spring frosts shifted to later dates and the first autumn ones occurred some 10-12 days earlier. The annual cycle of precipitation also changed. In 1959 the maximum precipitation fell during February-March and the minimum during September, whereas in 1970-1979 the maximum was observed in April and the minimum in July. A three-fold increase in reflected solar radiation in the Aral area due to a sevenfold rise in the albedo of the area previously occupied by the Aral Sea has contributed to an increase in the continentality of the climate.[88]

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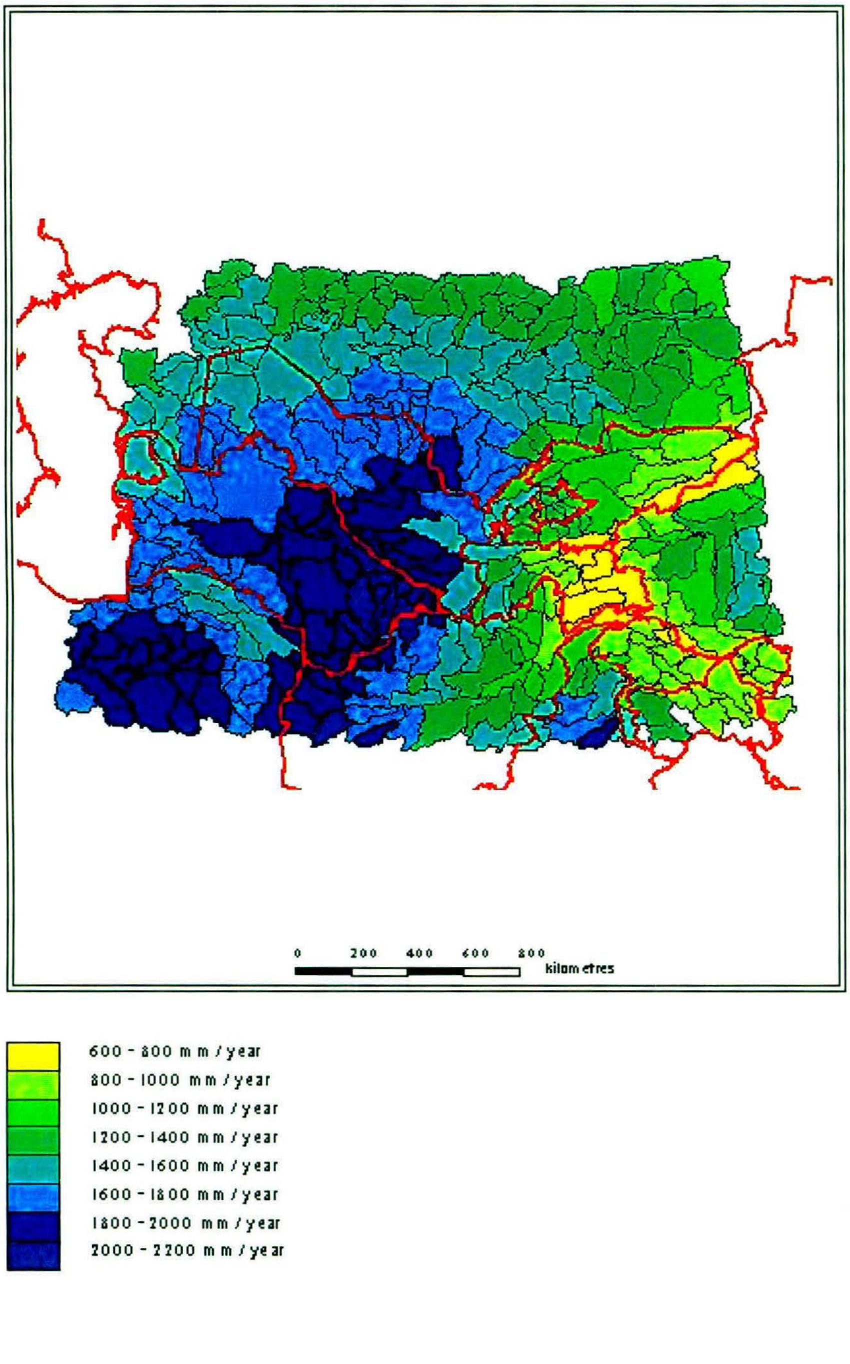
[86] Aladin, N. V., and Vladislav V. Khlebovich, (eds.), "*Gidrobiologicheskye problemy Aralskogo morya* [Hydrobiological problems of the Aral Sea]", Trudy Zoologicheskogo Instituta, v. 199. Leningrad, 1989, Zoologicheskii institut Akademiia Nauk SSSR.

[87] Molosnova, T. I., O. I. Subbotina, and S. G. Chanysheva., "*Klimaticheskiye posledstviya khozyaistvennoi deyatelnosti v zone aral'skogo morya* [Climatic consequences of economic activity in the zone of the Aral Sea]", 1987, Leningrad: Gidrometeoizdat.

[88] Kondratyev, K. Ya, A. A. Grigoryev, and V. F. Zhvalev., "Vliyaniye moschnykh pylevykh bur' na radiatsionnuyu energetiku atmosphery i pustyn' [The influence of powerful dust storms on the radiation power capacity of the atmosphere and deserts]", *Prirodnye resursy pustyn' i ikh osvoyeniye Ashkhyabad,* 1986, pp. 27-31.

Map 9: Potential Evapo-transpiration per watershed



http://www.ce.utexas.edu/prof/maidment/grad/akmansoy/aral/master_sa.pdf

Groundwater

In the arid conditions of the Aral Sea basin, the depth of ground-water is a key issue. Above a certain critical level, intensive water evaporation begins, water transformation intensifies, and soil salinization occurs.

Groundwater levels rose in many regions as a result of irrigation development. Thus, in the Tashauz area, land with a groundwater level above 2 m amounted to 20 per cent in 1959-1964, whereas in 1978-1982 it comprised 31.5 per cent. Over the whole of Turkmenistan, 87 per cent of the irrigated land has groundwater levels that have risen by at least 2.5 m; over 26 per cent of the area, levels are now higher by 1.5 m. In Uzbekistan, groundwater levels are above the critical value on 1.6 million ha.

In the delta regions of the central Asian rivers, variable changes in the depth of the groundwater level have occurred. Thus, according to Khakimov, drops in the water level in the rivers and sea have produced a lowering of groundwater levels of up to 50 cm per year on non-irrigated territories subjected to desertification.[89] In some regions, beginning with the early 1960s, groundwater levels have fallen by 10-15 m. On irrigated land, by contrast, the levels have risen by up to 50 cm per year. In many regions, in fact, the level has risen by several metres. In the Kara kalpak Republic, for example, the area of land with a critical groundwater situation increased from 72 per cent to 90 per cent during 1975-1989.

Salinization and Desertification

Rises in the groundwater level and water evaporation cause intensive soil salinization. Thus, in the newly irrigated areas of the Murghab oasis of Turkmenistan, the area of slightly salinized and un-salinized land decreased from 50 per cent to 25 per cent over eight years, and that of salinized land grew from 50 per cent to 75 per cent. In the Tedzhen oasis, 48,000 out of 70,000 ha of irrigated land are salinized. And in

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[89] Khakimov, Fikki I., "*Pochvenno-meliorativnye usloviya opustynivahyuschikhshya del't: Tendentsii izmenii prostrant'svennaya differentsiatsia* [Soil reclamation conditions of delta desertification: Tendencies of transformation and spatial differentiation]", 1989, Pushchino: Nauchoyi Tsentr biologicheskikh isseldovaniy AN SSSR.

Turkmenistan, 86.7 per cent of all irrigated land is salinized. In Uzbekistan, moderately and severely salinized soils constitute 60 per cent of all irrigated land. In some regions, the areas of salinized land are even larger; in Central Fergana, for example, they amount to 83.9 per cent, including 7.1 per cent of severely salinized and 31.3 per cent of moderately salinized irrigated lands.[90]

In the Karakalpak Republic, 377,000 ha out of the 485,000 ha of irrigated land are salinized. A similar situation prevails in other republics of the Aral Sea Basin: 35 per cent of irrigated land is salinized in Tajikistan, 40 per cent in Kyrgyzstan, and 60-70 per cent in Kazakhstan.[91]

As a result of decreases in river runoff and falling river water levels, and also owing to the fall in the Aral Sea level, the Syr Darya and Amu Darya river-beds have begun to function as drains, leading to even more rapid desertification of the coastal band.

According to Khakimov, alluvial-meadow and swamp-meadow soils are shifting into meadow-takyr and meadow-deserts. Meanwhile, the humus content of soils has decreased, and sodium and magnesium levels in the soil have risen.[92] Popov has predicted that, if the desertification trend continues, the area of hydro-morphic geo-systems in the southern Aral area will decrease by 2,000 ha, but the areas of the xeromorphic geo-systems will more than double.[93] The area of halomorphic geo-systems, which increased almost six fold from 1965 to 1985, will likely remain at the current level.

Biota

In the cultivation and inundation of land a number of animal species have perished. The total number of animals is decreasing, but the population density is increasing on the unploughed sites on the banks of canals. Thus, Persianova, Yadgarov, and Saraeva found

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[90] Popov, V. A., "*Opustyunivaniye v Uzbekistane i bor'ba s nim* [Desertification in Uzbekistan and its prevention]", 1988, Tashkent: FAN.
[91] Op cit, No. 88
[92] Op cit, No. 90
[93] Op cit, No. 89

that on irrigated land in the Dzhizak area 9 out of 27 species had disappeared and 4 more were endangered. Of 21 reptile species, 2 will probably perish completely.[94]

As a result of the Syr Darya delta drainage, flocks of waterfowl have been displaced during migration from the lower reaches of the Syr Darya River to the lakes of Turgai. Accumulations of white and Dalmatian pelicans have been observed beyond the northern boundary of the former Aral Sea.[95] Accumulations of migrating waterfowl have also appeared both in water reservoirs and in filtrational lakes formed in Central Asia.[96] Meanwhile, newly formed wastewater basins have created conditions for large hibernation sites for waterfowl in a number of regions. Overall, the diversity of mammals inhabiting the Aral area has decreased from 70 to 30 species and the number of bird species from 319 to 168. The disappearance of nesting sites for many bird species has led to the disappearance of 38 of the 173 bird species nesting in the lower reaches of the Syr Darya.

Tugai communities in the deltas are also endangered. These tugais were extremely rich florally since they had 576 superior plants, including 29 endemic to Central Asia. Currently, owing to desertification, 54 species are on the verge of extinction. Reed thickets, meanwhile, have perished in the Kara kalpak Republic in the Amu Darya delta, and the relict tugai forests are also becoming extinct.[97]

The Impact on Eco-systems and Human Livelihood

The most obvious impact of the crisis is the dramatic shrinking of the Aral Sea. At current rate of decline, it seems likely that even the larger *bolshoye* sea, after splitting

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[94] Persianova, L. A., T. Yadgarov, and Kh. M. Saraeva., "Zakonomernosti izmeneniya sostava miekopirayushschikh i presmykayushchikhsya v svyazi s obvodneniem zasushlivykh territorii [Patterns in the changes of fauna due to watering of arid territories]", In *Prirodnye resursy pustyn' i ikh osvoenie,* 1986, pp. 336-340, Ashgabad: Ilim.

[95] Novikova, N. M., and V. S. Zaletayev., "Vodnoye khozyeistvo kak faktor transformatsii prirodnykh ekosistem [Water economics as a factor in the transformation of natural ecosystems]", In *Biogeograficheskiye aspekty opustynivaniya* [Bio-geographical aspects of desertification], (eds.) Oleg A. Kibal'chich, Anatolii G. Voronov, and D. D. Vishyvkin, 1985, pp. 4-12. Moscow: Moskoviskii filial Geograficheskoe obshchestvo SSSR.

[96] Zaletayev, Vladimir S., "Zhizn'v pustyne (Life in the desert)", 1976, Moscow: Mysl.

[97] Ibid, No. 94

into a western and an eastern section, will further disintegrate into several smaller lakes and ponds, and will virtually disappear between 2015 and 2020. The eastern section of the large sea is shallow; the western part is deeper, but practically dead in terms of microbiology. Current thinking within the Uzbek government is to concentrate all water inflow from the Amu Darya into the western part, which can be revived and saved. This could be done by cutting off the eastern part from the river delta.

The smaller sea *Maloye S*ea grew slightly during the early 1990s.[98]This was probably because of an increased inflow in the Syr Darya river basin; in Kyrgyzstan, more water is let through in the winter for hydro-power production at Togtogul, causing water flows north-westwards into southern Kazakhstan. In the summer, less water comes through. The danger that insufficient water from the Syr Darya would feed into the *Maloye* Sea was recognized sometime ago, the Karatyup peninsula has almost joined the eastern shores of Aral, close to the Syr Darya delta: if the small sea were to be cut off from the Syr Darya delta, it would quickly perish.[99]

A second problem has arisen because the same fields have been irrigated for decades without any form of crop rotation or proper drainage, leading to water logging; this has stimulated processes of primary and secondary salinization, resulting in severe soil degradation in many parts of the Aral Sea Basin, especially in the mid and downstream areas of the Amu and Syr Darya. By 1985, after peak period of water diversion from the two rivers for irrigation purposes, 68 and 89 per cent (respectively) of all irrigated land in the Dzhizak and Syr Darya *oblasts* of the Syr Darya basin was salinized.

For Amu Darya basin, the levels were 60 per cent in Karakalpakstan (the delta area), 75 per cent in Khorezm and 90 per cent in Navoi in western Uzbekistan.[100] Consequently,

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[98] Glantz, Michael H & et. al., "Tragedy in the Aral Sea Basin", *Global Environment Change*, June 1993.
[99] Spoor, Max, "The Aral Sea Basin Crisis: Transition and Environment in Former Soviet Central Asia", *Development and Change*, Vol. 29, 2000, pp 409-435.
[100] Smith, David R., "Change and Variability in Climate and Ecosystem Decline in the Aral Sea Basin Deltas", *Post-Soviet Geography*, Vol. 35 (3), 1994, pp. 142-165.

more water is used for periodic leaching, in order to wash away the salt. Hence water is both the cause and cure of salinization.[101]

It was found that in the Amu Darya basin alone, a total of 84 million tonnes of salt is discharged annually into the river, transported with the water, which is used to irrigate the fields, the largest share being found midstream. The ratio between salinity of drainage disposal and water supplied varied between 3.3 to 7.1 g/l, which shows the severity of the problem. If this trend continues, and no salt management measures is taken, large areas of cultivated land in Central Asia will be unfit for agricultural production within a few decades. Crop yields can be substantially lower when salt content in the upper layers of the soil is too high, with the result that salinized soils are often abandoned in favour of newly reclaimed land.

Thirdly, excessive fertilizer and pesticide use, mostly in relation to cotton and rice cultivation, has contaminated surface and ground water, sometimes highly subsidized prices within the context of a planned farm economy provided no incentive for efficient use, often leading to excessive use and wastage of fertilizers and pesticides. Chemical pollution of drinking water has caused a high incidence of cancerous diseases, and substantial dioxin residues have been found in mother's milk, particularly in Karakalpakstan.[102]

It is not only agriculture, but also industries, which are causing water contamination. Concentrated in or around the main cities in the Aral Sea Basin, industrial complexes and mines discharge their poisonous residues into rivers, and into air. Problems of respiratory diseases are widespread, as maximum permissible levels of air contaminants are substantially violated.[103]

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[101] World Bank, "Developing a Regional Water Management Strategy: Issues and Work plan", ASBP Technical Paper Series (April), Washington & Tashkent, 1996.
[102] Op cit, No. 80
[103] UNEP, "The Aral Sea: Diagnostic Study for the Development of an Action Plan for Conservation of the Aral Sea basin", New York, 1993.

A fourth problem is that wind erosion and the increased occurrence of salt and sand storms in the Aral Sea basin, in particular in Karakalpakstan and Kzyl Orda, are causing soil degradation, lower crop yields, and affecting the health of the population living in these areas, as polluted particles are spread on the winds over large distances.[104] Air pollution caused by contaminated dust has a major impact on child mortality, which is around three times higher in Karakalpakstan than the average for the former Soviet Union.

Finally, the drying up, further salinization and contamination of the Aral Sea and the deltas of the Amu and Syr Darya are dramatically affecting their ecosystems. The fishery sector of the Aral Sea has been practically annihilated by the further salinization of the already salty water, destruction of deltas, and contamination by excessive use of fertilizers and pesticides used for cotton and rice. Traditional vegetation like the *tugay* forests in Amu and Syr Darya deltas are rapidly disappearing.[105]

WATER RESOURCE DEVELOPMENT IN 20TH CENTURY

From the first days of its existence the Soviet State concerned itself with land improvement problems. Thus, in 1918, Lenin signed a decree on the development of irrigation in Turkistan under which improvements were to be carried out on land already under irrigation and water brought to another 500,000 desyatins (about 600,000 hectares) in the Golodnaya Steppe, to ensure an adequate supply of cotton for textile industry in Russia. Two years later, in 1920, the Council of People's Commissars issued an Edict, signed by Lenin "On Allocations to the All-Russia National Economic Council for Irrigation of the Golodnaya Steppe". In the period of 1922-1927 agriculture was confronted with the task of increasing cotton production in all possible ways. Since this involved a considerable expansion of the irrigated area, the construction of irrigation projects had to be carried out at a high speed. Mechanization of agricultural production called for rearrangement of the irrigation systems and enlargement of small irrigated

[104] Martin, Keith., "Central Asia's Forgotten Tragedy", *RFE/RL Research Report*, Vol. 3 (30), 1994.
[105] Op cit, No. 99

fields. A big number of collective farms kept growing along with the state farms that had come into existence.

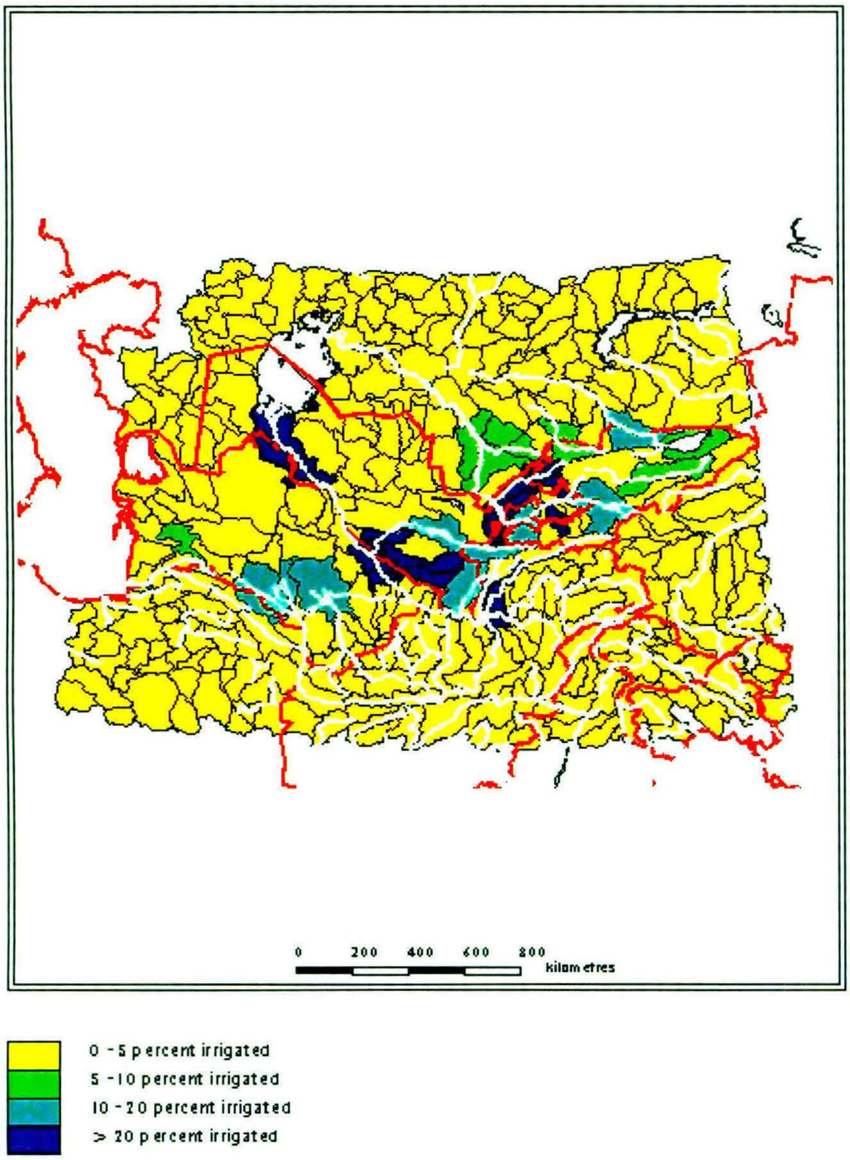
The Second World War spurred the industrial development of the region due to a large number of industrial enterprises being relocated from Russia to Central Asia. An ensuing limitation at this time was the availability of electricity generation. As a result, construction continued with more emphasis on cheap hydropower. Thus, the Chirchik–Bozsu hydropower cascade in the Chirchik river basin and the Farkhad hydropower station on the Syr Darya River were created. These works at the same time allowed regulation of the river flow in the interest of integrated water use.

In 1950-1970 large dams and water reservoirs were constructed: the Kairak Kum and Chardara reservoirs on the Syr Darya River, the South Surkhan on the Surkhan Darya River and reservoirs on the Kashka Darya, Chu and Talas rivers. Also some unique dams at Nurek and Baipasa on the Vakhsh River, and at Charvak on the Chirchik River were constructed. At the same time large pumping schemes were constructed to serve more than 20 per cent of the total irrigated area in the region.

The extensive growth of irrigation in the period of 1935 to1960 using fairly primitive irrigation techniques changed in 1960 towards the so-called "integrated method of development of desert lands". This new approach comprised not only the creation of irrigation and drainage networks, but also the overall infrastructure needed for settlement of people (villages, roads, water ways, power lines, etc.). More than 1.6 million hectares of new irrigated lands was developed this way in 1960 - 1990. Water abstraction from the rivers in the region increased proportionally.[106]

[106] Op cit, No. 98

Map 10: Irrigated area as percentage to total area



http://www.ce.utexas.edu/prof/maidment/grad/akmansoy/aral/master_sa.pdf

More than 80 water reservoirs have been constructed in the basin, each with a capacity of over 10 million m^3. To regulate the river flow, storage reservoirs were constructed either on rivers (off-stream and river-channel reservoirs) or on main canals (compensation reservoirs). The aggregate capacity of these water reservoirs exceeds 60 km^3, of which about 44 km^3 is usable (17 km^3 in the Amu Darya river basin and 27 km^3 in the Syr Darya river basin).

In addition, the basin has 45 hydropower plants with a total capacity of about 34.5 GW, the largest being the Nurek (in Tajikistan) with a capacity 2,700 MW, and the Toktogul (in the Kyrgyzstan) with a capacity of 1,200 MW.

Hydropower constitutes 27.3 per cent of the average energy consumption in the basin. The contribution of hydropower is largest in Tajikistan (about 98 per cent) and in the Kyrgyzstan (about 75 per cent), and the lowest in Turkmenistan (about 1 per cent). Potentially, the region can meet more than 71 per cent of its energy requirements from hydropower.

Water Demand

The main reasons for the rapidly increasing massive water withdrawal were the population growth, the agricultural specialization of the region, and the expansion of irrigation driven by the former federal government. However, water consumption per unit of production further decreased. For example, in the period 1960-1990 water withdrawals increased by only 1.8, while population expanded by 2.7, irrigated area by 1.7, agricultural output by 3.0, and GDP by 6. After 1990 the tendency towards a reduction of water intake continued and in 1995 water withdrawal decreased by about 9 cu km in comparison with 1990, and similarly over the recent years by 17 to 18 cu km (Table 21).[107]

[107] Op cit, , 2000

Table 21: Actual Water Use and Prospective Requirements in the Aral Sea basin (million m^3)

Country	Estimated level	Economic Sectors						
		Domestic water supply	Rural water supply	Industrial water supply	Fishery	Irrigate-d areas	Other	Total
Kazakhstan	1990	213	131	275	111	10136	451	11317
	1997	102	125	64	110	6814	99	7314
	2010	384	229	474	341	10935	600	12963
Kyrgyzstan	1990	94	70	68	0	4910	13	5155
	1997	92	69	42	5	4648	0	4856
	2010	352	266	315	0	7820	17	8770
Tajikistan	1990	485	696	607	0	11221	374	13383
	1997	436	615	931	0	9443	0	11425
	2010	770	650	1400	500	10380	600	14300
Turkmenistan	1990	121	70	126	35	24416	2	24770
	1997	320	80	135	38	22200	0	22773
	2010	1100	270	1150	400	25225	0	28145
Uzbekistan	1990	2051	839	1260	783	58338	0	63271
	1997	2259	1200	1070	582	48622	0	53733
	2010	5850	1630	1460	2240	48020	0	59200
Aral Sea Basin	1990	2964	1806	2336	929	109021	840	117896
	1997	3209	2189	2142	735	91727	99	100101
	2010	8456	2945	4899	3481	102380	1217	123378

Sources: For 1990: FAO (1997); for 1997: Reports [3-7]; for 2010: Report [1].

Irrigated agriculture used almost 92 per cent of total water demand (though a large part of this is returned to the river). Due to the economic deterioration, industrial use dropped dramatically. It is foreseen that irrigated agriculture abstraction will decrease in the future to 87 per cent of total water use. Domestic consumption will increase 1.9 times, industrial consumption 1.3 times, and fisheries 1.9 times. Kazakhstan, the Kyrgyz Republic and

Turkmenistan plan to lower demand for irrigated agriculture by 9.6 per cent, 6.3 per cent, and 19.5 per cent, respectively. Tajikistan plans some increase in irrigation water demand. In Uzbekistan, future demand will be stabilized at the recent level.

THE ARAL SEA PROBLEM

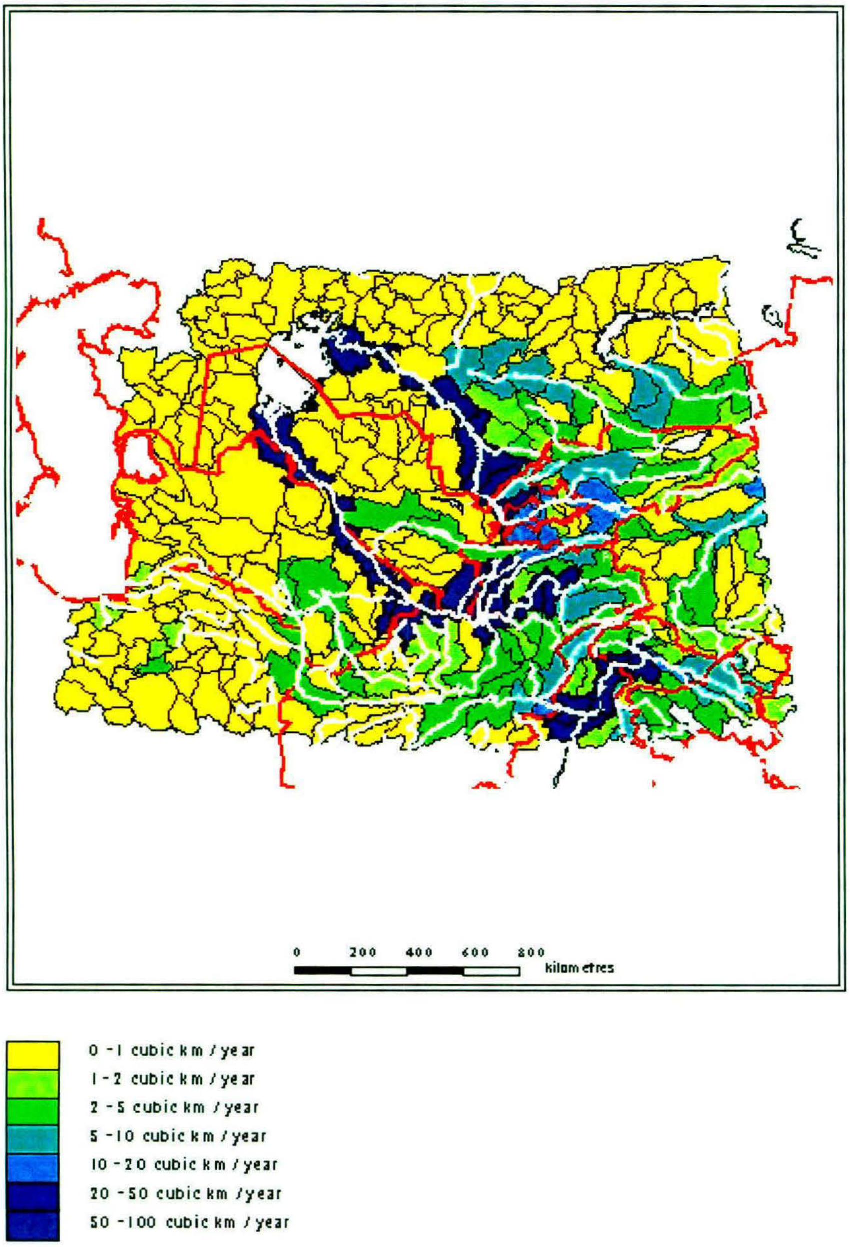
The problem of the Aral Sea did not appear overnight. As it is located at the end of a closed water basin, the sea size and the state of its deltas were directly influenced by the changes, which took place in the upper watershed. The intensive water withdrawal from the Amu Darya and Syr Darya during the last 40 years caused the sea to shrink. Its level dropped by 17-19 meters and currently only 25 per cent of the total water volume remains in the sea. The salinity in the sea increased from 10 per thousand up to 40 per thousand.

The end of the 1980s saw the division of the sea into two parts: the Small Sea to the north in Kazakhstan, and the Large Sea with a deep western part in Uzbekistan territory. After the sea separated into two parts various scenarios were suggested for their stabilization, amongst which that the Small Sea should be stabilized at the level of 41 to 42.5 m by a special dam, which is now under construction. No concrete efforts to stabilize the Large Sea have yet been attempted but proposals for improvement of the situation were identified in the "Inter-state Concept" in 1994, which will be described below.[108]

In the late 1950s, the Aral Sea was the Earth's fourth-largest inland body of water with respect to surface area. In 1960 the mean level of the Aral Sea was measured at 53.4 metres, its surface area at 66,000 km^2, and its volume at about 1,090 km^3. A flourishing sea fishery industry existed, based on the exploitation of a variety of commercially valued species. During the past three decades, the Aral Sea region has become a major world-level ecological and socio-economic problem. It is now the sixth-largest inland water body.

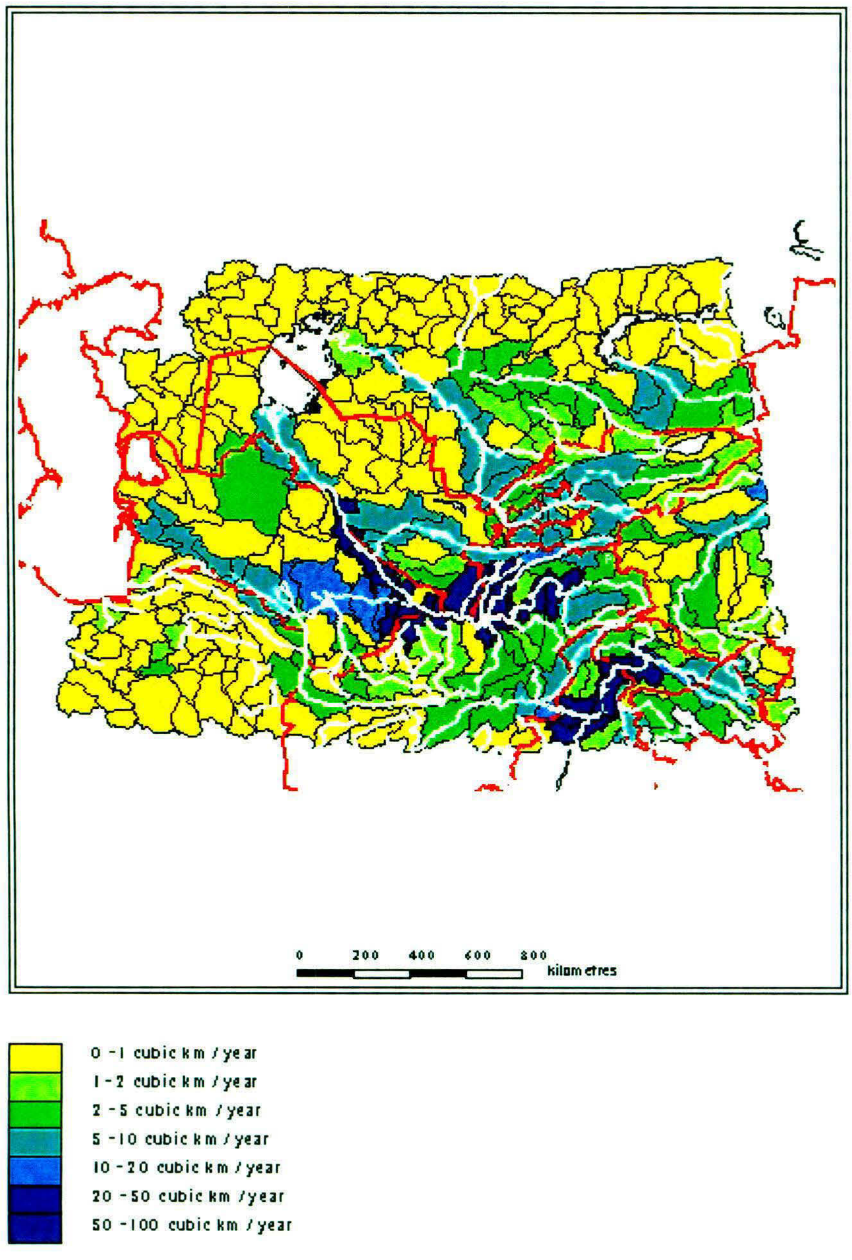
[108] Kobori, Iwao, and Michael H. Glantz., "Central Eurasian water crisis: Caspian, Aral, and Dead Seas", United Nations University Press, Tokyo, Japan, 1998.

Map 11: Water Balance without irrigation



http://www.ce.utexas.edu/prof/maidment/grad/akmansoy/aral/master_sa.pdf

Map 12: Water Balance with Irrigation



http://www.ce.utexas.edu/prof/maidment/grad/akmansoy/aral/master_sa.pdf

The stream flows of the two perennial river systems, the Amu Darya and Syr Darya, have, in the relatively recent past, sustained a stable Aral Sea level. Over the centuries, about half of the flow of the two rivers reached the Aral; a major expansion of irrigated cotton production altered this ecological balance. A sizeable portion of Central Asia's agricultural production is dependent on irrigation. Irrigated agriculture in the region pre-dates by millennia the era of tsarist conquests of the eighteenth and nineteenth centuries. What is "new" about irrigation in the region, however, is the huge amount of water diverted from the region's major rivers and, in turn, the large proportion of arable land devoted to cotton production. Beginning in the late 1970s, no water from the Syr Darya reached the Aral Sea, and the Amu Darya supplied only a minimal and ever-decreasing volume. Large diversions, poor irrigation construction and maintenance, and mismanagement of water resources have been identified as major causes of the decreased flow to the Aral Sea.[109]

Awareness of the potential degradation surrounding the Aral Sea draw-down was widespread, even in the 1950s and 1960s, a time when policy makers had a blind faith in the use of technological fixes to overcome obstacles in the paths to economic development and when the Soviet government did not allow organized dissent. The fate of the Aral Sea, under conditions of increasing diversions from the two major sources of Aral Sea water, was more or less known though there was no scope for intervention to stop or limit the diversions. Articles about the risks of degradation appeared in Soviet journals, at least from the 1960s, and were translated into other languages. However, even the most ardent advocates of preserving the Aral underestimated the range, rate of change, and intensity of the degradation that subsequently transpired.

There have been, and continue to be, decision makers who feel that the Aral Sea is of little intrinsic value to society. Thus, regardless of paying verbal homage to saving it, they do not care about its ultimate demise. Yet another group of people have supported the diversion of river water from the Amu Darya and Syr Darya, knowing that such

[109] Bedford, D P., "International Water Management in the Aral Sea Basin." *Water International*, Vol. 21, 1996, pp. 63-69.

diversions were drawing down the level of the Sea. However, they had been led to believe that the Siberian rivers diversion project would eventually be approved, bringing water to Central Asia and possibly to the Aral Sea. Central Asians continue to believe that Russia's Siberian river water is owed to them by Russian leaders, because of their sacrifices to the Soviet Union in previous decades at the behest of the Soviet government to foster the all-out production of cotton for Russian textile factories. In fact, attempts are under way today to revive these diversion schemes, as well as to propose newer ones.

Thus, much is already known about the decline in the level of the Aral Sea: when it began, why it happened, who benefited and who suffered as a result of the decline, what actions were proposed to deal with the declining levels and with the deteriorating circumstances there impact on human health and environmental conditions, and so forth.

Although all this is known with some degree of certainty, it is important to note that this particular environmental change (slow onset, low-grade, long-term, and cumulative decline in the level of the Aral Sea) is but one of a large family of such changes taking place in the Aral Sea basin. Although the primary focus of attention has been on the declining level of the Sea, in part because that change is highly visible (especially from space), it is but one creeping change in the basin to occur during the past half-century.

Creeping environmental problems in the Aral basin include the decline of the level of the Sea, reduced inflow to the Sea from the Amu Darya and Syr Darya, mono cropping, declining water quality, and adverse health effects. Because of the low-grade but cumulative nature of these problems, high-level policy makers, as well as low-level decision makers, have apparently had difficulties in identifying them as problems and then, once identified as such, in coping with them. As with other gaps elsewhere, it is often difficult to identify thresholds of change that could serve to catalyze action to arrest environmental degradation. Water quality degrades slowly over time. Vegetative cover and human health also degrade slowly over time. As for stream flow, there were readily identifiable threshold point where all could see that a major change in the Aral Sea was near: for example, in the late 1970s when the Syr Darya's water failed to reach the Sea.

And, for a few years in the 1980s, the mighty Amu Darya's water also failed to reach the Sea for the first time in recent history.

As a result of the lack of understanding of how societies can or should address such insidious environmental changes, there has been a tendency in the Aral Sea basin to "muddle through" with respect to the decision-making process. Only when a crisis has been perceived by a policy making body has action been taken, usually in the form of a costly and rapid mobilization of human and financial resources. Such actions usually address the symptoms of the problem and not its root causes. As noted earlier, although the "muddling through/crisis response" paradigm may work in the richer industrialized countries, the value of the paradigm is much more questionable in countries with scarce resources such as those in Central Asia. Because they lack the resources needed to respond at all to such crises, they are forced to seek, if not rely on, assistance from donor countries and organizations. If such assistance is not forthcoming, the downward spiral of degradation continues.

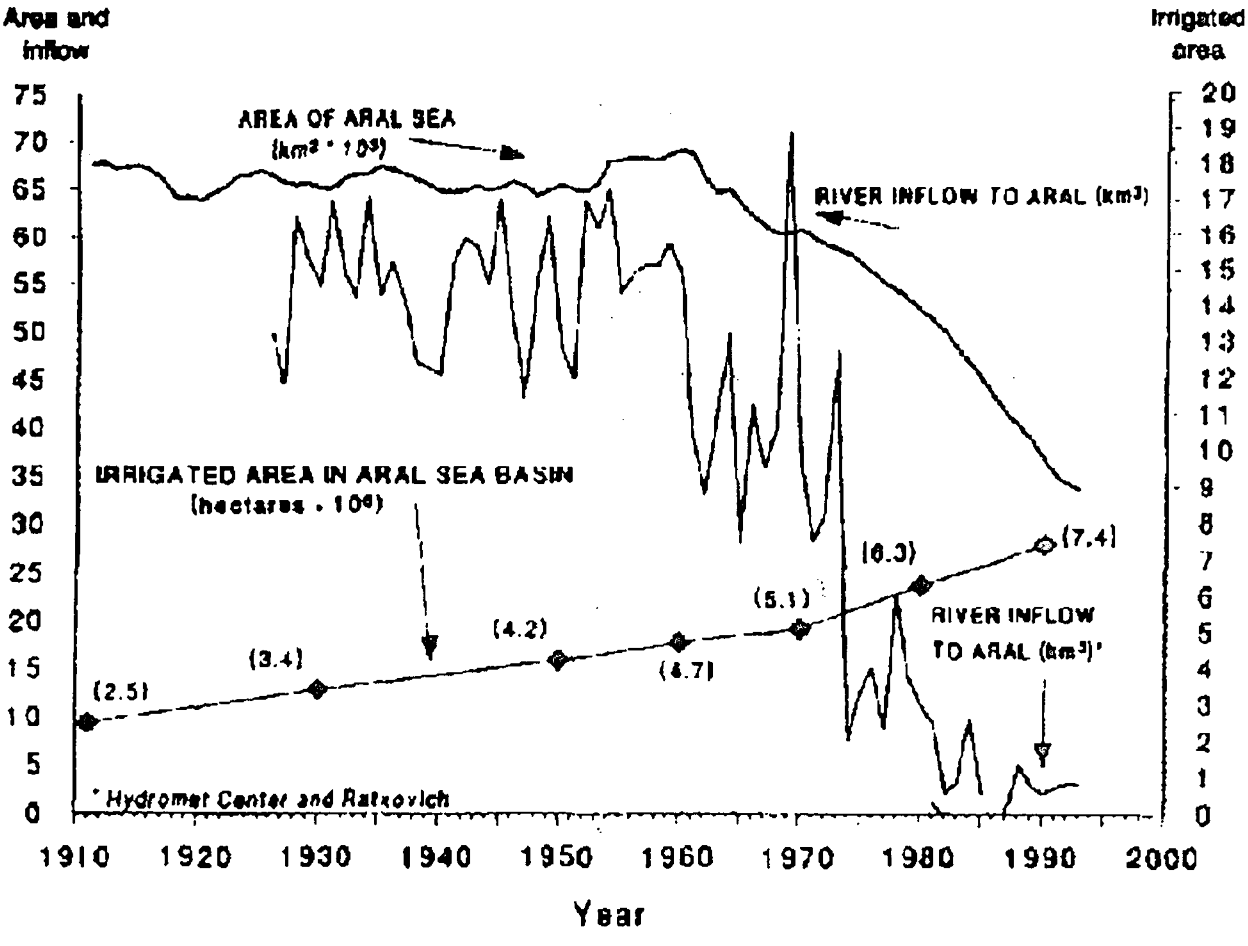
Expansion of Cotton Acreage

The desire to expand cotton production onto desert land increased the dependence of Central Asian republics on irrigation and mono cropping. Mono cropping has adverse impacts on soil conditions, which prompts increasing dependence on mechanization, pesticides, herbicides, and fertilizers. Socio-economically, this is also risky in the sense that a regional economy based on a single crop is highly vulnerable to the variability of climate (especially climatic extremes) as well as to the whims of the market place.

Cotton production requires a high degree of water for irrigation, at one time consuming over 50 per cent of agricultural water use in the region. Increased demands were met by increasing diversions from the Amu Darya and the Syr Darya.

Tables 22 and 23 shows, respectively, the land under irrigation in three republics between 1950 and 1986, and the expansion of cotton acreage in Central Asia between 1940 and 1986. The data provided in these tables cover the post-World War II period of expansion of irrigation up to 1986, the year that the Aral crisis was first exposed to the world. Each year additional amounts of water were required for the new fields and for the flushing of salts from the old ones, suffering from increasingly salinized soils. In addition, starting in 1954 with the construction of the Kara Kum Canal in Turkmenistan, large amounts of water were diverted from the Amu Darya to irrigate fields in that republic. The current estimate of withdrawals for the Kara Kum Canal from the Amu Darya is about 15-20 km^3 per year (or 23-30 per cent of flow).

Fig 7: Irrigated area in the Aral Sea basin, 1910-1990, and river inflow to the Aral Sea and surface area of the Aral Sea, 1910-1993



Source: Micklin and Williams, 1996

Table 22: Land under irrigations, 1950-1986 (thousand hectares)

Country	1950	1960	1965	1970	1975	1980	1985	1986
Uzbekistan	2,276	2,571	2,639	2,697	3,006	3,476	3,930	4,020
Tajikistan	361	427	468	518	567	617	653	662
Turkmenistan	454	496	514	643	819	927	1,107	1,185

Source: Critchlow (1991, p. 63).

The pie chart in figure 4 depicts the changes, since 1986, in the proportion of land (and therefore water for irrigation) devoted to cotton, grains, and fodder crops (such as alfalfa) and other crops in Uzbekistan.

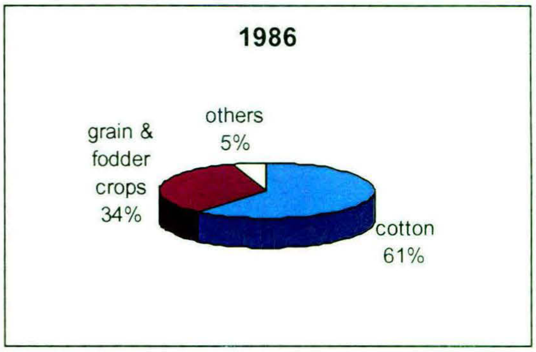
Table 23: Cotton sowings, 1940-1986 (million hectares)

Country	1940	1971-75[a]	1976-80[a]	1981-85[a]	1985	1986	Increase, 1940-86 (%)
Uzbekistan	0.924	1.718	1.823	1.932	1.993	2.053	122
Tajikistan	0.106	0.264	0.295	0.308	0.312	0.314	196
Turkmenistan	0.151	0.438	0.504	0.534	0.560	0.650	330

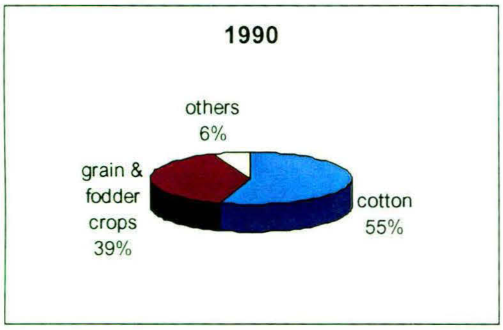
Source: Critchlow (1991, p. 64).

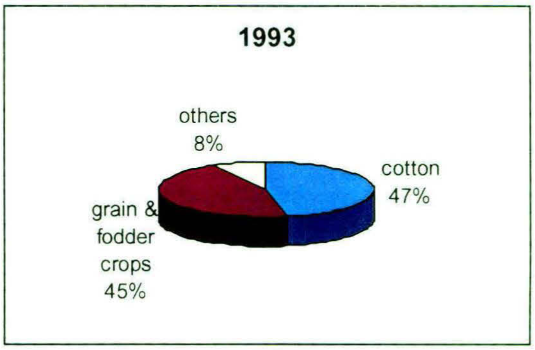
a. Average per year for this period.

Fig. 8: The composition of irrigated crops in Uzbekistan (as a % of total crop area)



(Source: UNDP, 1995)





Sea Level Decline

The decline in the level of the Aral Sea has received considerable political attention both domestically and internationally. It is a highly noticeable environmental change, visible directly on the ground as well as from space. Water diversions from the two main regional rivers robbed the sea and deltas of annual freshwater replenishment. The rate of decline of the Sea can be seen in figure 4. Note also that declining levels were accompanied by an even more rapid decline in the volume of the Sea and by an increase in salinity.[110]

It was not until the mid-1980s and Glasnost that the Aral Sea situation took on the aura of an environmental catastrophe to many foreign observers. Although it was newly exposed to the international media, and discussed with a new openness in the Soviet Union, it was, as suggested earlier, a known crisis situation that "crept up" on policy makers over a period of 30 years!

Related to declining sea level and reduced sea surface area is the increase in the number and frequency of dust storms. In the mid-1970s, dust storms captured the attention of Soviet policy makers when cosmonauts, during one of their space missions, photographed major dust storms in the receding shoreline in the south-eastern part of the Aral Sea. Exposed seabeds enabled winds to pick up dust laden with a variety of chemicals and carry it hundreds of kilometres from the original site. Farms downwind to these storms became covered with these dry depositions, and farmers claimed that the productivity of their land, as well as their health, was being adversely affected. Since then, the number and intensity of these dust storms along the continually newly exposed dry seabed have apparently increased. In fact, it was the appearance of major dust storms that exposed to Soviet leaders and the rest of the world the extent of human mismanagement of Central Asian rivers' waters.

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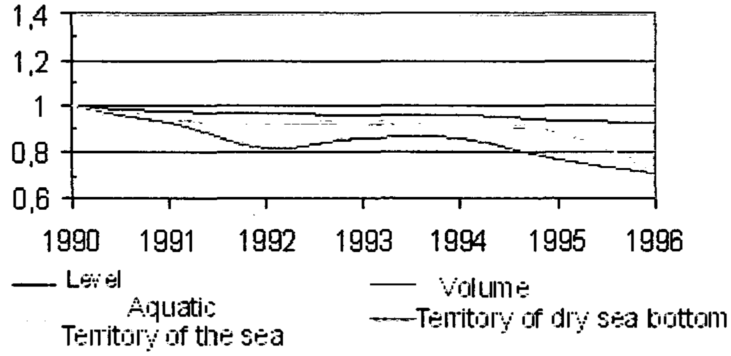
[110] Micklin, P. and W. D. Williams (eds.), "The Aral Sea Basin", NATO ASI Series 2: Environment, Vol. 12, Berlin: Springer-Verlag, 1996, pp. 5-6.

Fig 9: Dynamics of parameter changes of the Aral Sea 1990-96

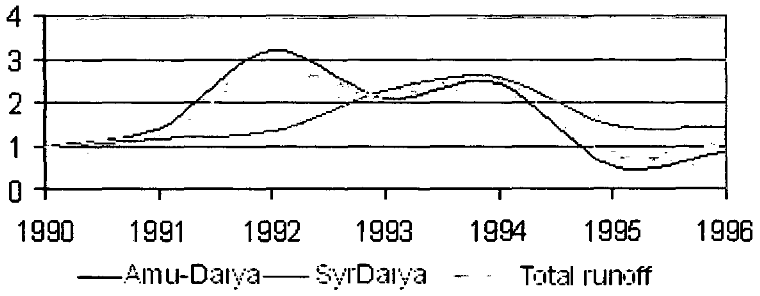
(1990 is the basin level)



Decreasing Flows of the Amu Darya and Syr Darya into the Aral Sea

The Amu Darya supplies about 70 per cent of the water to the Aral Sea, more than twice the flow of the second major river in the region, the Syr Darya. From the early 1960s, the decline in Syr Darya flow was noticed, and by the late 1970s no water from the Syr Darya reached the Sea. As for the Amu Darya, a sizeable amount of water is diverted from the river to the Kara Kum Canal (later the Lenin Canal and, today, the Niyazov Canal). The total amount diverted to this canal has been estimated at 15-20 km^3 per year, with diversions having increased at various stages of its completion. In the 1980s, there were a few years when virtually no water from the Amu Darya flow reached the Aral Sea. In recent years, however, as the result of favourable snow pack in the Pamir Mountains where the river has its origins, water has been reaching the Sea. The last leg of the Kara Kum Canal is complete, and with all likelihood will translate into the diversion of additional Amu Darya water to the canal's extension to south-western Turkmenistan.

Fig 10: Dynamics of Water flow in to the Pre-Aral area in 1990-96
(1990 is the basic level)



Before the rapid expansion of irrigated cotton production began in the 1960s in Uzbekistan and Turkmenistan, some Soviet scientists sought to alert their government to the possibility of a decline in sea level decades into the future, as large volumes of water became increasingly diverted from the two major regional rivers that had historically determined the Sea's level.

Decline in the Quality of the Water in the Rivers and in the Aral Sea

As fields were continually irrigated on a large scale, soil fertility rapidly declined. This prompted attempt to use increasing amounts of fertilizers, herbicides, and pesticides to maintain, if not expand, cotton productivity and production. Many of these chemicals found their way through the return flow to the rivers, as well as to the groundwater. In addition, to avoid (or really delay) the worsening of the salinization of soils, increasing amounts of water had to be used to flush the land of salts and other compounds. Much of this drainage water was returned to the rivers and, eventually, to the Sea. Drainage canals were eventually constructed to divert some of the contaminated water away from the Sea and into Lake Sarakamysh, a regional desert depression.

Degradation of the Deltaic Ecosystems

Another example of the ecological consequences of reduced stream flow into the sea is the degradation of the highly productive Amu Darya and Syr Darya deltaic regions which has become increasingly pronounced during the past 30 years.[111] One of the consequences of the desiccation of the delta region has been the diminution of vegetative cover, a loss that destroyed habitats for wildlife and migratory birds. Frederick highlighted the economic importance of the deltas in the recent past, noting that they provided a "feeding base for livestock, a source of reeds for industry, spawning grounds for fish, and sites of commercial hunting and trapping."[112] Each of these delta-related ecological and societal processes has either been sharply curtailed or ended.[113]

Wildlife disappeared around the delta and forests became decimated as the soils dried out or became salinized or waterlogged, depending on local soil conditions. Kuznetsov supported this view of the early observation of adverse impacts, when he wrote that the degradation of wetland soils in the deltas was noted quite clearly as early as the second half of the 1960s. For the preservation of the most fertile soils of the Amu Darya delta, it was proposed that they be artificially irrigated, for which it was recommended that 3.0-3.5 km^3/year of river water be used. However, professional water managers and land reclamation specialists paid no heed to this recommendation, nor to many others.[114]

Today, political interest in the Aral Sea appears to have been reduced to the deltas of the Amu Darya and Syr Darya. Supported by recommendations from the World Bank, Uzbek and Kazak leaders have proposed to rejuvenate deltaic ecosystems, abandoning the more ambitious schemes designed to save the entire Aral Sea, including the deltas.

Destruction of Fish Populations in the Aral Sea

With declining river water quality came a decline in the quality of Aral Sea water. At a 1977 Soviet conference on the environmental impact of a drop in the level of the Aral Sea, a paper prepared by two Uzbek republic scientists reported a sharp reduction in fish

[111] Op cit, No. 99
[112] Frederick, K D., "The Disappearing Aral Sea", *Resources*, Winter 1991, pp. 11-14.
[113] Novikova, N., "Creeping environmental changes in the pre Aral ecosystems under the Aral Sea crisis", in M H Glantz (ed), *Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin*, Cambridge University Press, Cambridge, 1998.
[114] Kuznetsov, N. T., "Geographical and Ecological aspects of the Aral Sea Hydrological Functions", *Post Soviet Geography*, Vol. 33 (5), 1992, p. 324.

landings.[115] They suggested that a demise of the commercial fishery would likely occur because of the desiccation of the Sea's fish spawning grounds.[116]

The sharp decline in fish landings provided a visible threshold for decision makers to see that their inaction with regard to declining sea level and water quality had its adverse biological consequences. By the late 1970s, it was quite clear that the Aral Sea fisheries were in an irreversible decline. A once-thriving fishing industry had become adversely affected by increasing amounts of pollutants entering the Sea by way of the river. The salinity of Aral Sea water increased to such an extent that several areas had the same salinity as the open ocean.

Today, no fish are caught commercially in the Sea; the Aral Sea ports of Muynak and Aralsk are now several tens of kilometres from the receding shoreline; and into the early 1990s fish had been shipped in from distant locations (the Arctic, the Baltic, and the Pacific) for processing. The loss of fish productivity sparked a collapse of the industry and employment in this sector. In 1960, 43,430 metric tons of fish were caught in the Sea, dropping to 17,400 tons in 1970, to zero tons in 1980, and remaining there until now.[117]

Increase in Human Diseases

The consequence of the dependence of several Central Asian republics on cotton monoculture not only adversely affected the physical environment by upsetting ecological balances in many parts of the Aral basin, but has also had a devastating impact on human health. Documented regional effects have only recently been exposed to the public: high infant mortality and morbidity rates, a sharp increase in esophageal cancers directly attributable to "poisoned" water resources, gastro-intestinal problems, typhoid, high rates of congenital deformation, outbreaks of viral hepatitis, the contamination of mothers' milk, and a life expectancy in some areas about 20 years less than for the Commonwealth of Independent States (CIS) in general. Groundwater supplies, too, have

[115] Gorodetskaya, M.Y and A S Kes., "Alma Ata Conference on the Environmental impact of a Drop in the level of the Aral Sea Basin", *Soviet Geography*, Vol. 19 (10), 1978, pp. 728-736.
[116] Reteyum, A. U., "Letter in Overview Section", *Environment*, Vol. 33 (1), 1991, p. 3
[117] Létolle and Mainguet., "Aral", Springer-Verlag, Paris, 1993, p. 182

been contaminated as a result of the widespread and wanton use of chemicals on irrigated cotton fields. By all statistical measures, the region's human health profile fares poorly in comparison with the rest of the CIS.[118] Adverse impacts of all-out cotton production on health have been compounded by the absolute dearth of medical and health facilities in the Aral basin. In addition, water treatment facilities in the region are wholly inadequate (and in many areas non-existent), necessitating the use of untreated surface waters from the rivers, irrigation canals, and drainage ditches for domestic purposes.

Systematic research on public health in the Aral Sea basin began in the mid-1970s. From that time, the negative dynamics of deteriorating public health conditions in the region were observed. Had such research been systematically undertaken earlier, these adverse public health conditions would have been identified by the end of the 1960s, and would probably have been linked to the presence of pesticides.[119] In addition, Kuznetsov noted that "unfortunately, secrecy over an entire series of research results in the 1970s, especially medical-epidemiological data, precluded their publication at that time and the predictions associated with them did not become available to the public in time."[120]

By way of illustration, one typical, tragic situation deserves mention, namely, the condition of the Kara kalpak, the Turkic-speaking people of autonomous Karakalpakstan in northwest Uzbekistan. More than 1 million people have been affected.

There is a shortage of clean water, and there is not enough even for drinking. In several parts of the region the consumption of water per person per day is about 5 litres, compared to an average of 200 to 300 litres. The mineralization (salt content) of this water stands at 2 to 4 grams per litre, and the bacteria content exceeds the maximum permissible concentration by 5 to 10 times. Through the dispensary system the Ministry of Health discovered a truly tragic picture: 60 per cent of those examined - children and

[118] Feshbach M and A Friendly Jr., "Ecocide in the USSR: Health and Nature Under Siege", Basic Books, New York, 1992.
[119] Elpiner L I., "Public Health in the Aral Sea Coastal Region and the Dynamics of Changes in the Ecological Situation" In M H Glantz (eds.), *Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin*, Cambridge University Press, Cambridge, 1998.
[120] Op cit, No. 113

adults have serious health problems; 80 per cent of pregnant women suffer from anaemia; intestinal infections are widespread; the infant mortality rate is much higher than national average figures and in several regions reaches up to 82 in 1000 newborns. Diseases never before seen here are appearing, for example gallstones and kidney stones.[121]

In the absence of any major improvement in regional health care or in detoxifying water and land resources in the Aral basin, the only way out for regional inhabitants, other than perpetuating the status quo, has been emigration. However, despite previous Soviet plans to encourage those most directly and most negatively affected (the people of Karakalpakstan) to migrate to areas outside Central Asia, few have opted to leave their homeland. Thus, with few steps to improve the health of the people or the environment in the Aral basin, the total sum of misery can only increase, because the region boasts an extremely high population growth rate ranging from 2.6 to 3.2 per cent. At such growth rates, a doubling of the present-day regional population of over 30 million to 60 million is expected in the early decades of the twenty-first century. The UN Development Programme is actively seeking to address some of the social issues that constrain capacity building, which is so necessary for the long-term "sustainable use of water and land resources in the basin".[122]

SOCIO-ECONOMIC DEVELOPMENT AND ROLE OF WATER

The water sector arguably plays the most significant role in the economic life and national incomes in the region. During the last three decades before independence (1960-1990), the irrigated agriculture sector and the sectors of the economy related to water management (hydropower, hydro-technical construction) contributed more than 50 per cent of the GNP. Now, in the process of gradual transition to a market-oriented economy, the region has experienced a general production decline. The macro-economic situation varies from country to country, but overall agricultural production now contributes only between a fifth and a quarter of GNP in the countries (Table 24).

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[121] Rudenko B., "Solenye Peski Aralkum (The Salty sands of the Aral)", *Nauka I zhizn*, Vol. 10, October 1989, p. 44

[122] UNDP, 1996

Table 24: Changes in the Economic Situation during the Transition

Country	GNP in US$ per capita		By sector of economy in per cent					
			Industry & construction		Agriculture, Forestry, Fishery		Services	
	1990	1998	1990	1998	1990	1998	1990	1998
Kazakhstan	2310	1330	36.1	27	28	10	35.9	63
Kyrgyzstan	1240	700	35.9	24	34.6	46	29.5	30
Tajikistan	910	340	33.7	25	27.1	25	39.2	50
Turkmenistan	1490	920	33.6	35	28.6	11	37.8	54
Uzbekistan	1000	970	32.5	30	31.3	28	36.2	42

The decline in GNP, with the biggest drop in Tajikistan and smallest in Uzbekistan, was accompanied by major shifts in the distribution of production between sectors. The agricultural sector is still the dominant employer with 25 to 60 per cent of the labour force.

The transfer to a market economy and the exposure of the local cotton to world market prices influences the farmers' ability to carry on agricultural production. Under these new conditions the specific income per hectare in the region increased from US $ 150 to 900, though in the case of cotton growing this increase is much lower.

Proper management, operation and maintenance of the irrigation infrastructure costs about US $ 65-120 hectares per year. Since farmers cannot afford to pay much more than 10 per cent of their income on operation and maintenance, the government would need to provide a major part of the funds to maintain the infrastructure in operational conditions (averaging 70 per cent). If agricultural production increases in proportion with the GNP, it is anticipated that the 1990 level will be reached between 2007 and 2015. With this increase in agricultural production, farmers will be able to pay a larger part of operation and maintenance. The decrease of agricultural production since 1990 also has a significant impact on the availability of food. This shortage is acute in poorer rural areas.[123]

NATIONAL STRATEGIES AND THEIR INFLUENCE ON THE WATER SECTOR

The common aspiration of the Central Asian states to adopt new forms of economic development has been accompanied by changes in government priorities. In the past, attention was primarily focussed on irrigated agriculture, but now each country has selected its own course for survival.

Kazakhstan has used a "shock therapy" for transition by removing subsidies to agriculture, and by creating the possibility for all new farmers to openly compete in the world market. The majority of industrial enterprises were privatized, many of them with the participation of foreign investors. The oil sector became the principal sphere of governmental interest.

The Kyrgyzstan, with almost a total absence of sources of fossil fuel, identified hydropower production as a first priority for ensuring self-sufficiency. In agriculture, the approach has also been to privatize farming and minimize the support from the government. Political instability has delayed government regulation in agriculture and industry, but even under the current conditions agriculture has not declined significantly.

Turkmenistan and Uzbekistan followed a path of a much more gradual transfer to privatization in agriculture and industry, but economic weakness has curtailed there attention for the water sector.

Tajikistan has been threatened until recently by political instability. The transition process began only one year ago but suffers from a very difficult economic situation.

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[123] Op cit, No. 48

The public sector should assume its role of regulating the transition processes. This is especially important for the arid Central Asian states, where water management and infrastructure at all levels of the economy and society should continue to be the focus of attention. The role of the government is underscored by the perilous and almost unworkable state of the huge infrastructure created in the Soviet times. Moreover, the large social consequences of the water supply within the existing conditions should be clearly taken into account.

THE CAUSES OF THE ARAL SEA PROBLEM

Firstly, the soviet legacy is taken to be crucial component of the Aral Sea Basin crisis. The 'forced' cultivation of cotton and the inefficiency in terms of the water management of the state farms (sovkhozy) and collectives (kolkhozy) during the socialist era were the main causes of this diversion for agriculture, water diversion for contamination, salinization and given the limited water resources within the basin (surface and ground water, precipitation) –the squeezing of water supplies for the Aral Sea.

The problem is further compounded by the fact that a large share of the water diverted from the rivers for the purpose of irrigation is actually wasted, because of severe problems in water management and irrigation infrastructure. The political economy of the cotton sector was intimately connected with vested interests at national and local levels.[124]

At the end of the 1950s the leadership of the former Soviet Union made a decision on an extensive development of irrigation in the Aral Sea Basin. The critical factor to make it happen was water. Two great rivers feed the Aral Sea, the Amu Darya and Syr Darya. The Soviet scheme was based on the construction of a series of dams on the two rivers to create reservoirs from which 40,000 kms of canals would eventually be dug to divert water to the fields. It was believed that the irrigation might become the main remedy in solving many agricultural problems of the USSR. It was expected that the expansion of irrigation in Central Asia would bring the prosperity both for the region and to the USSR

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[124] Rumer, Boris Z., "Soviet Central Asia: A Tragic Experiment", MA: Unwin Hyman, Boston, 1989.

as a whole. It was clear to the water resources experts that one of the main side effects would be the deterioration, if not the disappearance, of the Aral Sea. However, at that time it was not considered as an important issue.

Before 1960, the level of the Aral Sea was more or less stable. Its surface area was about 66,000 km^2 and its volume about 1,060 km^3. The combined average discharge of the Amu Darya and Syr Darya rivers to the sea was about 47-50 km^3/year, to which could be added 5-6 km^3/year of groundwater inflow and 5.5-6.5 km^3/year of precipitation over the sea. This total volume of 57.5-62.5 km^3/year compensated the evaporation over the lake, estimated about 60 km^3/year. The Aral Sea level was then fluctuating at around 50-53 m above sea level.

By the 1960 the Aral Sea had a volume of 1090 km^2, fed by the natural surface flow of the Amu Darya and Syr Darya (69.5 and 37 km^3 annually); around 45-55 km^3 reached the sea.[125] Things had already begun to change, however; with the construction of the famous Kara Kum canal in the early 1950s, diverting Amu Darya water at Kerki westwards in to the Kara Kum desert of Turkmenistan, discharge from the river in to the Aral Sea dropped substantially.

During the period 1960-80, the cotton acreage in Central Asia expanded rapidly, for example in Uzbekistan from 1.3 million to 2.1 million hectares, with increasing volumes of Amu and Syr Darya river water being used for irrigation.[126] Water use for the irrigation of agriculture was such that by the early 1980s on average not more than 7 km^3 reached the Aral Sea annually; in some years no water at all passed through the Amu and Syr Darya deltas. When the Tahaitash Dam was built on the Amu Darya near the city of Nukus, there was no water left in the riverbed to flow to the Aral Sea, hundreds of kilometres away.

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[125] Martin, Keith., "Central Asia's Forgotten Tragedy", *RFE/RL Research Report*, Vol. 3 (30), 1994.
[126] Smith, David R., "Change and Variability in Climate and Ecosystems Decline in Aral Sea Deltas", *Post Soviet Geography*, Vol. 35 (3), 1994; pp 142-65.

Approximately 95 per cent of Amu Darya, and 100 per cent Syr Darya Rivers, the main water sources for Aral Sea Basin, were regulated by more than 60 different water reservoirs, canals and dams. The quality of surface and ground water changed dramatically. The Amu Darya was the drinking water source for the lower part of basin until 1970s.

The Soviet policy assigned Central Asia the role of raw material supplier, notably cotton. Irrigation was necessary due to the arid climate prevailing over the lower reaches of the Amu and Syr Darya basins. The development of irrigation in the Soviet part of the Aral Sea basin was spectacular: from about 4.5 million hectare in 1960, it rose to almost 7 million hectares in 1980. The population increased from 14 million in 1960 to about 27 million in 1980. The total water withdrawal increased from 64.7 km^3 in 1960 to 120 km^3 in 1980, of which more than 90 per cent was for agricultural purposes. It resulted in the disruption of the prevailing water balance in the basin.

Table 25: Chronology of a Disappearing Lake

Year	**Average level (m)**	**Average area (sq km)**	**Average volume (cu km)**	**Average salinity (g/l)**
1960	53.4	66900	1090	10
1971	51.1	60200	925	11
1976	48.3	55700	763	14
1980	45.4	-	602	-
1985	41.4	-	418	-
1988	40.1	-	358	-
1990 (large sea)	38.6	33500	310	30
1990 (small sea)	39.5	3000	20	30
1993 (large sea)	36.9	30953	279	37
1993 (small sea)	39.9	2689	21	30
2000 (large sea)	32.4	21003	159	65
2000 (small sea)	41.0	3152	24	25

Source: Spoor, Max., "The Aral Sea Basin Crisis: Transition and Environment in the former Soviet Central Asia", Development and Change, Vol. 29, 1998.

Investments in the irrigation of Central Asia during 1960s-1980s were of the order of 50 billion dollars. The area of irrigated lands in the Aral Sea basin increased from 5 million to 7-8 million hectares. The consumption of water was excessive. Each hectare of cotton requires there about 17,000 m^3 a year, while the standard figure would be 8000 m^3. The new three million hectares for irrigation would mean eventually 51 km^3 of water a year not coming to Aral Sea, in addition to 55 km^3 traditionally taken. The approximate figure of 106 km^3 is what is used in the basin of Aral Sea and, hence, what the lake does not receive. It means that the river water have reached Aral only in the years with flow above average. The last figure is quite comparable with the volume of the flow of Syr Darya and Amu Darya. Indeed, during 1990s some river water reached Aral in the water-abundant years. The gradual development of new irrigated lands meant a steady decrease in the inflow to the Lake and the deterioration of the Sea.

Within 30 years (1960-1990) the water level of Aral Sea dropped down by 14.3 m. The volume decreased by 790 km^3 or 3.6 times, and the surface has shrunk by almost 30,000 km^2 or 1.8 times. The mean depth changed from 16.0 m to 7.9 m. By 1995 the water level dropped by 2 m more. The salinity of water in the lake reached the oceanic one that is 35 g/l.

In 1988-1989 two parts of the lake, - the smaller northern part called Small Sea or Small Aral and the larger southern part called Big Sea or Big Aral divided completely. Some Syr Darya water goes predominantly to Smaller Sea, and its water level became more or less stable. The area of Big Sea keeps shrinking. Big and Small Seas are connected with a strait through which some excess water from the latter go to Big Sea.

However, the states of Central Asia (Uzbekistan, Turkmenistan, Tajikistan, and Kyrgyzstan) and Kazakhstan initiated a large-scale opening up of new lands through irrigation and then the equilibrium between the water demand and supply of the lake changed drastically. Water that was required for a healthy functioning of aquatic systems in the basin has been destroyed. It took only about 30 years to develop into a major ecological crisis of the Aral Sea Basin.

The ecological degradation became especially critical east of the Aral Sea, in the lower reaches of the Amu Darya and the Syr Darya where the Republic of Karakalpakstan, the

Khoresm Region of Uzbekistan and the Tashauz Region of Turkmenistan are situated. Manipulation of rivers for water, construction of dams and barrages and diversion of water for predominantly irrigation uses have led to a decline in the Aral Sea water level, and increase in salinity. The consequences of overuse and mismanagement of the crucial water resources were far reaching. In the table an inverse relationship is seen between the drying up of the Aral Sea and the increase in salinity, which by now has reached levels close to ocean waters. The reduction of the water volume and water depth has been increasing in pace, from around 1 km^3 per annum before 1960, to 14.1 km^3 in the 1960s, 32.2 km^3 in the 1970s, reaching a peak in the first half of the 1980s at 36.8 km^3 per annum. The slowing down in the rate of volume reduction since then can be attributed partly to an increased environmental consciousness within the leadership and partly to pressure from water management systems.

Fig 11: Measured discharges in the Amu Darya and Syr Darya and trends

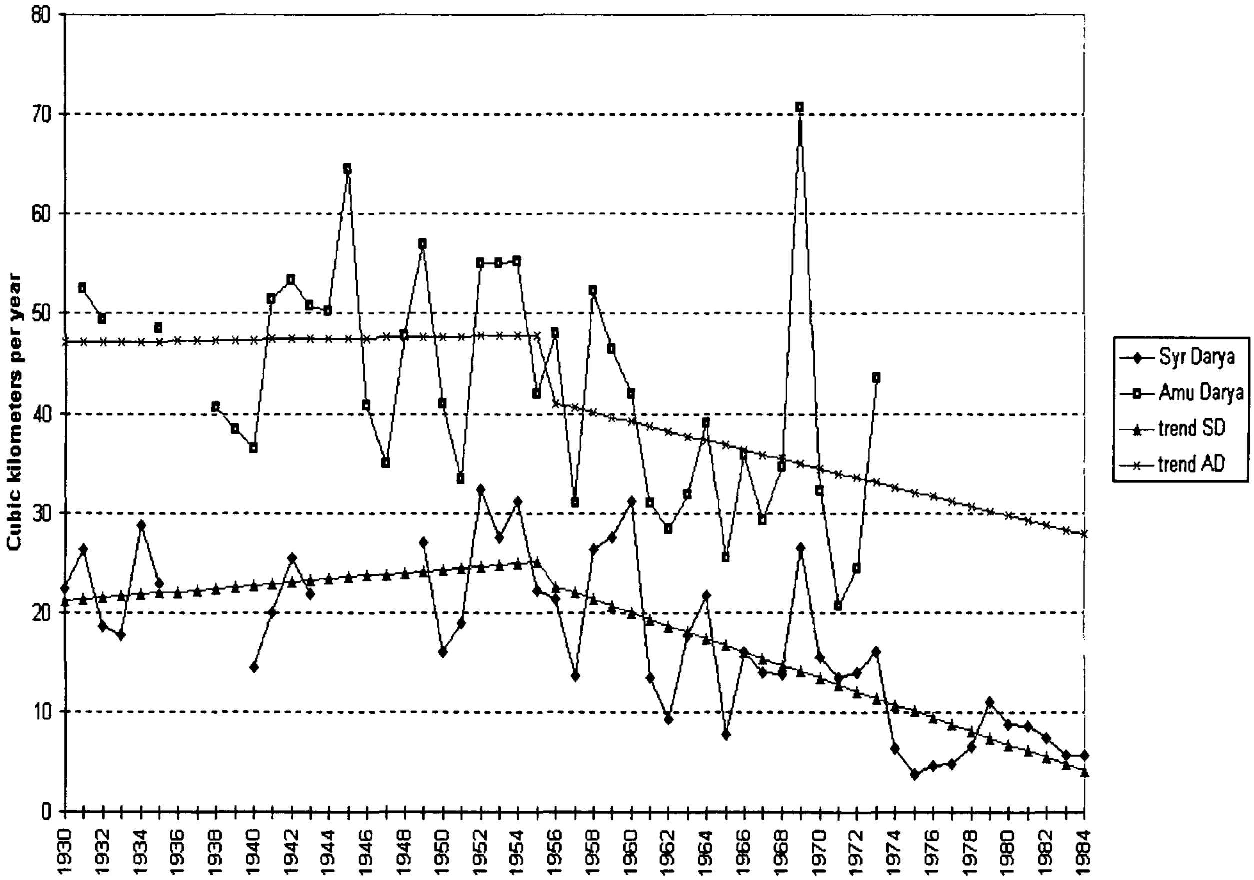
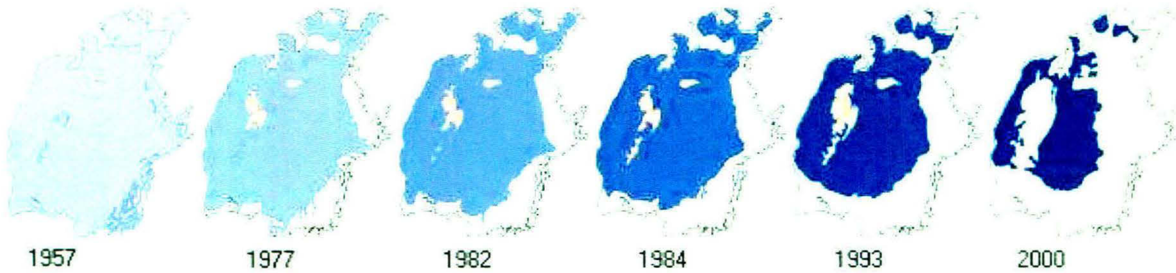


Fig 12: Chronology of the Aral Sea changes



Source: State of Environment of the Aral Sea Basin, 2000.

CONCLUSION

The drying of the Aral Sea has been accompanied by a profound degradation not only of its own ecological system but also of those neighbouring on it. The ecological degradation became especially critical east of the Aral Sea, in the lower reaches of the Amu Darya and the Syr-Darya where the Republic of Karakalpakstan, the Khorezm Region of Uzbekistan, and the Tashauz Region of Turkmenistan are situated. This was the direct impact of water resource manipulation through the construction of dams and barrages and diversion of water for predominantly irrigation use. There has been a change in fish stocks of the major rivers, with sturgeon, shovelnose and Aral trout virtually disappearing from them.

Pollution through agrochemical inputs has caused a major problem especially in the drainage-fed water bodies, such as the Sarykamysh Lake, where most of the fish are declared unsuitable for human consumption. The lakes based on receiving drainage waters are also undergoing a process of gradual increase in water salinity, which eventually makes the environment unsuitable for the great majority of freshwater fish species. The future of the fishery in the lower Amu-Darya depends much on solving the problem of the Aral Sea and its catchment areas. Only implementation of a water resource rehabilitation programme could lead to the rehabilitation of fish stocks and fisheries. Some of the measures such as redistribution of the water resources and

In short, during the Soviet period in Central Asia, the destruction of the traditional water management and crop rotation systems in the early stage of the Soviet era, followed by the 'cotton at all price' policy from Moscow from the 1960s onwards, greatly endangered the environmental sustainability of the Aral Sea Basin. The exclusive focus on 'white gold', as cotton is known in Central Asia, under a social organization of production that ignored the environmental impact of inadequate long-term resource management, has indeed turned into a 'tragic experiment'.[127]

In summary, the Aral Sea basin environmental crisis has severely affected the human ecology of the area; million of people are dependent on soils, water and air which are often highly contaminated, while agricultural employment opportunities are under pressure in a context of rural population growth, in regions with relatively small areas of cultivated land.

[127] Op cit, No. 124

INSTITUTIONAL FRAMEWORK: CHALLENGES AND PROSPECTS IN THE ARAL SEA BASIN

INTRODUCTION

Generally speaking, the rise and fall of ancient kingdoms in the Aral Sea basin depended to a great extent on control of water sources and courses. Since the 1960s, enormous efforts by the former Soviet regime to develop cotton fields along the Amu Darya and Syr Darya basins have produced large quantities of cotton but also severe degradation of the land, mainly salinization. Furthermore, the construction of many irrigation canals has decreased the influx of water to the Aral Sea.

The Aral Sea of today presents a miserable picture, having lost almost half of its area of the 1960s. According to the analysis of data obtained by satellite, the Aral Sea could disappear some time in the twenty-first century. As a result of initiative taken to solve the problems of Aral Sea by the Presidents of Central Asian States, the Aral problem has become an integral part of the state politics of the five newly independent states.

The scope of the Aral disaster can be illustrated with the following statistics:

- Of the initial surface area of the Aral Sea itself - 66,458 km^2 slightly more than half remained in the early 1990s;
- Of the former volume of water -1,022 km^3 - only about one-third remained;
- The salt content of the water increased from 10 ppm to 31 ppm;
- The temperature change during the summer months has increased by 2 degrees;
- Each hectare of land in the Aral disaster region has 500-700 kg of salt dust that has fallen on it as a result of more frequent and severe dust storms on the newly exposed Aral Sea bed.

The drying out of the Aral Sea has taken place in the course of only one human generation, i.e. during a 25-year period, and that cannot but be reflected in both the physical and the spiritual worlds of its people. The rate of population growth has stayed the same, but this is the result of the higher than average birth-rate.

The policies for the development of new areas and for changing the direction of flow of rivers were the guiding principle for the state industrial and agricultural systems in the period of totalitarian rule. And at the time people believed in a bright future. When that "bright future" dissolved with the disintegration of the former USSR, the indigenous people of the Aral region seemed to have no hope left concerning the Sea's preservation or a better future. Some people had the means to move to prosperous places and others simply have to live there and face the consequences. Today, the notion of "environmental refugees" appears in the media. Those who had nowhere else to go remained in the land of their ancestors.

Now, however, the people of the Aral region can begin to hope for rescue, thanks to the increase in activity in international circles, due in large measure to the United Nations and especially to the support from international organizations in the form of humanitarian assistance.

Water management in Central Asia during the Soviet era was often associated with the Aral Sea basin disaster. Following their independence in 1991, the five Central Asian republics - Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan - requested assistance from the international community in finding a solution to the critical situation in the Aral Sea Region.

Several new bodies were created to address water problems in Central Asia. They led to a series of agreements, supported by developmental programmes and technical assistance projects. Four bodies seem to be more prominent than others. The first is the Inter-state Commission for Water Co-ordination (ICWC) that was initiated in 1992 and is responsible for water management issues of common interest for all five states. The International Fund for the Aral Sea (IFAS) is another key entity, in charge of the financing of the activities of the Interstate Council on the Aral Sea Basin Problems the adoption of a regional water strategy. The preparation of this water strategy, as well as regional studies and pilot projects for a new approach in water management, have received attention and funding from several international organizations and bilateral agencies. The International Fund for the Aral Sea (IFAS) and the Interstate Council for the Aral Sea Problem (ICAS) have been established in order to co-ordinate the initiatives and the financial resources to a regional approach.[131]

Water Supply Management

The first solutions envisaged to face the problems were based on water supply management. During the Soviet period, the possibilities of water diversion from the Ob River to the Amu Darya River through a 2,200 km-long canal or from the Volga River to the Aral Sea were studied. These options were abandoned with the ending of the Soviet Union. Currently, a proposal to transfer water from the Caspian Sea to the Aral Sea is being studied.

Greater use of agricultural drainage water and wastewater, as well as the introduction of more salt-tolerant crops, has also been envisaged and in part implemented. In 1993, agricultural drainage water was estimated at about 40 km^3/year and the re-use of industrial and domestic wastewater was about 3 km^3/year. About 6 km^3/year of agricultural drainage waters or wastewater are directly re-used for irrigation.[132]

Some 37 km^3/year unit of water return to natural depressions or rivers where they are mixed with freshwater and can be re-used for irrigation or other purposes. Dam construction and canal regulation have also been undertaken to make the water supply meet the water demand in a more timely fashion. Although these options have enabled further irrigation development, the improvements induced have not been sustainable.

[131] Op cit, No. 130
[132] Ibid.

Water Demand Management

The governments of the five Central Asian republics have thus decided to focus on demand management, which is now a key element of the national and regional water strategies. The countries have started implementing programmes, which all aim to reduce the water withdrawal per hectare, but which have the primary objective of satisfying crop water requirements.

From a technical point of view, all the measures aim to increase the global irrigation efficiency: through canal rehabilitation and/or lining, which leads to a reduction of the losses; and through canal regulation for better irrigation scheduling. However, in view of the very limited funds available, these measures will be implemented gradually, relying mostly on international assistance and funding.

From an economic point of view, several countries have introduced water fees and fines for the use of water in excess of the allocation per farm. Moreover, with the move towards a market-oriented economy, farmers' responsibility has increased. For example, the decision on the crops to be grown on irrigation schemes, which has direct consequences on the water requirements, is the farmers' responsibility. In Kazakhstan, rice, a large water consuming crop, has been replaced by other cereals. In Turkmenistan and Uzbekistan, the area grown with cotton, also a large water-consuming crop has decreased while the area grown with grain has increased substantially. Although these measures may lead to a reduction of the water withdrawal, they make planning and monitoring water distribution more difficult.[133]

FUTURE PROSPECTS

Much progress has already been made since 1990. The total water withdrawal in the basin has now stabilized at about 110-120 km^3/year. However, further improvement is needed to meet the increasing demand from new water users. The living standards of the population near the sea are also a major concern, with most socio-economic indicators

[133] Op cit, No. 130

(life expectancy, health, drinking water supply, etc.) being dramatically negative. The responsible authorities are expected to take the necessary measures.

It has been estimated that at least 73 km^3/year of water would have to be discharged to the Aral Sea for a period of at least 20 years in order to recover the 1960 level of 53 m above sea level. The governments of the riparian countries do not consider this as a realistic objective.

Other more feasible options for the future of the Aral Sea have been envisaged by different parties:

- The stabilization of the Aral Sea at its 1990 level (38 m above sea level) would require a total inflow of about 35 km^3/year, including the demand for the delta area. However, this would not end the environmental degradation and desertification in the exposed seabed.
- The restoration of the Small Sea, or Northern Sea, to the level of 38-40 m above sea level would require an inflow of at least 6-8 km^3 in that part of the Aral Sea for the next five years.
- The restoration of wetlands in the Amu Darya delta and the conservation of the Western Sea would require an inflow of 11-25 km^3/year, with at least 5-11 km^3 of fresh water. Since 1989, a project has been implemented in Uzbekistan, which aims to bring more water to the delta through the collector-drainage network.

This water, combined with freshwater, is used to replenish shallow lakes. It has allowed the re-development of flora and wildlife in the abandoned areas and stopped the aeolian erosion of the former exposed seabed. Another result of this project has been a higher fish capture, estimated at 5 000 t/year in 1993, compared with 2 000 t/year in 1988.

Because the water resources of the basin are more or less stable, or even slightly decreasing due to the climatic change induced by the Aral Sea drying up, all extra water flowing to the Aral Sea should be saved from upstream existing uses. Major efforts should be made to: reduce losses in the rivers and canals, notably through lining and automatization of the distribution; stop irrigation expansion; to generalize micro-irrigation and other water saving techniques on existing irrigated areas; redirect drainage water and other spilled reservoir and canal water directly to the sea; return the non-consumed fraction of the water diverted into irrigation schemes to the Aral Sea.

According to the World Bank, the introduction of a water market could help save more water. Water quality problems increase from upstream to downstream due to the increasing salinity and pesticide content of agricultural return flow and the poor state of wastewater treatment plants in the basin. The defining of water quality standards and their observance may significantly affect the quantity of water considered as available for use. The introduction of a polluter pays tax would then be possible.

If they were sure that the water would actually go to the Aral Sea, the upstream countries would be ready to release more water. One important measure for the future would be to consider the Aral Sea and the two deltas as a sixth entity, in addition to the five Central Asian republics, to which a water allocation should be given. In the round of discussions between the countries, a figure of 20 km^3/year in normal humid years has been advanced for this environmental water demand, reduced to 12 km^3/year in the one dry year out of ten.

All these options and solutions have been studied for the regional water strategy exercise, which is the result of a cooperation of the riparian countries. This has been made possible by the setting up of an institutional framework to address the Aral Sea problem through selected national macro-economic and sectoral policies for achieving sustainable land, water and other natural resources development. This institutional framework currently includes only the countries of the FSU. However, Afghanistan, which covers about 12% of the Aral Sea basin, will probably become a greater water user as its stability increases, in effect reducing the flow of the Amu Darya tributaries accordingly. At a later stage, Afghanistan should be included in the agreements regarding the Aral Sea basin in order to guarantee sustainable water resources management in the basin.

MEETINGS AND DECLARATIONS

In September 1995, the five heads of the Central Asian republics endorsed the Nukus Declaration that was signed at the end of a three-day international conference on "Sustainable Development of the Aral Sea Basin", held in Nukus, Karakalpakstan. Among other things they promised to devote more effort and funds to ameliorate the Aral Sea crisis and improve the lives of the millions of people affected by it.[134]

Further efforts of the five Central Asian States Presidents directed at the Aral Sea crisis liquidation were developed at the Alma-Aty and Ashgabad meetings and their declarations. At the meeting held in Alma-Aty on February 28 1997, the presidents Nazarbaev N. (Kazakhstan), Akaev A. (Kyrgyzstan), Rahmonov A. (Tajikistan), Niyazov S. (Turkmenistan) and Karimov I. (Uzbekistan) were present.

ALMATY MANIFEST[135]

We, Presidents of fraternal states of Central Asia - the Republic of Kazakhstan, the Kyrgyz Republic, the Republic of Tajikistan, Turkmenistan and the Republic of Uzbekistan:

- striving for independence and sovereignty in strengthening of our countries, and raising the living standards of the people,
- resulting from the fact that the ecological safety is one of the main components of the national security and the most important aspect of interests and priorities protection in the Central Asian states,
- taking into account that the ecological disaster problem in the Aral Sea basin is of global character and its solution can not be delayed,
- taking into account that the extreme ecological situation in the Aral region negatively influences the natural living environment and living conditions of millions of residents not only in the Aral Sea basin, but also other regions of our planet;

[134] http://www.grida.no/aral/aralsea/english/about/region.htm
[135] Ibid.

- confirming our adherence to "Agenda for the 21st century" statements of the UNO world programme on environment supporting the tendency to work out and realize a single strategy on sustainable development of the Central Asian countries,
- recognizing that water resources management of transboundary rivers should have an ecosystem approach and be realized in a just and reasonable way without mutual damage, confirming the duties taken early for large scale cooperation at international and interstate levels,
- expressing the opinion of our countries, signed the Treaty on non-proliferation of nuclear weapons, and realize the necessity of declaring Central Asia a nuclear-free zone,
- resulting from steady striving for common actions in the name of overcoming the consequences of ecological crisis in the Aral Sea basin,

Declared:[136]

- the year of 1998 as a year of environment protection in the Central Asian region under the aegis of UNO.
- on the eve of the 50th anniversary of the Semipalatinsk test ground to call on all interested countries to support the idea of declaring Central Asia a nuclear-free zone open for joining by other states of the region,
- to mark efforts of the Central Asian states to undertake considerable measures for improvement of the ecological situation in the Aral Sea basin, in the region of the Semipalatinsk test ground and other zones being under nuclear test pressure, in spite of economic difficulties,
- to recognize the necessity of developing a complex programme of ecological safety including the Aral problem, to create a nuclear-free zone in Central Asia, and to struggle against nuclear technologies and raw material drain,
- to call on the UNO and its specialized agencies to pay great attention to the crisis situation in the Aral Sea basin and to undertake real measures to protect the

[136] Op cit, No. 134

environment in this region, drawing special attention to measures on rendering assistance to the grievous population of the Pre-Aral zone,

- to confirm readiness to promote international organizations and institutions in their activities to realize the programme of concrete actions and other regional projects,
- to complete together with international organizations the project development of the Convention on sustainable development of the Aral Sea basin

ASHAGABAD MANIFEST[137]

The meeting of Presidents of the 5 Central Asian states was held in Ashagabad (Turkmenistan) on April, 9, 1999. They confirmed the principles of the Alma-Aty declaration and outlined stages of task solutions in the future. The results of the meeting are reflected in the Ashagabad declaration:

"On the threshold of the 21st century humanity encountered drastic ecological problems impeding sustainable development. Degradation of environment is the result of irrational use of natural resources."

The consequences of the Aral crisis influenced negatively the life of the population in Central Asia, primarily by aggravating social protection and pure fresh water provision. The Central Asian states pay persistent attention to the improvement of the situation in the region, and to the attraction of international attention to aid in solving the problem. In co-operation with international organizations the project "Water resources and environment management" is realized with support from the Global Ecological Fund (GEF). It is directed to radically improve the use of water and other resources, raise the efficiency and the culture of nature use in the region, and improve the ecological situation as a whole. But the measures that have been taken so far to solve the Aral Sea problems have not been sufficient.

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[137] Op cit, No. 134

We, the Presidents of the fraternal states of Central Asia - the Republic of Kazakhstan, the Kyrgyz Republic, The Republic of Tajikistan, Turkmenistan and the Republic of Uzbekistan:

- striving for providing well-being and belief in the future of our people,
- recognizing the necessity to work out joint measures in the regional strategy and specific actions on rational water resources use of the region based on ecosystem and integral principles of water economy activity,
- taking into account that water resources use in the basin of the Aral Sea should be observed according to the principles of neighbourhood and mutual interests by all parties,
- underlying the role of member-states of the Fund to strengthen cooperation in the field of water resources and environment protection management, and rehabilitation of water ecosystems, preventing transboundary water from pollution,
- confirming the measures taken on the joint realization of the specific action program on the Aral sea problems,
- confessing that public awareness is an important condition for agreed actions in ecological, social and economic policy in the region resulting from steady attempts to overcome the crisis consequences and improve the ecological situation in the basin of the Aral Sea together,

Declare:[138]

- to recognize the significance of a complex problem solution connected with the improvement of social and ecological situation in the basin of the Aral Sea,
- to strengthen activity of the states and their representatives abroad for attracting attention of the international public, means and possibilities of state-donors, funds and organizations to programs and projects on the Aral Sea basin problems,

[138] Op cit, No. 134

- to provide conceivable assistance and support of the World Bank and Global Ecological Fund project "Water resources and environment management in the basin of the Aral Sea",
- to pay more attention to problem solution of the mountainous territories - zones of river flow formation in the basin of the Aral Sea,
- to realize measures and projects of priority directions in social protection of the population inhabiting the basin of the Aral Sea
- to activate efforts directed towards the struggle against desertification and pollution of transboundary water,
- to promote international organizations and institutions in their activities in program and project realization in the basin of the Aral Sea,
- to contribute to higher public awareness on actual problems of environment, rational nature use and improvement of living environments for the present and future generations through educational and other programs.

THE FRAMEWORK FOR REGIONAL COOPERATION

Agreements in the Soviet Period

Cooperation in the Soviet period involved international agreements and regional arrangements for water resources in the Amu Darya and Syr Darya basins. International agreements on the uses and quality of frontier waters were signed between the USSR and Afghanistan in 1946[139] and 1958[140]. These agreements established an international commission to deal with the use and quality of frontier water resources.

Since the collapse of the Soviet Union, the Amu Darya basin states have inherited the responsibilities of the commission, but appear to have made little progress in achieving further cooperation with Afghanistan[141]. Since Afghanistan is an upstream riparian, sharing with Tajikistan several tributaries of the Amu Darya it is essential that the Central

[139] Frontier Agreement between Afghanistan and the USSR (with Protocol), 13 June 1946, Moscow.
[140] Caponera, D.,'Legal and institutional framework for the management of the Aral Sea basin water resources', Report for the European Union – TACIS Programme, Tashkent, 1995, pp.25–26.
[141]Nanni, M., 'The Aral Sea Basin: legal and institutional issues', RECEIL, Vol. 5, pp.130, at 1996, pp.131–132.

Asian republics negotiate further agreements (once there is someone to negotiate with) on the equitable utilization of these water resources[142]. Otherwise, the unilateral diversion of water by Afghanistan for its own purposes (to the detriment of downstream states) would result in further economic hardship, environmental damage, and create a potential for conflict.

Regional schemes in the Soviet period – under the central management of the Ministry of Water Management – provided the construction of the hydraulic works needed to satisfy irrigation and other water demands in the Syr Darya and Amu Darya river basins. These central plans also apportioned water from each tributary, reservoir, canal or water intake, calculated according to crop needs, and was subject to modification by the Republics to address more specific and seasonal water requirements[143]. However, none of these arrangements regulated the quality of drainage water which was disposed into the rivers.

Agreements among the Independent Republics

Having recognized the need to cooperate on water issues and within a year of the dissolution of the Soviet Union in 1991, the five Central Asian Republics reached an agreement concerning transboundary water resources[144]. This early attempt at cooperative utilization and protection of 'common and integral' water resources led to the establishment of the Interstate Commission for Water Management Coordination (ICWC), with a mandate to control and ensure rational utilization and protection of the interstate water resources[145].

Until recent changes, the ICWC was responsible for the development of regional water management policies to ensure rational utilization of water resources and to provide incentives for adherence to the regional water allocation regime. The ICWC also governed the activities of the two regional Basin Water Management Bodies

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[142] Bourne, C., 'The International Law Association's contribution to International Water Resources Law', *Natural Resources Journal*, Vol. 36, 1996, pp.155–216.
[143] Op cit, No. 141
[144] Agreement on cooperation in the management, utilization and protection of interstate water resources, 18 February 1992, Kazakhstan-Kyrgyzstan-Tajikistan-Turkmenistan-Uzbekistan (1992 Agreement). For a detailed analysis of the agreement, see Vinogradov, pp.406–412.
[145] Op cit, No. 144

(Bassejnovoe Vodnoje Ob'edinenie – BVO): BVO 'Amu Darya' and BVO 'Syr Darya', both of which were created in 1986. Since 1992, the ICWC and the two regional BVOs were responsible for short and long-term water development and allocation planning, water quality control, conservation and environmental protection.

The momentum for regional cooperation was maintained by the establishment of four other intergovernmental institutions between 1993 and 1995. These institutions were:

- The Interstate Council on the Aral Sea Basin (ICAS), intended to formulate policy, provide inter-sectoral coordination and review the projects and activities conducted in the Basin;
- The Executive Committee of ICAS (EC-ICAS), intended to implement the Aral Sea Program;
- The International Fund for the Aral Sea (IFAS), entrusted with the coordination of financial resources provided by member states, donors and international organizations[146]; and
- The Sustainable Development Commission (SDC), designed to ensure that economic, social and environmental factors are given equal weight in planning decisions[147].

While this institutional framework has been criticized for its lack of clarity with respect to the functions of different organs of the same institution (i.e. ICAS and EC-ICAS); for confusion between decision making organs and executive organs; and for duplication of functions between different institutions, it may be considered as a stage in the development of the framework for joint decision making and management of transboundary water resources among the Republics[148].

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[146] The decision to create the IFAS WAS taken by leader of the Aral basin states on 4 January 1993. The Statue (Regulations) of the Fund was adopted at a meeting in Kzyl Orda on 26 February 1993. The IFAS Board and the Auditing Committee were created pursuant to a Resolution of the IFAS President on 20 March 1997.

[147] Boisson. de Chazournes, L., 'Elements of a legal strategy for managing international water courses: The Aral Sea Basin', in: Salman, S. and Boisson de Chazournes, L. (Eds.) International Watercourses: Enhancing Co-Operation and Managing Conflict (World Bank Technical Paper, No. 414), 1998, pp.65–76.

[148] Op cit, No. 140

Subsequent efforts to clarify and rationalize the responsibilities and functions of these institutions may be observed through a series of draft agreements, focusing on three main issues related to water resources in the Aral Sea Basin.

RECENT AGREEMENTS AND DRAFT AGREEMENTS

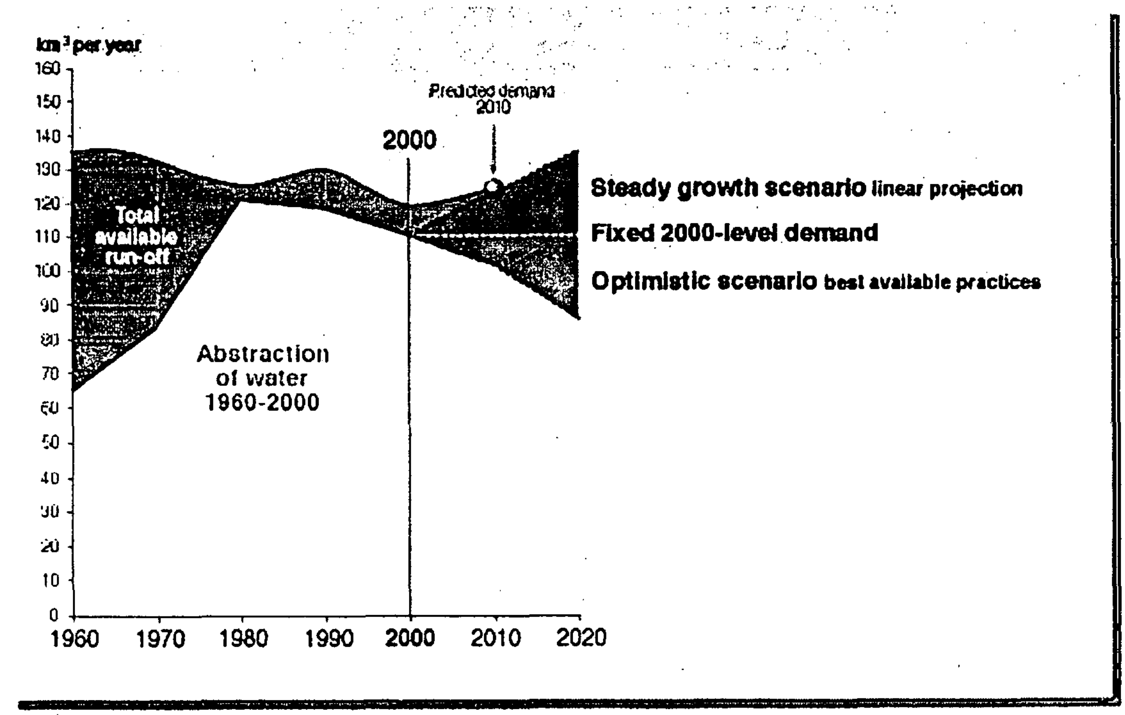
Efforts since 1995 to achieve progress on issues of use and management of transboundary water resources among the Aral Sea Basin states have focused on institutional issues (the clarification of mandates for the various international organizations concerned with the Aral Sea), the current uses of scarce water resources, and the joint planning (cooperative management) and protection of water resources among the parties. The European Union (TACIS Program) launched a program in 1995 to support the drafting of water sharing agreements through the organization of training activities, the establishment of working groups and the provision of advice by experts on international water law[149].

The Aral Sea Basin Management Model

Irrigated agriculture in Central Asia has history of more than 5 thousand years. But during the last 40 years the overuse of the water resources resulted in the Aral Sea crisis when almost all water that used to go to the Aral Sea was being used for irrigation. This is shown in the graph below. The white area depicts the usage of water. The upper wave-shaped line is the total water that is available from rivers, while the blue area represents the water that is remaining for the Aral Sea. The amount of available water fluctuates over time and due to climate change affects the amount of water available from the rivers and is slightly diminishing over the years. Now in the third millennium we face an enormous dilemma: due to economic developments the demand for water could increase again, even to a level using all available water, leaving nothing for the Aral Sea. The challenge is to moderate water demands so that it remains on the current usage level but better still, to improve the situation for the Aral Sea by reducing demands.

149 Op cit, No. 147

Fig 13: The Aral Sea Basin management model

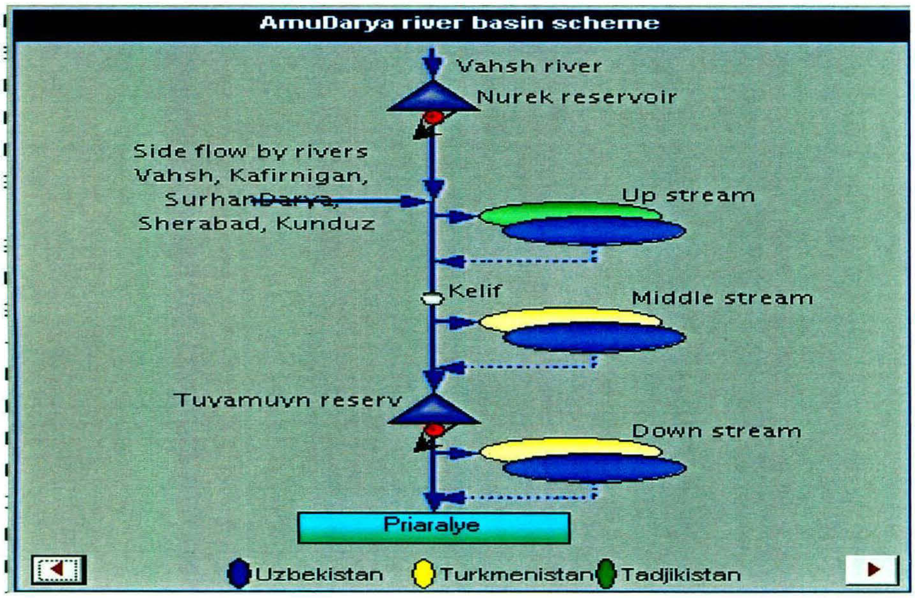


Sources: SIC ICWC, IFAS, World Bank

The Hydrological Model (HYM)

The Aral Sea Basin is unique in the world: the flow of water in the area is completely controlled by humans. Large structures like dams, reservoirs, channels, bifurcations and constructions determine where, when and how much water will flow. A model describing these flows requires a lot of specialized knowledge. Taking a generic model and modifying this a little will not suffice. Fortunately, the expertise is there, as well as the capability to put this in a model. The details (which elements are used) as well as the software are hidden from the user. The results however are made available. The model is capable of allocating water depending on activities and considerations as "hydropower first", "irrigation first", or "balance water between irrigation and hydropower". Given the complexity of the system, even a powerful computer needs some time to calculate the water flows and mineralization.

Fig 14: The hydrological model (HYM)

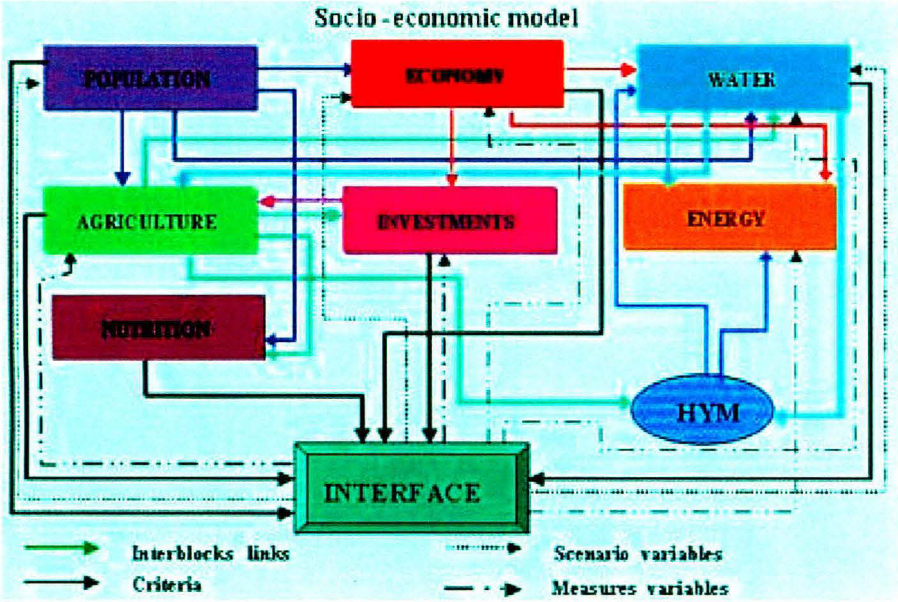


The Socio-economical Model (SEM)

This model attempts to predict what will happen with the socio-economical system. Human behaviour is very important here, and not very predictable. Nevertheless it is possible to extrapolate some current figures to future situations. The model does this for:

- Population (number of people, births, deaths, health)
- Economy (growth, income, employment)
- Water (demands; availability is calculated by the hydrological model)
- Agriculture (crops, cattle, arable land, yield)
- Investments (industry)
- Energy (production and consumption)
- Nutrition (production and consumption in calories)

Fig 15: The socio-economical model



There is interaction between this model and the hydrological model: water usage is determined by the demand (calculated here) versus the supply (calculated by the hydrological model). The socio-economical model deals with these areas and brings forth synergies between these two models.

Joint Planning of Transboundary Water Resources

Two additional draft agreements address issues related to the 'joint planning of transboundary water resources' among the Central Asian republics[150]. The primary outcome of the preparation of these draft agreements has been the elaboration of a Regional Water Strategy with short (one-year), medium (five-year) and long-term (15 to 25 year) objectives. The overall objectives of the Regional Water Strategy are to assess regional water resources and the potential for changes in their quality and quantity; to assess national and regional water requirements and the possibility of curtailing these

[150] Draft Agreement No. 3 on joint planning of the transboundary water resources, 28 February 1997, Kazakhstan-Kyrgyzstan-Tajikistan-Turkmenistan-Uzbekistan; Draft Agreement on joint planning of the use, development and protection of the transboundary water resources, 3 April 1997, Kazakhstan-Kyrgyzstan-Tajikistan- Turkmenistan-Uzbekistan.

demands through effective management; to promote the conditions necessary for a sustainable ecosystem in the Aral Sea zone[151].

The Strategy also recognizes the importance of considering alternative uses for water resources and irrigated lands as part of a more rational development plan for the region. The Strategy notes that regional development depends upon the elaboration of legal, economic, technical and institutional mechanisms to promote compliance and to reduce conflicts over water resources. However, it fails to elaborate on the legal and economic mechanisms appropriate for this particular region. Articles 4–7 of the Strategy provides details for the physical management of water resources through 'perspective', 'medium term' and 'current' planning regimes under the auspices of the ICWC. The Strategy urges the parties to pursue technical standardization of all rules, instructions, methods of measurement and other normative documents among institutional bodies. In addition, articles 8 and 11 provide basic procedures for the implementation of initiative projects, with regard for the impact of these projects on other parties.

Provisions relevant to joint planning under the 1997 UN International Watercourses Convention include the obligation:

1. to cooperate to attain optimal utilization and adequate protection of the international watercourse (i.e. through joint mechanisms or commissions)[152]

2. to protect its ecosystem through the prevention, reduction and control of pollution[153], and;

3. to enter into consultations concerning the management (i.e. sustainable development, rational and optimal utilization, protection and control) of the international watercourse[154].

[151] Op cit, No. 150
[152] Ibid.
[153] Ibid.
[154] Ibid.

Future agreements should make direct reference to these principles and reflect the experience gained through cooperation in existing joint mechanisms and commissions in various regions throughout the world.

INSTITUTIONAL ISSUES

The evolution of the institutional framework for the management of transboundary water resources in the Aral Sea Basin may be observed in a series of agreements and draft agreements entitled 'development of cooperation and improvements of protection, management and development of the water resources in the Aral Sea Basin'. The objective of these agreements has been to streamline the interstate bodies and organizations involved. In September 1995, representatives of the Republics met in Nukus and Uzbekistan to sign a Declaration on the sustainable development of the Aral Sea Basin. The parties affirmed their financial obligations to the International Council for the Aral Sea (ICAS) and the International Fund for the Aral Sea (IFAS), and their commitments to strengthen the Interstate Commission for Socio-economic Development and Scientific, Technical and Ecological Cooperation (then called the 'Sustainable Development Commission')[155].

A subsequent draft agreement prepared in 1996 set out the composition and functions of the ICAS in highly general terms, including the improvement to the ecological situation of transboundary waters, and the development of water management policies and perspectives. The draft agreement also emphasized the importance of capacity building for interstate water management organizations and attempts to clarify the activities of the Scientific Centre (SC-ICWC) and the functions and status of the respective Basin Water Management Bodies (BVO Syr Darya and BVO Amu Darya).

After several drafts, the parties eventually agreed that the institutional framework would fall under the auspices of the International Fund for Saving the Aral Sea (IFAS) and its

[155] Proceedings of the Nukus International Conference on Sustainable Development of the Countries of the Aral Sea Basin (Nukus Report), Nukus, Sept 1995, pp. 15.

Executive Committee (EC IFAS); and the Interstate Commission on Water Management Coordination (ICWC) and its executive bodies: the Secretariat, the Scientific Centre (SCICWC), the Basin Water Management Body Syr Darya (BVO Syr Darya) and the Basin Water Management Body Amu Darya (BVO Amu Darya)[156].

International Fund for the Aral Sea (IFAS)

Established in 1997, the new International Fund for the Aral Sea (IFAS) – as a successor to the former ICAS as well as to the former structure of the IFAS – has a Board composed of Deputy Prime Ministers of the five states, with portfolios involving agriculture, water and the environment[157]. The Board meets at least three times a year to discuss the views of member states and to decide on the policies, programs, and institutional proposals recommended by the Executive Committee (renamed the Executive Committee of IFAS), which is the permanent working body of the fund. The IFAS also retains its former responsibilities for managing contributions and financing program activities, pursuant to a set of regulations on the IFAS and its Auditing Committee[158].

The International Commission on Water Management Coordination (ICWC)

The relationship between the new IFAS and the International Commission for Water Coordination (ICWC or 'Commission') remains somewhat unclear. For example, the 1997 Draft institutional agreement designated the commission as the umbrella organization with the requisite international legal status to coordinate water management programs in the Aral Sea Basin[159]. The Commission was to be composed of ministers or delegates entrusted by their governments to represent state interests at quarterly meetings.

[156] Draft Agreement on development of co-operation and differentiation of the functions of the interstate organizations in the sphere of protection, management and development of the water resources in the Aral Sea Basin, 20 October 1996, Kazakhstan-Kyrgyzstan-Tajikistan- Turkmenistan-Uzbekistan, (Version No. 4); Draft agreement on development of cooperation and improvement of protection, management and development of the water resources in the Aral Sea Basin, 2 April 1997, Kazakhstan-Kyrgyzstan-Tajikistan- Turkmenistan-Uzbekistan.

[157] Regulations on the work of the Board of the International Fund for the Aral Sea and the Auditing Committee, para. 1 (20 Mar. 1997).

[158] Ibid.

[159] Ibid.

Delegates to the Commission were simultaneously to consider all sectors of their national economies, as well as the regional interests of the basin and of the Aral Sea itself[160]. However, these functions now seem to come under the mandate and procedures of the new IFAS.

Nonetheless, the functions of the Commission are not entirely displaced. Surviving functions include supervision over the management of transboundary water resources in accordance with interstate agreements; distribution of annual water limits to the parties and to the Aral Sea, and development of measures to maintain the regimes of water supply and distribution[161]. These functions are consistent with the concept of the Commission and its organs as an implementing agency, whereas the IFAS would be responsible for policy and financial decisions.

The 1997 Draft institutional agreement also provides that the Commission would draft legislation to clarify the management regime for transboundary water resources in the Aral Sea Basin[162]. While the importance of the legal framework for cooperation in the Aral Sea Basin cannot be overemphasized, the effectiveness of any model legislation or agreements will depend on the clarity of the instruments, their consistency with prior agreements and with international standards. It is apparent that the requisite legal expertise has not been sufficiently involved in the drafting of agreements to date.

Dispute Resolution

The lack of legal precision is also apparent in the absence of adequate provisions for dispute resolution in the post-independence agreements. The 1992 Agreement refers water disputes to the Ministers of Water Resources for the five republics[163]. However, it does not provide for situations in which the Ministers are unable to resolve the dispute. A subsequent draft international convention provides that any intentional violation by a

[160] Op cit, No. 150
[161] Ibid.
[162] Ibid.
[163] Ibid.

basin state beyond water withdrawal limits, regimes and schedules, determined by the ICWC and its executive bodies, causing damage or affecting the interest of other basin states, leads to a penalty and to liability for compensation. Such cases are to be heard by an arbitral court composed of three nationals of third states[164].

Although the 1997 Draft institutional agreement deals with such important matters as the distribution of annual water limits and the determination of reservoir releases, it makes no reference to dispute resolution. Another 1997 draft Agreement on the use of water resources in the present conditions has an arbitration clause providing that the ICWC will create an Arbitration court to 'consider claims and make relevant decisions'[165]. However, the clause lacks reference to applicable law or procedure. It is further weakened by a subsection which provides that the Party in fault is exempt from 'indemnities and penalties if its actions were not prejudiced, not systematic or caused by emergency situations (flood, natural calamity, military actions)[166].

There is a need for a dispute settlement mechanism that clarifies the type of tribunal, the applicable law and procedure, and the authority of the dispute settlement body. Beyond interstate negotiation, one option for dispute resolution could be the creation of a body within the Aral Sea Basin states, independent of the Commission or successive executive bodies. This body could seek the advice of international water law experts while remaining sensitive to the political context of the dispute. In the event that such an internal mechanism was unable to resolve a dispute, recourse to international arbitration may be advisable. This system could provide a flexible dispute resolution mechanism that is appropriate for the Aral Sea Basin states. Thus, the relevant provisions should be included in future agreements to avoid the present system of leverage, negotiation and recurrent conflict.

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[164] Op cit, No. 140

[165] Draft Agreement on the use of water resources in the present conditions, 28 February 1997, Kazakhstan-Kyrgyzstan-Tajikistan-Turkmenistan-Uzbekistan.

[166] Op cit, No. 150

The ICWC Secretariat

The Secretariat, based in Khodjent (Tajikistan), acts as a standing executive organ of the ICWC, reporting the implementation of decisions taken by ICWC. The Secretariat organizes the meetings, prepares the budget and programs of the ICWC. The budget for the Secretariat is paid by the Republic of Tajikistan, presumably as part of its share of the overall ICWC budget[167].

The Scientific Information Centre (SIC-ICWC)

The SIC-ICWC is based in Tashkent (Uzbekistan), with branches to be established in Kazakhstan, Kyrgyzstan, Tajikistan and Turkmenistan. It includes[168]:

- the regional Scientific Research Institute, SPA SANIRI;
- the regional planning Scientific Research institute, Vodavtomatika and Metrologia;
- five national scientific information centres; and
- six national organizations.

The functions of the SIC-ICWC are mostly of a technical nature. They include the creation and management of a unified database for water resources in the Aral Sea Basin, the development of automated systems to be used in the management of the BVO Amu Darya and BVO Syr Darya, and the organization of regional training courses for water management personnel. However, clarification is necessary with respect to the role of the Scientific Information Centre in policy development and international project coordination[169].

The BVO Amu Darya and BVO Syr Darya

The BVO Amu Darya, which is based in Urgench, was established as an interstate organisation in April 1992. It is directly responsible for water allocation, quality control and operation of structures in the Amu Darya river basin. Similarly established and based

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[167] Op cit, No. 150
[168] Ibid.
[169] Ibid.

in Tashkent, the BVO Syr Darya has the same set of responsibilities for the Syr Darya river basin. In order to guarantee the water supply to the Aral Sea, Kazakhstan transferred control of all structures on the Syr Darya to the BVO[170].

Current Use of Water Resources

The issue of current water utilization in the region is particularly sensitive, as evident in ongoing negotiations and disputes among the governments of the Central Asian republics over water allocation. Some recent decisions by upstream riparian governments – to reduce the water made available to downstream states and to charge for water in excess of previously agreed allocations – have resulted in disputes over allocation, pricing and payment. For example, representatives met in the Tajik city of Khujand in July 1997 to discuss Kazak and Uzbek requests to increase the volume of water flowing from the Kaira Kum Reservoir in Tajikistan into the Syr Darya. The issue remained unresolved, as the Tajik representative reportedly stated that only the central government of Tajikistan could make such a decision. At the same time, Kyrgyzstan reportedly announced plans to charge its neighbours for water from the Naryn River[171]. Also, public reaction to water shortages in Kazakhstan (perceived to be the result of Uzbek cutbacks) has taken the form of open demonstrations[172].

Whereas long term planning is of critical importance, current utilization and allocation of water resources is an indicator of not only demand patterns among the Republics, but also the state of negotiations and compromise that engender the overarching issues of regional cooperation and sharing of scarce water resources. This is also the forum where radically new approaches and concept can be tested. The concept of trading energy resources among the Republics (hydrocarbon resources to be used in power generation, for water critical to agricultural sectors) is gaining momentum at present. Before such innovations

[170] Op cit, No. 150

[171] B. Pannier & S. Aioubov., 'Central Asia: Tajik and Uzbek Presidents Meet' (Prague, 6 January 1998, Radio Free Europe) (19 August 1998).
www.rferl.org/nca/features/1998/01/F.RU.980106134242.html

[172] Goble Paul., 'Central Asia: analysis from Washington – a watershed in Central Asia', (Washington, 25 July 1997, Radio Free Europe) (19 August 1998).
www.rferl.org/nca/features/1997/07/F.RU.970725144746.html

are fully considered, let us consider the most recent draft agreements on the 'use of water resources in present conditions'.

Two draft agreements prepared in 1997 proceed from the interest in joint use of water resources in the Aral Sea Basin and the acknowledgement of international legal principles relevant to the use of transboundary water resources[173]. These 1997 draft agreements on utilization seek to provide common definitions and to clarify the applicability of the agreements to all transboundary water resources. However, they do not apply to water resources that are local in nature (i.e. not connected to transboundary waters) river, ground or return waters.

The main provisions of the 1997 draft agreements on utilization include joint management clauses, which refer to the 'basin principle'[174], providing for the equality of the parties' right to use, and responsibility to ensure rational utilization and protection of the water resources of the region, which are defined as 'common and integral'. The basin principle appears to have been elaborated to include the 'rational' use of water resources and the prevention of 'considerable harm' to all users and natural ecosystems. The parties also agree not to use more water than allocated to them[175].

While these provisions are certainly an improvement over earlier arrangements based on the concepts of 'water apportionment' and 'maximum utilization', efforts must go further to recognize the principle of 'equitable and reasonable utilization and participation', in accordance with Article 5 of the UN Convention on the Law of the non-navigational uses

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[173] Draft Agreement No. 2 on the use of water resources in the present conditions, 28 February 1997, Kazakhstan-Kyrgyzstan-Tajikistan-Turkmenistan-Uzbekistan; Draft Agreement on the use of water resources in the present conditions, 3 April 1997, Kazakhstan-Kyrgyzstan-Tajikistan-Turkmenistan-Uzbekistan.
[174] Op cit, No. 150
[175] Ibid.

of international watercourses[176]. The principle of 'equitable and reasonable utilization' takes into consideration (but it is not limited to) such factors as:

- geography, hydrographic, hydrological, climatic, ecological and other factors of a natural character
- social and economic needs of the States concerned
- the population dependent on the water resources; the effects of usage on other States; existing and potential uses
- conservation, protection, development and economy of use of water resources, and
- the availability of alternatives to a planned or existing use[177]

Additional principles of the 1997 UN Convention on International Watercourses which are of particular relevance to the Aral Sea basin States include:

- the obligation not to cause significant harm to other watercourse States[178]
- the general obligation to cooperate (through joint mechanisms or commissions)[179]
- to exchange information on a regular basis,[180] and
- to provide timely notification of planned measures and emergency situations which may have a significant adverse effect upon other watercourse states[181]. Nevertheless, where significant harm is caused to another state, the party responsible for causing such harm in consultation with the affected state is obliged to take appropriate steps to eliminate or mitigate such harm, and where appropriate, to discuss the question of compensation[182].

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176 The Convention is annexed to U.N.G.A. Res. 51/229, 21 May 1997, adopted by a vote of 103 for and 3 against, with 27 abstentions; reprinted in (1997) Int. Legal Materials, Vol. 36, pp.700–720 (1997 UN International Water Courses Convention').

177 Ibid.

178 Ibid.

179 Ibid.

180 Op cit, No. 150

181 Ibid.

182 Ibid.

PROSPECTS FOR REGIONAL SOLUTIONS

Energy resources in the Aral Sea region

The Central Asian republics have recognized that cooperation over the planning, development and utilization of scarce water resources is essential. Efforts to establish an institutional framework to coordinate environmental cooperation have made progress. One of the problems is that attempts to resolve ecological problems and water scarcity have until very recently focused almost exclusively on water resources. However, there are indications that other natural resources are increasingly considered as part of a holistic approach to the water supply and demand in the region.

Hydrocarbon Resources

Central Asia is known to be rich in hydrocarbon resources, including oil, natural gas and coal. Estimated potential coal resources (concentrated mostly in Kyrgyzstan and Uzbekistan) are 30.5 million tonnes[183]. Potential oil reserves (1.4 billion tonnes) and potential gas resources (17.3 trillion m^3) had been located in Turkmenistan and Uzbekistan. Explored reserves represented 40 per cent of the initial potential oil resources, and 34.6 per cent of the natural gas resources. At the end of 1996, Kazakhstan alone had proved oil reserves of 8.0 thousand million tonnes, enough at annual production rates to last 48 years[184]. Proved natural gas reserves total 1.84 trillion cubic feet in Kazakhstan, 2.89 trillion cubic feet in Turkmenistan and 1.89 trillion cubic feet in Uzbekistan[185]. Developed and ready-for-extraction deposits accounted for approximately 53 per cent of the explored coal reserves, 82 per cent of the oil reserves, and 93 per cent of the natural gas reserves[186]. In addition, the first discoveries in the Aral Sea region are estimated to contain 2 billion tons of recoverable oil reserves[187]. Discussions are now underway about the creation of an Aral Petroleum Consortium. While greater certainty exists over the borders between Kazakhstan and Uzbekistan on the Aral Sea, it remains to be seen whether an Aral Consortium could proceed without legal and territorial disputes

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[183] UNEP., "Diagnostic study for development of an action plan for the conservation of the Aral Sea Basin", 1992.
[184] BP Statistical Review of World Energy 1997, p.4.
[185] Ibid
[186] Op cit, No. 183
[187] Aral Invites Investors, (November 1997) Oil and Gas of Kazakhstan, Vol. 6, p.29

similar to those in the Caspian Sea. However, the possibility remains that the development of petroleum resources could promote the solution of ecological problems in the Aral Sea Basin through cooperative exploitation and support for regional institutions that manage the Aral Sea Basin.

Hydroelectric Resources

The Syr Darya and Amu Darya river basins house a complex system of dams and reservoirs, primarily used for water storage in winter and release for irrigation and power production in summer. The World Bank counts more than 80 water reservoirs, 45 hydropower plants and 57 large dams in the Aral Sea Basin[188]. Hydroelectric resources are concentrated in Tajikistan (with the third largest in the former Soviet Union) and Kyrgyzstan. The potential hydroelectric resources of the Amu Darya and Syr Darya total 306 and 162 billion kilowatt hours, respectively. The economic potential of the hydroelectric resources for the entire region is 127 billion kilowatt hours, including 80 billion kilowatt hours in Tajikistan, 37 billion kilowatt hours in Kyrgyzstan, and 10 billion kilowatt hours in Uzbekistan[189].

Trade in Natural Resources

Trade in natural resources may provide solutions to water scarcities affecting the entire Aral Sea region. First, it is important to recognize the difference between upstream power generation and downstream irrigation in terms of seasonal demands for water. The peak demand of the upstream riparian in the Aral Sea Basin for power generation is in the cold winter months. However, Tajikistan and Kyrgyzstan generally store runoff from the Pamir mountain glaciers in reservoirs during the summer months to ensure adequate supplies for power generation in the winter. The dry summer months are precisely when downstream riparian have peak demand for agricultural irrigation. This anomaly is the crux of conflicting demand patterns that affect the Aral Sea Basin on an annual basis, and the origins of current conflicts over upstream decisions to charge for releases from its reservoirs.

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188 Op cit, No. 147

189 Op cit, No. 183

The substantial petroleum and coal reserves in Kazakhstan, Uzbekistan and Turkmenistan could be used to fuel power stations in Kyrgyzstan and Tajikistan. Reduced demand for water to generate hydroelectric power in Tajikistan and Kyrgyzstan could make additional water resources available for agricultural and industrial uses in the other Republics, and for the Aral Sea itself. While this option is now being discussed and tested in a series of annual agreements to trade hydrocarbons and water between Uzbekistan, Kazakhstan and Kyrgyzstan, the parties will undoubtedly encounter further obstacles, including issues related to valuation, compliance and monitoring. Effective dispute resolution mechanisms will be essential to these trade arrangements, as is the case with most regional trade agreements. If these considerations are taken care of, there is definite potential for regional solutions through trade in natural resources.

With the objective of achieving a system for trade in natural resources, the prime ministers of Kazakhstan, Uzbekistan and Kyrgyzstan (with observers from Russia and Tajikistan) met in March 1998 at Bishkek, the capital of Tajikistan. Six documents were signed, including an Agreement to form a consortium on hydro-energy resources. In addition, Kazakhstan reaffirmed its intention to barter coal for water supplies from Kyrgyz reservoirs; and Uzbekistan again promised deliveries of natural gas for Kyrgyz water deliveries[190].

PROSPECTS AND CHALLENGES

Coordinating Central Asia Research

Research in Central Asia is carried out by three groups: national academies of sciences, institutes of higher learning, and industrial research institutes and centres. The national academies of sciences of Central Asia are the most prestigious centres of scientific research, to the extent that almost all leaders of each country are full members of their academy. The national academy, though fully retaining its independence, cooperates with the government in formulating plans for scientific research and development. The

[190] Central Asian Customs Union Meets, RFE/RL Newsline Vol. 2, No. 52, Part I, 17 March 1998. The same report indicated that the presidents of the three countries were to meet again in Tashkent on 26 March 1998.

academy is a state agency whose main functions are to organize scientific management and to supervise theoretical research in the natural and social sciences being conducted in all the country's research centres. In addition, the national academy also determines the overall direction of research and coordinates it countrywide.

Among the academy's activities are the training of research personnel, the strengthening of ties between science and education, and the introduction of the latest knowledge and discoveries into the curricula and research programmes of higher education institutions. The broad cornerstone of an academy's activities is to blend the development of fundamental and applied research and to strengthen relations between science and the needs of the economy.

It seems clear that we need a carefully developed comprehensive research project for the regeneration of the environment of Central Asia, which should have an international level of significance and be implemented in close cooperation with colleagues from abroad. And it is the national academies of sciences of each republic that possess sufficiently high and versatile scientific potential to produce such a project. Their academies have great experience in the study of natural resources, the environment, and ecology - suffice to say that a score of academic institutes deals directly with the research problems of the environment and nature.

The Establishment of an International Research Centre

Researchers from Kyoto University in Japan and the Kazakh National Academy of Sciences propose to establish an International Centre for Central Asian Ecology in Central Asia. Its primary aim is to undertake research on such global environmental problems as desertification, climate aridization, and radioactive pollution. A second goal is to identify and adapt new technologies and new institutions to Central Asian countries.

This International Centre will welcome talented scientists in various fields from abroad as well as support (both morally and financially) scientists from Central Asia. The International Centre project proposes to integrate the resources of various scientific specialties on an interdisciplinary basis in order to offer solutions to the major environmental problems of the contemporary world. This will require a concentration of scientific expertise at an international level, and sound cooperation between the academic and industrial sectors.

The Rationalization of Water Use

The problem of the rationalization of water use must be addressed based on the comprehensive analysis of regional social and ecological factors. Unfortunately, during the Soviet period, economic decisions were often made without taking into consideration the importance of protecting the environment and the social and economic welfare of the regions involved. For example, a root cause of the "Aral Sea Problem" was the short-sighted economic view of those involved in the development and management of extensive irrigation projects. Driven by the potential for high profit, the environmental consequences of irrigation development were often ignored. This situation still exists in some of the Central Asian republics situated in the upper regions of the Syr Darya waterbed. The task of the scientists is to reveal the underlying processes of agricultural and economic development and its impacts and to give qualitative or quantitative forecasts of the consequences of large projects.

The Need to Improve Water Quality

The other important challenge is how to improve water quality by means of sewage treatment and disposal, and the limitation of waste discharges and of mineral fertilizer use. The uncontrolled use of mineral fertilizers and pesticides has a negative impact on the environment and especially on human health. In the growing season, pollution of Syr Darya's waters by pesticides reaches 12 MPC (maximum permissible concentration); for nitrates it amounts to 46 MPC. Mineralization of water in the Syr Darya (previously fresh) reached 3 gm/litre, which is 10 times the recommended health standard.

In view of these conditions, the evaluation and control of environmental quality and economic activities in this area should be included in the emergency programmes of the region's policy makers. It has become important to determine priorities for regional environmental policies and to reform the structure of agriculture. Environmental systems are generally considered as multi-objective systems. Optimal standards for environmental quality and economic activities include many conflicting goals. In Sultangazin and Tsukatani some mathematical models were constructed for the evaluation and management of regional environmental systems. Waste disposal planning is defined at two levels in models.[191]

The Need to Protect and Re-create Landscapes and Ecosystems

The degradation of vegetation is occurring over practically the whole of the Aral Sea basin. This is primarily caused by the salinisation of soils, resulting from irrigation and salt-dust storms. The number of salt-dust storms has increased with alarming frequency. At present the area of dried seabed is 36,000 km^2 and it is located mostly along the eastern part of the Sea. Every year about 150,000 metric tons of dust and salt are lifted into the atmosphere. If we don't stop this process in future, then the active desertification of adjacent territories and the merging of the newly created Aral desert (the Aral Kum) with the Kara Kum and other deserts in the region may lead to the creation of a new desert of Saharan proportions at the centre of the Euro-Asian continent, which can have only negative consequences. Therefore, first of all it is necessary to create artificial landscape ecosystems in the river deltas and in the dried-up bottom of the Aral Sea. Some results of scientific investigations of phyto-melioration prepared by the Academy of Sciences can be used for the creation of artificial ecosystems.

The Kazakh Academy of Sciences has made considerable strides toward solving the problems of natural resource usage in the republic. The research and development activities of a number of institutes during the past ten years have covered a wide scientific spectrum of the dynamically changing nature of Kazakhstan. For example, the Institute of Hydrology and Hydro-physics is monitoring and investigating the state and environmental condition of groundwater resources in the territory of the republic. The Institute of Geography is investigating the hydro-ecological stability of the Aral and the

[191] Sultangazin, U. M. and T. Tsukatani., "*Modelling of the Kazakhstan Economy and Environment*" Discussion Paper No. 416, 1995 Kyoto University, Japan.

Caspian Sea basins and is studying the anthropogenic influences on deserts and other geo-systems. The Institute of Soil Sciences is investigating the ecological disturbance to soils in southern Kazakhstan (in the valleys of the Syr Darya, Chu, Ili, Talas, Karatal, etc.) and in the region of the Aral Sea, and disturbances on the slopes of Kazakhstan's Tien Shan mountain range.

The Institute of Botany is developing phyto-meliorative for the arid areas of the exposed seabed and is conducting investigations into the productivity of pastures and into the biology and ecology of plants in the Aral region. It is also developing maps of plants and of desertification for the territory of Kazakhstan. The Institute of Zoology is studying technogenic factors and agricultural activity that adversely influence the flora and fauna of the republic. At the Institute of Zoology, the state of ecosystems has been analysed, based on surveys of the whole of Kazakhstan. This research has shown that the coastal regions of the Aral and the Caspian Seas are in fact in a state of total degradation.

In spite of rich data obtained by the various institutes of the Academy of Sciences, it is still difficult to obtain an accurate and comprehensive representation of the state of the national environment and the trends of change. Ground level monitoring is carried out in only a limited number of areas and the extrapolation to other regions is often approximate. Therefore, the application of remote sensing may be very useful for future research and monitoring of environmental changes in Kazakhstan. In applying remote sensing, investigations carried out through test sites by the institutes will be of great importance with deciphering aerospace imagery. The system of environmental monitoring of the territory of Kazakhstan is projected as a set of instruments oriented to resolve existing problems. The system will be developed and new problems will be included in the package.

For example, for the atmosphere the following very important problems can be highlighted:

- Dust storms in the Aral Sea region, when millions of tons of salt are spread over a large area causing desertification;

- Gaseous emissions as a result of accidental breaks in pipes;
- The state of snow cover and icecaps in the Pamir Heights and Tien Shan mountains.
- The transfer of water vapour to Central Asia from other regions.

Concrete tasks for all will also be developed. Work on complex analyses, using mathematical models, is under way. Information obtained at three levels (space - air - ground) passes through the following stages: data acquisition, transmission, and reception, primary data processing, archiving, and the proposal of solutions to applied problems. The project envisages accomplishing all of the stages. Observations from space will be provided by satellites. Aerial observations are to be carried out on flying laboratories in aircraft. Surface-based observations will be conducted primarily on the testing ground in the Priaralie (the area immediately adjacent to the Aral Sea) and in the neighbouring regions of Almaty.

RECOMMENDATIONS

The five countries of Central Asia have adopted a plan to solve the ecological problems of the Aral Sea and its adjacent regions. In order to realize this plan, it is necessary first of all to determine the optimal distribution of water resources among industries. For this task, we will require information on the economic framework of the republics, the priorities of various industries, population projections, regional geographical information systems (GIS), and watershed management data. We will then be able to use some systems analysis methods to address the problem of the optimal distribution of water resources. Such an approach was introduced in the paper by Sultangazin and Tsukatani (1995), which deals with the distribution of water resources in the Syr Darya basin.

At the policy level all the states of the region set free the region's two great rivers, the Amu Darya and the Syr Darya, and readjust their agricultural activities in order to save water resources; it is necessary in planning water consumption to take into consideration the possible needs of the Aral Sea and its surrounding areas. The cooperation of regional states' activities in solving the ecological, economic, and legal problems of the Aral ecological disaster zone, relying when necessary on the help of independent experts from the United Nations and other governmental and non-governmental organizations.

At the technical level, geographical information system should be created for the optimal control of the distribution of water resources and of waste disposal, taking into consideration the social and economic interests of the republics in the Aral Sea basin. This can be achieved through the application of the information system described by Sultangazin and Tsukatani, and by mathematical models of the environment and economy.[192]

Secondly, in order to undertake research into global environmental problems of desertification and global warming of the atmosphere and to evaluate the regional environmental situation, it would be valuable to establish an International Centre for Central Asian Ecology in Almaty.

The information system for environmental control comprises three levels: first, monitoring and processing; second, modelling of the environment-economic system; third, environmental control. The scheme for the optimal control of industries in the Syr Darya basin takes into consideration the ecological interests of the Aral Sea. The main constraint is the request for a minimum volume of inflow to the Aral Sea. Other constraints are imposed by the level of technology available to the agricultural sector.

CONCLUSION

The institutional and legal framework related to water management in Central Asia is very complex and somehow confusing. Despite many initiatives and actions, the view is that the water situation in the region is still deteriorating – the Aral Sea is still shrinking at an alarming level. The principle of national sovereignty is dominating water distribution and use, creating tensions. Existing agreements and conventions are rather static and do not allow for much flexibility when conditions change. In that respect, more

[192] Op cit, No. 191

importance should also be given to water quality and the potential impact of global climatic changes. De facto, Turkmenistan remains an outsider in the regional water management schemes. Such a lack of interest in regional co-operation may partly reflect a low dependency on Aral Sea basin water resources.

Considering domestic governance and the decision to create the "Lake of the Golden Century", there might still be room for discussion and amendment because the Turkmen government acceded to the "Aarhus Convention", that allows civil society to ask for transparency on governmental decisions that have environmental dimensions.

From a realistic perspective, one may assume that water problems in Central Asia will continue to be addressed by what could be seen as a multi-tier scheme. The Syr Darya countries – Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan – are showing a continuous interest in co-operating within common legal frameworks. Considering the downstream section of the Amu Darya that is shared by Turkmenistan and Uzbekistan, bilateral negotiations and agreements will have priority and could partly rely on existing models in Central and Western Europe. Following the example of Kazakhstan, other Central Asian countries should be encouraged to accede to the (Helsinki) Convention on the Protection and Use of Trans boundary Watercourses and International Lakes "to prevent, control and reduce pollution of water causing or likely to cause a Trans boundary impact".

Legal and institutional mechanisms play an increasingly important role in cooperative efforts to manage transboundary water resources in the Aral Sea Basin. Confidence will grow as further progress is made with the institutional framework and as the parties begin to recognize and adhere to the international legal principles most relevant to transboundary water resources including: equitable and reasonable utilization, the obligation not to cause significant harm, sustainable development and joint management through appropriate institutional mechanisms. Future conflicts over natural resource allocation in the region may be avoided through improved communication among national governments and the willingness to seek consultation with other riparian before taking actions that cause harm to others. Other geopolitical considerations, particularly with respect to Afghanistan require further attention.

Trade in natural resources may provide additional options by reducing the competition for limited water resources while addressing the energy needs of all riparian. While the development of hydrocarbon resources in the Aral Sea Basin holds the potential to stimulate local economies, it could also enhance the ability of the Central Asian republics to find regional solutions to the Aral Sea crisis. These solutions have already been conceived, but further progress in the legal and institutional arenas is essential to future success.

CONCLUSIONS

BACKGROUND

Sustainable development requires stakeholders in the system, people at the local level who are committed to the long-term health of the environment. But the trend toward authoritarianism in Central Asia, where governments are consolidating their power at the expense of human rights, undermines the ability of local constituencies to assume problem-solving responsibilities.

In today's context, while oil and gas may grab the international community's attention, the most critical natural resource in Central Asia is water. Since the collapse of the Soviet Union, water resource management has been a source of regional tension. The five Central Asian nations--Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan – all draw water from a common stream, yet have conflicting notions of how to best utilize this precious resource.[193]

Enormous quantities of water in addition to existing uses are required for meeting needs of the growing population in Central Asia. If meeting the water requirements for sustenance of life and development over time is a challenge, it is not because nature has been too niggardly in bestowing this valuable resource on us, but more because we have wanting in using this resource with care and vision. There has not been adequate attempt for an integrated approach to water use with a perspective of overall development of the region.

No serious attention has been paid to developing legal and institutional framework for rational use of water, and above all, there have been lack of vision in the programmes and projects for the development of water resource in the region.

[193] Hogan Bea., "Central Asian states wrangle over water", in http://www.eurasianet.org/index.shtml, 2000.

The daunting prospect of the disappearance of the Aral Sea is just as realistic now as it was in the early 1990s, when the first major studies of this environmental tragedy were made public. In an epoch in which public knowledge about the severe environmental disaster has spread, and in which the Central Asian governments have become independent players, there are two rather contradictory phenomena visible in Central Asia.

On one hand, there have regional initiatives of establishing the interstate council for Aral Sea and the River Basin Authorities, to manage and allocate limited water resources,[194] recognizing that the Aral Sea 'will be regarded as an independent consumer'.[195] Furthermore in several countries policy reforms are being initiated, aimed at the introduction of water pricing, the reduction of chemical contamination, and improved water efficiency.

On the other hand, at the farm level-especially in Uzbekistan and Turkmenistan-the centrally planned water allocation and distribution system does not provide incentives to improve water efficiency, nor does it reduce costs for those who do save water. At national and regional levels, the system of water allocation is therefore still leading to the 'use it to loose' philosophy among consumers.

The downstream countries of Uzbekistan and Turkmenistan have expanded their acreage of irrigated crops, although remaining within the existing water quota. At the same time, they have shifted crop mix somewhat towards wheat and rice in order to promote self sufficiency of food at national level without taking into account the real production and environmental costs involved, including the energy costs.

[194] UNDP., "Aral Sea basin capacity development project", Project Document for Phase II, Final Draft RER/97/001, UNDP, New York, Dec 1996.
[195] World Bank., "Developing a Regional Water Management Strategy: Issues and Workplan", ASBP Technical Paper Series (April), Washington and Tashkent, 1996.

Water is often transported over long distances or pumped to overcome extreme altitude differences.[196] In terms of industrial water pollution, the Central Asian States have the possibility to tax the polluters, through environmental taxes and effluent charges. The Central Asian States have already formulated their National Environmental Action Plans (NEAP), where some States focus on environmental monitoring, water pricing and pollution charges. Nevertheless, there is severe lack of institutional capacity to implement these policies at national and local levels.

As we have seen on several summits, the five Presidents of the Central Asian States have agreed to a more efficient and sustainable use of the available water resources. In spite of this, however national interests have prevailed, sometimes even expressing themselves under an 'ethnic banner'.

On the other hand many conferences had been organized and hundreds of studies have been produced to make the world aware of the problems that the Soviet legacy of forced cotton cultivation has left in Central Asia, expressed in desiccation, salinization, desertification, and deterioration of health conditions and the rapid shrinking of Aral Sea. The problem is that many of the proposed solutions, that include measures for improved water efficient and sustainable water use, need a combination of national policies and a major international effort in terms of infrastructural investment (in irrigation systems, drainage, sustainable agricultural development and reforestation), well above the current level of pledged aid provided by the World Bank, UNEP, UNDP, EU, USAID, ADB.[197]

Whether the pledged and disbursed aid and loans will be of the scale needed to solve the crisis is a serious question; a further problem is that the room for manoeuvre which is available for policy implementation and water management reforms in the Central Asian States themselves is not being sufficiently utilized. There is a need for clear intersectoral coordination in relation to the Aral Sea basin crisis, at national levels and within the existing ICAS (Interstate Council for the Aral Sea Basin) institutional structure, where

[196] World Bank., "Review of the Amu Darya Right Bank Collector Drain", Final Report, NEDECO, Washington, 1994.
[197] Op cit, No. 194

water, environment and agriculture are often dealt with by entirely different government agencies, with little institutional communication between them.

Finally, a clear change in the political will of the Central Asian leadership is warranted; in spite of the official discourse, they seem to underestimate the danger for their economies and for human ecology that the drying up of the Aral Sea would imply. Whether short-term solutions to the Aral Sea basin crisis are feasible with in the current political economy framework of the Central Asian States will only become clear in time- but for the Aral Sea and the millions of people living in the disaster areas, time is running out.

The Central Asian States and ongoing economic hardships in the region have hampered the countries ability to tackle environmental issues. The Soviet environmental legacy still looms large in the region. There are many other serious environmental issues confronting the region, including hazards prompted by deteriorating biological and chemical weapons facilities, the widespread contamination of drinking water, and soil degradation.

INTERNATIONAL LEGAL PRECEDENTS

Domestic laws in any sovereign state are usually written laws based on tradition, common law, and administrative rules which citizens are obligated to follow. In the international arena, laws are consensual and a country usually consents to international laws because the long-term benefits outweigh the longterm costs. International laws can be proven or established by the existence of treaties or conventions to which a large number of nations have agreed to be bound. An international law can also be shown to exist if it has been formally adopted by the United Nations General Assembly. Adoption by any other UN agency may provide support for the assertion that a principle is in fact an international law, but such an adoption cannot stand alone. It can provide significant proof only when a substantial majority including major world powers have adopted the resolution.[198]

[198]Draper, Stephen., "International Duties and Obligations for Transboundary Water Sharing", *Journal of Water Resources Planning and Management*, Nov/Dec 1997.

There are not many treaties or laws that dictate the proper use of international waters. The United Nations provides the mechanism to identify solutions to disputes or problems, and to deal with virtually any matter of concern to humanity. The United Nations has only one convention on international waters, which addresses the problem of equitable sharing, The Helsinki Rules of the International Law Association on the Uses of the Waters of International Waters (1966). The "Helsinki Rules" were adopted by the International Law Association (ILA) in 1966 and the United Nations International Law Commission (UN-ILC) in 1994 (MFA, 1996). The Commission is composed of 34 members who serve in their individual capacity as international law experts and represent the principal legal systems of the world. The Commission, which was established on 21 November 1947 by the UN General Assembly to initiate studies and make recommendations for the purpose of encouraging the progressive development of international law and its codification, has been at the centre of standard setting in its preparation of drafts that have served as the basis for the adoption of legal rules to regulate relations among States.

Chapter 2, Article V of the Helsinki Rules states the following (Appendix A):

1. Each basin State is entitled, within its territory, to a reasonable and equitable share in the beneficial uses of the waters of an international drainage basin. This equitable sharing is to be determined in the light of all the relevant factors in each particular case.

2. Relevant factors which are to be considered include, but are not limited to:

- The geography of the basin, including the extent of the drainage area in the territory of each basin State;
- The hydrology of the basin, including the contribution of water by each basin State;
- The climate affecting the basin;
- The past utilization of the waters of the basin, including existing utilization;
- The economic and social needs of each basin State;

- The population dependent on the waters of the basin in each basin State;
- The comparative costs of alternative means of satisfying the economic and social needs of each basin State;
- The availability of other resources;
- The avoidance of unnecessary waste in the utilization of waters of the basin;
- The practicability of compensation to one or more of the co-basin States as a means of adjusting conflicts among uses; and
- The degree to which the needs of a basin State may be satisfied, without causing substantial injury to a co-basin State.

3. The weight to be given to each factor is to be determined by its importance in comparison with that of other relevant factors. In determining what is a reasonable and equitable share, all relevant factors are to be considered together and a conclusion reached on the basis of the whole.

This law was revised in May 1997 and called "The Convention on the Law of the Non-navigational Uses of International Watercourse". However most of the relevant factors related to equitable and reasonable utilization of water remained the same.

The reliability and obligation of using the Helsinki Rules to determine water rights must be established before applying the Helsinki Rules to water rights in Central Asia. Draper discusses the four duties under international law of sharing transboundary water resources: the duty to cooperate and to negotiate in good faith, the duty to prevent unreasonable harm, the duty of equitable utilization, and the duty to exchange data and information. He argues that there does not appear to be any sufficient proof that the principle of equitable utilization is an international legal norm to which all states involved in water sharing agreement must adhere.[199]

For this study area, this argument can easily be discredited. Although the UN General Assembly has not formerly adopted the Helsinki Rules, the UN International Law

[199] Op cit., No. 198

Commission, established by the General Assembly, has adopted the Helsinki Rules. Also, all five of the Central Asian countries are members of the UN and have repeatedly quoted and supported the Helsinki Rules as a basis for water rights in documents, meetings, and treaties.

This also discredits Draper's questions about whether countries are obligated to follow "equitable and reasonable" principles as a matter of international law or whether these obligations must be explicitly agreed upon.

Draper also argues that the fulfilment of the duty to prevent unreasonable harm and the duty of equitable utilization can be challenged due to the vagueness of terms; does "reasonable and equitable utilization" mean beneficial use, what is the difference between reasonable harm and unreasonable harm, and how can a country quantify the difference between using waters for agricultural purposes and environmental protection and which is a priority?[200]

GLOBAL CHALLENGES FOR SEMI-ARID REGIONS

Semi-arid ecosystems are extremely vulnerable to over-exploitation and inappropriate use of given resource, especially water. Poverty, population growth, deforestation, poor irrigation practices and centuries of over-grazing have undermined the water resources, and land resources in the semi-arid regions. Often located in regions of great scenic beauty, these regions have seen higher than average population growth in the last few decades, putting further stress on limited water and land resources. Sustainable water management is critical – regionally, provincially, nationally, and globally.

Challenges in Aral Sea basin

In semi-arid Aral Sea basin, the challenges to sustainable water management are particularly significant. The region is the most intensely farmed and irrigated in Central Asia, accounting for large contribution to the GDP of the respective nations. Despite the limitations of a restricted water supply the region's economy continues to grow. With an

[200] Op cit, No. 194

understanding and knowledge that managing limited water resources is the key to the area's prosperity.

Any concrete measures to mitigate if not solve altogether the Aral Sea problem must take into account the fact:

- that the sustainable development of Central Asia is dependent on a well-structured framework of research;
- that water related research has not focused upon sustainable development in semi-arid regions until recently;
- that research capacity and interaction between researchers and end users in community and private sectors, intermediaries and policy makers are crucial to the understanding of key water issues and their successful resolution;
- that public communication relative to water research is minimal and an informed public is a key partner in various initiatives; and,
- that strong collaborative networks are essential to innovation and knowledge transfer,

Water Quality and Public Health

Research in this theme should address public health issues related to drinking water, wastewater disposal and reuse, and recreational water activities. Research should strive to understand pollutant sources, pathways, and impacts and must be geared:

- To ensure safe water supply for human and animal consumption.
- To ensure environmentally compatible and sustainable growth.
- To protect aquatic life and ecosystem balance; and.
- To develop sustainable water consumption models for implementation locally and globally.

Watershed Ecology

Moreover, as the challenges and limitations associated with watershed ecology involves many disciplines and area a multi-dimensional approach is must. This multi-discipline approach should consider the economic health of communities; apply biophysical processes in a comprehensive geographic approach including all the living organisms, their physical surroundings, and the natural cycle that sustains them. Watershed ecology should aim:

- To facilitate riparian health.
- To ensure the healthy balance of a semi-arid ecosystem.
- To develop hydrological forecast through climate change modelling.
- To develop adaptation and mitigation strategies for water management under extreme weather.
- To develop agricultural practices beneficial to ecosystem CO_2 sequestration.
- To assist in regional weather forecasting.

WATER RESOURCES MANAGEMENT

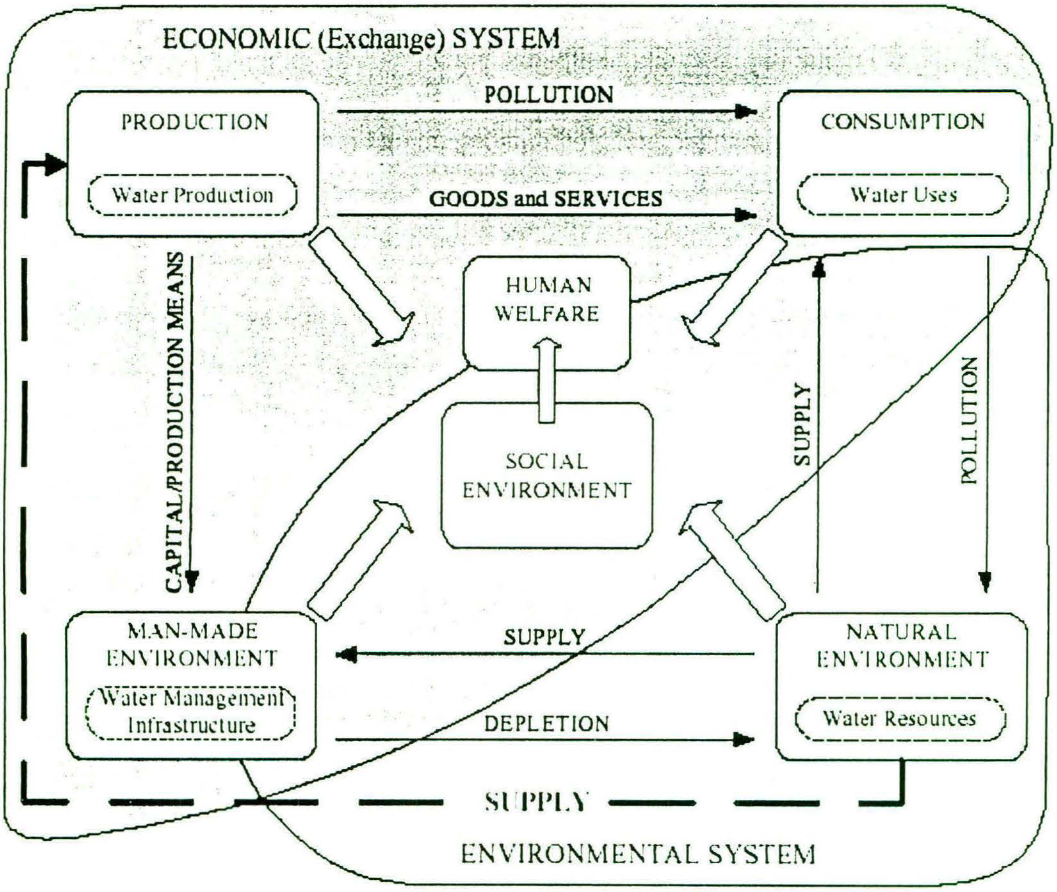
Understanding the water resource system is vital for water management. Emphasis should rest on the 'water value chain' for both rural and urban consumers. This should involve data capture, performance assessment, flow forecasting and evaluation, river hydraulics, and the provision of advice to industry and government regarding water supply policy and regulatory issues. Water resource management gives emphasis:

- To develop sustainable (environmental, social and economic) and more efficient irrigation water and land management.
- To develop agronomic, ecologic and economic models of irrigation for decision-making.
- To establish WISE as a global leader in research and information packaging for irrigation management in semi-arid ecosystems.
- To develop sustainable water consumption models for implementation locally and globally.

Approach

The central idea of the water resource management recognizes that the existing framework of water management infrastructures, natural environment, water supply (production) and consumption, institutional and socioeconomic conditions is the main factor in determining the appropriate strategies for improved water resources management. The interactions among the main components of the socioeconomic and environmental systems (Fig 16) determine the decisive issues that the water resource management framework analyses.

Fig. 16: Water resources management framework

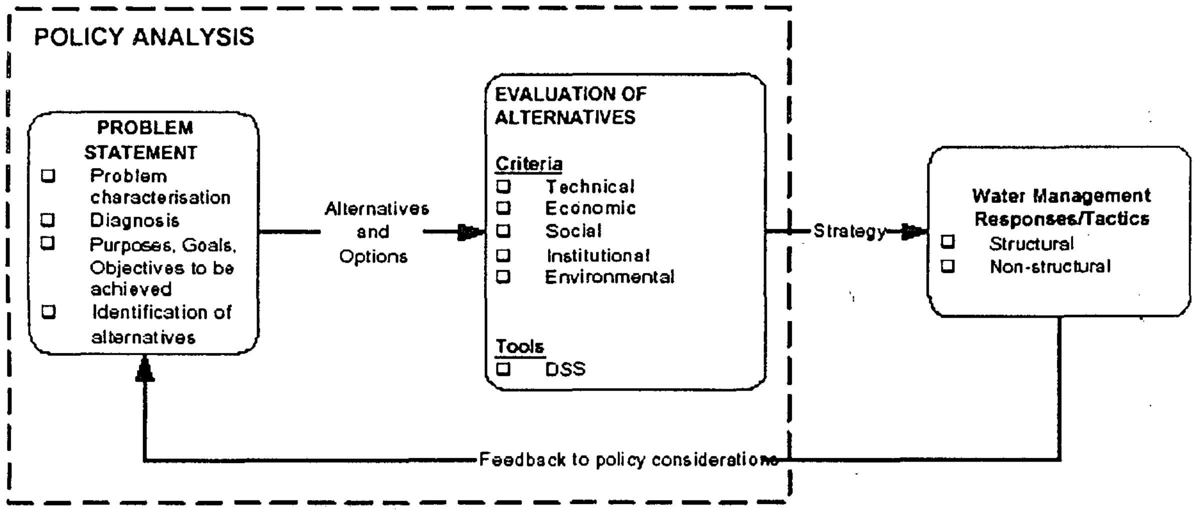


The initial step of the overall methodology in this framework is based on this recognition and focuses on the definition and modelling of a coherent typology of water deficient regions by outlining the basic differences and similarities on key issues related to water resources management. The selection of representative case studies, as specific paradigms, provides the required step for a detailed study of the interrelation of water production and consumption system and the man-made and natural environment and will highlight the specific water problems of arid and semi-arid regions. A multi-criteria methodology for coping with water management decisions will integrate available models and tools into a decision-making approach for selecting appropriate strategies for each paradigm. The synthesis of the results from the paradigms analysis will conclude to general guidelines and protocols for improved water management practices in water deficient regions. The development of water cost recovery strategies for improved resources management should encompass scientific information related to the water system dynamics and stakeholder requirements related to the interactions of economic, social and environmental systems. Such strategies should be based on the detailed evaluation of direct and indirect costs of water use, the estimation of appropriate water prices and the comparison of alternative water management scenarios through an integrated multi-criteria approach.

In this regard, the following premises characterize the methodology (Figure 17):

- Application of holistic policy analysis that enables decision makers to coordinate various governing authorities, delineate and assess a wider range of alternatives, and finally select and implement relevant water pricing plans.
- Development of a methodology that is based on the above analysis, may make possible the application of an integrated management approach that should primarily focus on the identification of sustainable alternatives for water cost recovery according to anticipatory planning, on providing control and alarm criteria and finally on implementation strategies of significant value for the stakeholders.
- Usage of the information technology in the form of a decision support tool, as an integral part of the pertinent methodology and through which improvement in decision-making may occur in analyzing quantitative and qualitative impacts; in describing the entire gamut of potential responses; and in suggesting appropriate solutions.

Fig. 17: Framework



Water resource management will address the following issues in order to provide suitable responses to the Aral Sea problem through the framework of water resource management:

- It will develop a typology of water deficient regions on the basis of hydrologic patterns and water management conditions and will derive representative paradigms for the analysis of water systems dynamics and environmental impacts of man-made interventions. The selected paradigms will provide the theoretical framework to examine, test and improve existing water management tools and models.
- It will review/evaluate the available methods and models for the assessment of water resources supply and use. It will review/evaluate methods of assessing direct and indirect costs of water management options and enhanced this theoretical background to fit the characteristics of arid and semi-arid regions.
- It will unite/modify appropriate models and tools for the identified paradigms in the framework of integrated multi-criteria decision-making environment in order to describe the physical as well as the socio-economic interactions of the water, social, economic and environmental systems.

- It will analyze region-specific water problems in the selected paradigms with the aid of the Decision Support System and will develop/compare alternative scenarios of water resources allocation among competing uses.
- It will formulate strategies and through the identification of the common elements, both within and between the selected paradigms will develop guidelines and protocols for the application of water management approaches in water deficient regions.
- Train decision-makers and authorities

Towards Sustainable Development

Integrated management of the water resources in the arid and semi-arid regions of Central Asia requires the whole spectrum of efforts from local and community stakeholders to national and transboundary river basin management.

There are no magic solutions in sustaining water supplies, as neither market forces, military might, mega-projects nor money alone are able to solve the world's water problems. On top of the technical problems the social aspect of the problem should be integrated along with conservation and community initiatives to solve the root problems of water scarcity, which otherwise may incur immense human cost.

Water resource development is to be seen not merely as a single-sector-end-objective, but as a prime mover in developing large systems with multiple linkages. This calls for a well set out multidisciplinary research agenda covering not only technological issues but also issues of social, economic and legal and environmental concerns. A trained motivated manpower being the backbone of a developmental activity, in the water sector also, there is need for human resource development.

The challenge in water sector is to simultaneously take care of needs of development and environmental health and thereby ensure sustainability of development. The problems are not beyond the present state of knowledge and technology. Given the needed political will and society's awareness the region shall be able to meet the challenge.

BIBLIOGRAPHY

PRIMARY SOURCES

Asian Development Bank., "An Environmental Profile of the Republic of Uzbekistan", Mazyland, 1996.

ASCE (American Society of Civil Engineers) and UN/IHP (United Nations International Hydrologic Program)., "Committee on Sustainability Criteria, Water Resources Planning, and Management Division", Sustainability criteria for water resources systems, IV Project M-4.3, 1998.

Biodiversity Conservation, Republic of Uzbekistan, National Strategy and Action Plan, Tashkent, 1998.

Brown, A., "The Cambridge Encyclopaedia of Russian and Former Soviet Union" Cambridge, Cambridge University Press, 1994.

Department of Water Resources of the Kyrgyz Republic., "Annual Report on Land Reclamation and Water Use", Bishkek, 250p. 1998 (in Russian).

Dukhovny, V., "Civilization and Water Resources Management in Central Asia", Report prepared for the World Bank, Tashkent, 1995.

"Eastern Europe and the CIS", (III ed.), Europa Publications, London, 1996.

Ebrahim, Liam, "Environmental Series" Vol. 1, UN, New York.

Economic commission for Europe, Committee on Environmental Policy, "Environmental Performance Review: Uzbekistan", Environmental Performance Reviews Series No. 14, UN, New York and Geneva, 2001

EC (European Commission)., "Water resources management & agricultural production in the central Asian republics", WARMAP Project Report, Vol. 1–6, 1995.

FAO (Food and Agricultural Organization)., "Irrigation in the countries of the former soviet unions in figures", Water Report 15, Rome, 1997.

FAO., "Food production: The critical role of water", World Food Summit, Rome, Italy, 1996.

FAO., "Soil and water conservation in semi-arid areas", by Norman W. Hudson, Soil Resources, Management and Conservation Service, FAO Land and Water Development Division, Food and Agriculture Organization of the United Nations Rome, 1987.

FAO., "Irrigation in Asia in figures", Water Reports 18, Rome, 1999..

FAO., "Drylands development and combating desertification", Bibliographic study of experiences in countries of the CIS by Florian Plit, Joanna Plit, Wladyslaw Zakowski, 14 FAO Environment Paper, Rome, 1995.

FAO., "Dry lands development and combating desertification", Bibliographic study of experiences in countries of the CIS by Florian Plit, Joanna Plit, Wladyslaw Zakowski, 14 FAO environment paper, Rome, 1995.

Global Environment Facility and World Bank., "Water and Environmental Management Project", Aral Sea Basin Program, Project Document, May 1998.

ICG (International Crisis Group)., "Central Asia: Water and Conflict", 30 May, 2002.

International Fund for the Aral Sea, and World Bank., "Fundamental Provisions of Water Resources Management Strategy in the Aral Sea Basin", Tashkent, 214 p, 1997.

Inter-state Commission for Water Coordination ICWC., "WARMAP-2 - Water Use and Farm Management Survey – Improvement in Water Productivity", Annual Report, Tashkent,1999.

International Fund for the Aral Sea, and World Bank., "Water Management Information System of the Aral Sea Basin – Feasibility Study: Operational Water Resources Management and Control in the Amu Darya and Syr Darya River Basins" Program –7, Tashkent, 1998.

"Irrigatsiia Uzbekistana", Vols. 1-4, Tashkent: Fan, 1975-81. (in Russian)

"Istoriia sovetskogo gosudarstva i prava Uzbekistana", Vols. 1-3. Tashkent: Izdatel'stvo Akadamii nauk Uzbekskoi SSR, 1960-68. (in Russian)

Kirmani, Syed and Guy Le Moigne, "Fostering Riparian Cooperation in International river Basins", World Bank technical paper no. 335, The World Bank, Washington, D.C. 1997.

Loucks, D.P., et al., "Sustainability of Water Resource Systems: Criteria for Planning and Management", Joint UNESCO/ASCE monograph, 1996.

Ministry of Macroeconomics and Statistics of the Republic of Kazakhstan., "Basic Indicators of Social and Economic Development of the Republic of Kazakhstan in 1998", Astana, 248 p, 1999.

Ministry of Macroeconomics and Statistics of the Kyrgyz Republic., "Basic Indicators of Social and Economic Development of the Kyrgyz Republic in 1998", Bishkek, 212 p, 1999.

Ministry of Macroeconomics and Statistics of the Republic of Tajikistan., "Basic Indicators of Social and Economic Development of the Republic of Tajikistan in 1998", Dushanbe, 232 p, 1999.

Ministry of Macroeconomics and Statistics of Turkmenistan., "Basic Indicators of Social and Economic Development of Turkmenistan in 1998", Ashgabad, 218 p, 1999.

Ministry of Macroeconomics and Statistics of the Republic of Uzbekistan., "Basic Indicators of Social and Economic Development of the Republic of Uzbekistan in 1998", Tashkent, 224 p, 1999.

Ministry of Agriculture and Water Resources of the Republic of Uzbekistan., "Annual Report on Land Reclamation and Water Use", Tashkent, 220 p, 1998. (in Uzbek)

Ministry of Agriculture and Water Resources of Turkmenistan., "Annual Report on Land Reclamation and Water Use", Ashgabad, 240p, 1998. (in Russian)

Ministry of Water Resources of the Republic of Tajikistan., "Annual Report on Land Reclamation and Water Use", Dushanbe, 200 p, 1998. (in Russian)

Nigam, P S, "Water Resource Development & Planning", Vol. 1 & 2, Central Board of Irrigation and Power, New Delhi, 1985.

OECD (Organization for Economic Co-operation and Development). The Athens Workshop, 1998, Sustainable management of water in agriculture: Issues and policies.

Petrenko, Yu., "Problems of Water and Energy Security in Central Asia", USAID, June 1999.

Proceedings of the International Seminar on "Water Management in Arid & Semi-Arid Zones" Haryana Agricultural University, Hisar, Nov 1986.

Proceedings of the workshop on "New Approaches to Water Management in Central Asia", Aleppo, Syria, Nov 2000.

Proceedings of the Nukus International Conference on Sustainable Development of the Countries of the Aral Sea Basin, (Nukus, Sept 1995) (Nukus Report) pp. 15.

Resolution for international recognition of the severe human health consequences from the ecological and socio-economic crises in the Aral Sea Region, Discussed and approved at the 8th ISDE World Assembly (Amsterdam, 1998).

State Committee for Water Resources of the Republic of Kazakhstan., "Annual Report on Land Reclamation and Water Use", Almaty, 200 p, 1998. (in Russian)

State committee of Republic of Uzbekistan for nature protection., "The national report on a condition of environment and use of natural resources of the Republic of Uzbekistan (1996)", Tashkent, 1998.

Stuart, R J (ed.), "Scanning the Global Environment", UNEP, Nairobi.

TACIS (WARMAP Project)., Phase I – Project Preparation Reports, Vol. 6: Legal and Institutional Aspects. Tashkent: TACIS, 1996.

TACIS (WARMAP)., "Irrigated Crop Production Systems", Tashkent, 1996.

TACIS (WUFMAS)., "Improving the Productivity of Water in Central Asia", Annual Report for 1999.

Tashkentskaia kartograficheskaia fabrika. Ekologicheskaia karta Respubliki Uzbekistan: masshtab 1:1,000,000. Tashkent : TKF, 1992.

TERI., "Looking Back to Think Ahead GREEN India 2047", New Delhi, 1998, pp. 43-59.

"Turkestan-Our Common Home," Konrad-Adenauer-Stiflung and Commission for the Rescue of the Aral Sea, Tashkent, 1995.

UNCED (United Nations Conference on Environment and Development)., "Report of the United Nations conference on environment and development, Chap. 5 and 18, Rio de Janeiro' 1998.

UNDP (United Nations Development Programme) and ICAS., "International Conference on Sustainable Development of the Aral Sea Basin", Final Report. Nukus, 18-20 September, Tashkent, UNDP, 1995.

UNDP., "Uzbekistan: Human Development Report 1995", Tashkent, Uzbekistan, UNDP, 1995.

UNDP., "National strategy of sustainable development of the Republic of Uzbekistan", Uzbekistan. Tashkent, 1999

UNDP., "Tentative Strategy for UNDP's Contribution to the Aral Sea Program". UNDP/EC-ICAS, Version 3, 3 April, 1996.

UNEP (United Nations Environmental Programme)., "Environment Data Report 1993-94", Blackwell Publications, London, 1995.

UNEP., "The Aral Sea: Diagnostic Study for the development of an action plan for the Conservation of the Aral Sea", United Nations Environmental Programme, Nairobi, 1992.

UNEP and International Water Association., "Water Management", London, 2002.

UNEP, "The Aral Sea: Diagnostic Study for the Development of an Action Plan for Conservation of the Aral Sea basin", New York, 1993.

UNESCO (United Nations Educational Scientific and Cultural Organization)., "Water Related Aral Sea Basin Vision for the Year 2025. UNESCO, 237p, 1999.

UNESCO., "The Courier", Paris, January 2000.

UNESCO., "Water Related Vision for the Aral Sea Basin for the year 2025", 2000.

UNESCO, "UNESCO's initiative for the Aral sea basin", Tashkent, Uzbekistan, 6 November 1998.

UNU (United Nations University)., "Environmental Management of the Aral Sea Region", Report of the International Symposium held at UNU Headquarters, Tokyo, Japan, 29 September 1992.

US Central Intelligence Agency., "The World Fact Book 1995", US Gov. Printing Office, Washington, D.C., 1995.

USSR National Committee on Irrigation and Drainage., "History of Irrigation and Drainage in the USSR", International Commission on Irrigation and Drainage, New Delhi, 1985.

WARMAP., "Water Resources Management and Agricultural Production in the Central Asian Republics", 7 Volumes, Ashgabad, 1995.

WCED (World Commission on Environment and Development)., "Our common future. ("The Brundtland Report")" Oxford University Press, 1987.

"Water Development & Management", Proceedings of the UN Water Conference, Part 4, Mer del Plata, Argentina, March 1997.

"Water Resources a Changing Strategy", Proceedings of the Conference, London, October 1980.

World Commission on Environment and Development, Our Common Future, Oxford University Press, 1987

World Resource Institute., "Wetlands in Asia, A booklet to accompany the Map of Wetlands of International Importance in Asia", Produced by Wetlands International - Asia Pacific and The World Bank, 2002.World Resources, World Resource Institute, 1998-99.

World Resource Institute., "A Guide to Global Environment", A joint Publication with UNEP, UNDP & World Bank, Oxford University Press, 1998.

World Bank., "Social Assessment and Agricultural Reform in Central Asia and Turkey", World Bank Technical Paper No. 461, Edited by Ayse Kudat, Stan Peabody, and Caglar Keyder. Washington, DC: World Bank, 2000.

World Bank., "Aral Sea Basin", Project 3.1.B. Agricultural water quality improvement. EC IFAS., Tashkent, 1997.-p.51

World Bank., "Developing a Regional Water Management Strategy: Issues and Work plan", ASBP Technical Paper Series (April), Washington & Tashkent, 1996.

World Bank., "Proposals on national water strategy in the Republic of Uzbekistan" Tashkent, 1995.

World Bank., "Republic of Uzbekistan: National action plan on environment", Tashkent. 1998.

World Bank., "Transition toward a healthier environment: environmental issues and challenges in the newly independent states", A background paper prepared for the Fourth Pan-European Conference of Environment Ministers Held in Arhus, 23-25 June 1998.

World Bank., "Aral Sea Basin Program: Phase 1", Progress Report No. 2, Washington DC, Sept.1995.

World Bank., "Irrigation in Central Asia: Social, Economic and Environmental Consideration", February 2003, www.worldbank.org/ecs/environment

World Bank., "Water Resources Sector Strategy: Strategic Directions for World Bank Engagement", February 2003.

World Bank., "Development and the Environment", World Development Report, Washington, 1992.

SECONDARY SOURCES

Books

Abulkhaev, R. A., “Razvitie irrigatsii i osvoenie novykh zemel' v Tadzhikistane”, Dushanbe: Donish, 1988. (in Russian)

Akramov, Z. M., “Proshloe, nastoiashchee i budushchee Aral'skogo moria”, Tashkent: Mekhnat, 1990. (in Russian)

Aladin N.V and L.A. Kuznetsov, (eds.) “Sovremennoe sostoianie Aral'skogo moria v usloviiakh progressiruiushchego osoloneniia”, Leningrad : Zoologicheskii institut AN SSSR, 1990. (in Russian)

Aladin, N. V., and Vladislav V. Khlebovich, (eds.), “Gidrobiologicheskye problemy Aralskogo morya [Hydrobiological problems of the Aral Sea]”, Trudy Zoologicheskogo Instituta, v. 199. Leningrad: Zoologicheskii institut Akademiia Nauk SSSR. (in Russian)

Alaerts, F.J.A. Hartvelt and F.-M. Patorni (eds.) “Water Sector Capacity Building: Concepts and Instruments”, A.A. Balkema, Rotterdam/Brookfield.

Aleksandrov, I.G., “Proekt orosheniia iugo-vostochnoi Fergany (obshchaia skhema)”, Moskva: Izdanie TES, 1923. (in Russian)

Allworth, E.A., “The Modern Uzbeks”, Hoover Press, Stanford, 1990.

Andrianov, B.V., “Drevnie orositel'nye sistemy Priaral'ia v sviazi i istoriei vozniknoveniia i razvitiia oroshaemogo zemledeliia”, Moskva: Nauka, 1969. (in Russian)

Anon., “Lithuania’s environment: status, processes, trends”, Environmental Protection Ministry, 1994, Vilnius.

Antonov V.N., “Water resources of Uzbekistan, their use in modern conditions and in the future”, Collection of scientific articles: Water resources, the Aral problem and environment. Tashkent, "University"", 2000.

Azimov, R., “APK Uzbekistana: problemy razvitiia”, Tashkent: Mekhnat, 1987. (in Russian)

Barthold, V.V., “Nachrichten uber den Aral-see und den unteren Lauf des Amu-darja von den altesten Zetien bis zum XVII”, Jahrhundert. Leipzig: O. Wigand, m.b.H., 1910. (in German)

Baturin, S.I., “Sovetskaia irrigatsiia Uzbekistana: vsenarodnoe tvorenie. Tashkent: Gosudartsvennoe izdatel’stvo”, Uzbekskoi SSR, 1954. (in Russian)

Beautmont., "Environmental Management & Development in Dry lands", Routledge, London, 1989.

Becht, Edwin, J & L D Belzung, " World Resource Management: Key to Civilization and Social Achievement" Prentice Hall Inc, New Jersey, 1975.

Benneh, G., W.B. Morgan and J.I. Uitto (eds.), "Sustaining the Future: Economic, Social and Environmental Change in Sub-Saharan Africa", UN University Press, Tokyo, Japan, 1996.

Berg, L.S., "Aral Sea", St. Petersburg, 1908. (in Russian)

Beknazarov, R.U. and Iu. Novikov., "Okhrana prirody", Tashkent: Oqituwchi, 1995. (in Russian)

Black, C., et al, "The Modernization of Inner Asia", New York, 1991.

Blaikie, P. M. and H. C. Brookfield., "Land Degradation and Society", Methuen, London, 1987.

Bos, M G. (eds.)., "The Inter-relationship between Irrigation, Drainage, and the Environment in the Aral Sea Basin", Kluwer, Boston, 1996.

Borovsky, V. M., "The drying out of the Aral Sea and its consequences", Scripta Publishing Co. (from Izvestiya Akademii Nauk SSSR, seriya geograficheskaya), No. 5. 1980.

Bruins, H.J. and H. Lithwick., (eds.), "The Arid Frontier: Interactive Management of Environment and Development" Kluwer Academic Publishers, AH Dordrecht, The Netherlands, 1997.

Burroughs, W.J., "Does the Weather Really Matter? The Social Implications of Climate Change", Customer Services Dept., Cambridge University Press, 1997.

Butakov, A.I., "Dnevnye zapiski plavaniia A.I. Butakova na shkuna "Konstantin" dlia issledovaniia Aral'skogo moria v 1848-1849 gg", Tashkent: Izdatel'stvo Akademii nauk USSR, 1953.

Cai, X., "Modeling framework for sustainable water resources management", Unpublished Ph.D. dissertation, University of Texas at Austin, 1999.

Caponera, D., "Legal and institutional framework for the management of the Aral Sea basin water resources", Report for the European Union – TACIS Programme, Tashkent, 1995, pp.25–26.

Chamkin, A.S., "Sotsial'noe upravlenie kompleksnym osvoeniem zemel' srednei Azii", Tashkent: Fan, 1985. (in Russian)

Cherdantsev, G.N., "Vodnoe pravo Turkestana v ego nastoiashchem i proektakh blizhaishchago budushchago", Tashkent: Tipografiia Turkestanskogo tovarishchestva pechatnogo dela, 1911. (in Russian)

Chorley, Richard., (eds.), "Water, Earth and Man: A Synthesis of Hydrology, Geomorphology and Socio-Economic Geography", Methuen & Co Ltd, London, 1969.

Conolly, Violet., " Beyond the Urals: Economic Development in Soviet Asia", London: Oxford University Press, 1967.

Critchlow, J., "Nationalism in Uzbekistan: A Soviet Republic's Road to Sovereignty", Boulder, Colorado, West view Press, 1991.

Douglas, James L & Robert R Lee., "Economics of Water Resource Planning", Mc Graw Hill Book Co. Inc, New York, 1971.

Dukhovnyi, V.A., "Irrigatsionnye kompleksy na novykh zemliakh srednei Azii", Tashkent: Uzbekistan, 1983. (in Russian)

Eden, Michael J and John T Parry, "Land Degradation in the Tropics: Environment and Policy Issues", Pinter Press, London, 1996.

Eickelman, D. F., (ed.), "Russia's Muslim Frontiers: New Directions in Cross Cultural Analysis", Bloomington, Indiana, Indiana University Press, 1993.

Esenberlin, I., "Kahar, tarikhi roman [Anger. A historical story]", Alma-Ata: Dzhazushi, 1969. (in Russian)

Fedorovich, B., "Deserts Given Water", Moscow: Foreign Languages Publishing House, 1958. (in Russian)

Ferguson, Robert W., "The devil and the disappearing sea: murder & mayhem amid the Aral Sea disaster", Vancouver, Raincoast Books, 2003.

Feshbach, Murray and Friendly, Alfred Jr., "Ecocide in the USSR: Health and Nature Under Siege" New York: Basic Books, 1992.

Fierman, W (eds.), "Soviet Central Asia: the Failed Transformation", West View Boulder Co., 1991.

Ganaoulis, J, & et. al. (eds.)., "Transboundary Water Resource Management: Institutional and Engineering Approaches", Skopelos Islands, Greece, 1994.

Geller, S.Y. (eds.)., "Problems of the Aral Sea", Moscow, 1969. (in Russian)

Geller, S.Y. (eds.)., "Fluctuations of and change in river drainage", Moscow, 1960. (in Russian)

Glazovskii, N.F., "Aral'skii krizis: prichiny voznikovaniia i puty vykhoda", Moskva: Nauka, 1990. (in Russian)

Glazovsky, N.F., "Recent salt accumulation in arid regions", Nauka, Moscow 1987. (in Russian)

Glantz, M. H., (ed.), "Creeping environmental problems and sustainable development in the Aral Sea basin", Cambridge, UK, and New York: Cambridge University Press, 1999.

Gleditsch, N.P. (ed.), "Conflict and the Environment", Kluwer Academic Publishers, AH Dordrecht, The Netherlands, 1997.

Gleick, P.H., "Water in Crisis: A Guide to the World's Fresh Water Resources", Oxford University Press, New York, 1993.

Goudie, Andrew, "The Human Impact on the Natural Environment", Kaserprint Co. Ltd, Oxford, UK, 1987.

Gore, A., "Earth in the Balance: Ecology and the Human Spirit", Boston: Houghton Mifflin, 1992.

Grechikhin, V. and Kochubei, M., "Zemel'nyi fond Uzbekistana i perspektivy ego ispol'zovaniia", Tashkent: Mekhnat, 1988. (in Russian)

Grigg, Neil S., Water Resources Management: Principles, Regulations, and Cases, McGraw-Hill, New York, 1996.

Groshev, V. A., "Irrigatsiia iuzhnogo Kazakhstana v srednie veka", Alma-Ata: Nauka, 1985. (in Russian)

Guliamov, Ia.G., "Istoriia orosheniia Khorezma s drevneishikh vremen do nashikh dnei", Tashkent, Izdatel'stvo Akademii nauk Uzbekskoi SSR, 1957. (in Russian)

Hoffer, E., "The Ordeal of Change", New York: Harper & Row, 1952.

Igamberdiev, R.S. and A.A. Razzakov., "Istoriia melioratsii v Uzbekistane (na materialakh Golodnoi stepi)", Tashkent: Fan, 1978. (in Russian)

Ishchanov, M., "Ekonomiko-geograficheskie problemy razvitiia oroshaemogo zemledeliia v nizov'iakh Amudar'I", Tashkent: Fan, 1981. (in Russian)

Jalilov, S., "Farghana vadiysining sugharilish tarikhidan (XIX-XX asr bashlari)", Tashkent: Fan, 1977. (in Russian)

Kahneman, D., P. Slovic, and A. Tversky., "Judgment under Uncertainty: Heuristics and Biases", Cambridge: Cambridge University Press, 1982.

"Karakumskii kanal i izmenenie prirodnoi serdy v zone ego vliianiia", Moskva: Nauka, 1979. (in Russian)

Karev, V.B. and V.I. Shlyk., "Ekonomika ispol'zovaniia vodnykh resursov v oroshaemom zemledelii", Moskva: Kolos, 1979. (in Russian)

Karlin L.N. and S.V. Kotov., (eds), "Rezul'taty ekspeditsionnykh issledovanii po Aral'skoi problematike za 1991 g", Sankt-Peterburg : Leningradskii gidrometeorologicheskii institut, 1991. (in Russian)

Kasimov, A., "Razvitie orosheniia zemel' Sovetskogo Tadzhikistana", Dushanbe: Irfon, 1985. (in Russian)

Kasperson, J. et al. "Regions at Risk: Comparisons of Threatened Environments", Tokyo: UNU Press, 1995.

Kes', A. S., "Istoriia zaseleniia i drevnee oroshenie iugo-zapadnoi Turkmenii", Moskva: Nauka, 1980. (in Russian)

Khakirnov, F.I., "Soil-melioration conditions of desertification of deltas", Pushhino, 1989. (in Russian)

Khodzhiev (Khojiev), E.Kh. "Istoria orosheniia i osvoeniia Golodnoi stepi (1917 - 1970 gg.)"Tashkent: Fan, 1975. (in Russian)

Khusanov (Husanov), R. Kh., "Agrarnaia reforma. Teoriia, praktika, problemy", Tashkent: Ozbekistan, 1994. (in Russian)

Kobori, I. and M.H. Glantz (eds.), "Central Eurasian Water Crisis: Caspian, Aral and Dead Seas" United Nations Press, Tokyo, 1997.

Kondratyev, K. Ya., F. Pena and I. Galindo., "Sustainable Development and Population Dynamics" Universidad de Colima, Avenida Universidad, Mexico 1997.

Kula, E., "Economics of Natural Resources: the Environment & Politics", Chapman & Hall, London, 1994.

Kuznetsova, L.P., "Transfer of moisture in the atmosphere over the USSR territory", Nauka, Moscow, 1978. (in Russian)

Lavrishchev, A., "Economic Geography of the USSR", Progress Publishers, Moscow, 1969.

Leach, M. and Mearns R. (eds.)., "The lie of the land: challenging received wisdom on the African Environment", James Currey, Oxford, 1996.

Letolle, Rene., "Der Aralsee : eine okologische Katastrophe", New York: Springer, 1996. (in Russian)

Létolle, R. and M. Mainguet., "Aral", Paris: Springer-Verlag, 1993.

Levina, L. M., "Etnokul'turnaia istoriia vostochnogo Priaral'ia: I tysiacheletie do n.e.-I tysiacheletie n.e", Moskva: Vostochnaia literatura, 1996. (in Russian)

Lewis, Robert A. (eds.), "Geographical Perspectives on Soviet Central Asia", London, New York, 1992.

Lisitsyna, G. N., "Stanovlenie i razvitie oroshaemogo zemledeliia v iuzhnoi Turkmenii : opyt istoricheskogo analiza materialov kompleksnykh issledovanii na iuge SSSR i blizhnem vostoke", Moskva: Nauka, 1978. (in Russian)

Lymarev, V.I., "Aral'skoe more", Moskva: Gosudarstvennoe izdatel'stvo geograficheskoi literatury, 1959. (in Russian)

Lymarev, V.I., "Berega Aral'ksogo moria - vnutrennogo vodoema aridnoi zony", Leningrad: Nauka, 1967. (in Russian)

Maksimov, S. P., "Obshchii otchet izyskanii na r. Murgabie, v tsieliakh izucheniia obezpechennosti orosheniia Murgabskago Gosudareva imieniia", S.-Peterburg : Tip. Ministerstva putei soobshchenii, 1914. (in Russian)

Mal'tsev, A.E., "Zemel'no-vodnye resursy srednei Azii i ikh sel'skokhoziaistvennoe ispol'zovanie", Frunze: Ilim, 1969. (in Russian)

Mandel, Robert., "Conflict over the World's Resources" Green Wood Press, New York, 1998.

Marinus, G. Bos., (eds.), "The Inter-Relationship between Irrigation, Drainage and the Environment in the Aral Sea Basin", International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands, 2001.

Mavliianov, G.A., "Mnogoletnii rezhim gruntovykh vod oroshaemykh territorii v basseine Aral'skogo moria", Tashkent: Fan, 1980. (in Russian)

McKinney, D.C. and A.K. Kenshimov (eds.), "Optimization of the Use of Water and Energy Resources in the Syrdarya Basin Under Current Conditions", Technical Report 00-06-W, Environmental Policies and Institutions for Central Asia (EPIC) Program, US Agency for International Development, Almaty, Kazakhstan, 2000.

Micklin, P & W. D. Williams., "The Aral Sea Basin, NATOASI Series 2: Environment, 11", Springer Verlag, 1996

Micklin, Philip., "Managing Water in Central Asia", BI Press, Washington, 2000.

Mirzoev, M. A., "More trudnoi sud'by. Aralo-Kaspiiskii region: iz istorii izucheniia i osvoeniia", Alma-Ata: Kazakhstan, 1992. (in Russian)

Molosnova, T. 1., O. I. Subbotina, and S. G. Chanysheva., "Klimaticheskiye posledstviya khozyaistvennoi deyatelnosti v zone aral'skogo morya [Climatic consequences of economic activity in the zone of the Aral Sea]", 1987, Leningrad: Gidrometeoizdat. (in Russian)

Mukhamedzhanov, A. R., "Istoriia orosheniia Bukharskogo oazisa: (s drevneishikh vremen do nachala XX v.)", Tashkent: Fan, 1978. (in Russian)

Nikanova, Svetlana., "Aral': segodnia i zavtra", Kainar, Alma-Ata 1990. (in Russian)

Nikolayeva, R. V., "Osnovnoye morfologicheskoye kharakteristiki aral'-skogo morya. Problemy Aral'skogo morya [The main morphological characteristics of the Aral Sea: The problems of the Aral Sea]", 1969, Moscow: Nauka, pp 25-38. (in Russian)

Novichenok, V.G., "Effektivnost' ispol'zovaniia zemel'nykh resursov v usloviiakh orosheniia", Frunze: Ilim, 1977. (in Russian)

Pereira, L.S. and J.W. Gowing (eds.) Water and the Environment: Innovation Issues in Irrigation and Drainage, E & FN Spon, London, 1998.

Parry, M. and T. Carter, "Climate Impact and Adaptation Assessment: A Guide to the IPCC Approach" Earthscan Freepost 1, London, 1998.

Petrov, N., "Ob irrigatsii v Turkestanskom krae", Tashkent: S.I. Petukhov, 1894. (in Russian)

Postel, S., "Pillar of Sand-Can the irrigation miracle last?", New York: W.W. Norton, 1999.

Popov, V. A., "Problema Arala i landshafty del'ty Amudar'i: strukturno-dinamicheskoe sostoianie landshaftov Iuzhnogo Priaral'ia v sviazi s problemoi Arala", Tashkent : Fan, 1990. (in Russian)

Popov, V. A., "Opustyunivaniye v Uzbekistane i bor'ba s nim [Desertification in Uzbekistan and its prevention]", Tashkent: FAN, 1988.

Poslavskii.V V., "Problemy orosheniia v srednei Azii", Tashkent: Fan, 1983. (in Russian)

Pryde, Philip R., "Environmental Management in the Soviet Union", Cambridge: Cambridge University Press, 1992.

Pryde, Philip R., "Conservation in the Soviet Union", Cambridge: Cambridge University Press, 1992.

Rakhimov E.D., (eds.), "Sotsial'no-ekonomicheskie problemy Arala i Priaral'ia", Tashkent: Fan, 1990. (in Russian)

Rajshekhara C V (ed.) "Global Environment Series" Vol. II, III, IV, V, Discovery Publishing House, New Delhi, 1992.

Rashid, A., "The Resurgence of Central Asia: Islam or Nationalism?" Karachi: Oxford University Press, 1994.

Razakov R.M., "Use and protection of water resources in Central Asia", Tashkent, 203 p, 1991.

Redclift, Michael., "Sustainable Development: Exploring the Contradiction", Methuen, London, 1987.

Reznichenko, Grigori., "The Aral Sea Tragedy", Moscow: Novosti, 1992.

Rizaev, K., "Rynochnye problemy sel'skoi ekonomiki Karakalpakstana: problemy stanovleniia novykh ekonomicheskikh otnoshenii v agropromyshlennom komplekse", Nukus: Karakalpakstan, 1993.

Rizenkampf, G.K., "Problemy orosheniia Turkestana", Moskva: Vishii sovet narodnogo khoziaistva, Otdel redaktsionno-izdatel'skii, 1921. (in Russian)

Robert, A. (eds.)., "Geographical Perspectives on Soviet Central Asia", London, New York, 1992.

Rubinova, F.E., "Izmenenie stoka r. Syrdar'i pod vlianiem vodokhoziaistvennogo stroitel'stva ee basseine", Moskva: Gidrometizdat, 1979. (in Russian)

Ruffin, M. Holt and Daniel Waugh (eds.), "Civil Society in Central Asia", 1995.

Rumer, Boris, "Soviet Central Asia: A Tragic Experiment" M.A. Unwin Hyman, Boston, 1989.

Rupersinge, et. al. (eds.), “Ethnicity and Conflicts in a Post-Communist World: The Soviet Union, Eastern Europe and China”, New York, 1992.

Salman, S. and Boisson de Chazournes, L. (eds.)., “International Watercourses: Enhancing Co-Operation And Managing Conflict”, World Bank Technical Paper, No. 414, 1988.

Sarybaev, K., “Rol' orosheniia v sotsial'no-ekonomicheskom razvitii Karakalpakistana: k istorii orosheniia i irrigatsii Karaklpakskoi ASSR”, Nukus: Karakalpakistan, 1986. (in Russian)

Sarykulov, D.S., “Razvitie vodnogo khoziaistva Kazakhstana”, Alma Ata: Kainar, 1979. (in Russian)

Sevastianov. D.V. (eds.), “Istoriia ozer Sevan, Issyk-Kul', Balkhash, Zaisan i Aral'”, Leningrad: "Nauka," Leningradskoe otdelenie, 1991. (in Russian)

Shakhnazarov, A.I., “Sel’skoe khoziaistvo v Turkestanskom krae”, S. Peterburg: V.O. Kirshbaum, 1908. (in Russian)

Shlegel’, B. Khr., “Vodnoe khoziaistvo srednei Azii”, Moskva-Leningrad: Tsentral'noe upravlenie pechati VSNKh SSSR, 1926. (in Russian)

Shukla, S K. & P R Srivastava (eds.), “Environment Resource Conservation”, Commonwealth Publishers, New Delhi, 1992.

Shults V.L., “The rivers of Central Asia”, Gydrometeoizdat, 1965.

Siniavskii, K.N., “Po voprosu ob isskustvennom oroshenii svobodnykh zemel' v Ferganskom oblasti”, Skobelev: Tip. Fergan. oblastn. pravlen., 1909. (in Russian)

Sokovkin, V.I., I.Iu. Sizova, and D.V. Trotskianskii., “Okhrana okruzhaiushchei sredy v sel’skokhoziaistvennom proizvodstve”, Tashkent: Mekhnat, 1988. (in Russian)

Startsev, T.A. and Ia.K. Kozel., “Irrigatsiia kolonial'nogo Turkestana i sovetskikh respublik srednei Azii”, Tashkent: Tipolit, Pravda vostoka, 1932. (in Russian)

Stewart, J M (ed.), "The Soviet Environment: Problems, Policies & Politics", Cambridge University Press, New York, 1990.

Tatur, S. K., “The Hungry Steppe Becomes a Land of Plenty”, Moscow: Novosti Press Agency Publishing House, 1974. (in Russian)

Thurman, J. Michael., “Modes of Organization in Central Asian Irrigation in the Late 1920s and 1930s”, 1997. http://members.tripod.com/jmthurman/atrafmuhit/vodkhoz.html

Thurman, Mike, and et. al., “Irrigation in Central Asia: Social, Economic and Environmental Considerations”, World Bank, 2001.

Thurman, J. Michael., “Modes of Organization in Central Asian Irrigation: The Ferghana Valley, 1876 to Present”, Ph.D. Dissertation, Bloomington, IN: Indiana University, 1999.

Turnbull, M, "Soviet Environmental Policies & Practices: the most critical Investment" Dartmonth Publishing Co., Aldershet, Sydney, 1991.

Uitto, J.I. And A. Ono., (eds.), “Population, Land Management and Environmental Change”, UN University Press, Tokyo, Japan, 1997.

Weinthal, Erika., “Making or Breaking the State? Building Institutions for Regional Cooperation in the Aral Sea Basin”, Ph.D. Dissertation, Columbia University, 1998.

Weinthel, Erika., “State Making and Environmental Cooperation: Linking Domestic Na International Politics in Central Asia”, MIT Press, New York, January 2000.

Weiner, Douglas R., “Models of Nature: Ecology, Conservation, and Cultural Revolution in Soviet Russia”, Bloomington: Indiana University Press, 1988.

Wheeler, G., “The Modern History of Soviet Central Asia”, F.A. Praeger, New York, 1964.

Wolfson, Ze'ev (pseud. Boris Komarov)., “The Geography of Survival: Ecology in the Post-Soviet Era”, Armonk, N.Y.: M.E. Sharpe, 1994.

Wood, Herbert., “On the Shores of Lake Aral”, London: Smith, Elder, 1876.

Yaziliev, C., “Turkmenshaya celshaya obshina”, Ashgabad, 1992. (in Russian)

Zaharchenko, B. T., “Voda v turmenskoi zhizni”, Ashgabad, 1990. (in Russian)

Zaletayev, Vladimir S., “Zhizn'v pustyne [Life in the desert]”, Moscow: Mysl.1976.

Zaorskaia, V.V., and K.A. Aleksandr., “Promyshlennyia zavedeniia Turkestanskago kraia”, Petrograd: Ekaterinskaia Tipografiia, 1915. (in Russian)

Zel’kina, E., “Ocherki po agrarnomu voprosu v srednei Azii”, Moskva: Izdatel’stvo Kommunisticheskoi akademii, 1930. (in Russian)

Zhalalov (Jalalov), S. Ch., “Oroshaemoe zemledelie v usloviiakh defitsita vodnykh resursov”, Tashkent: Chinor ENK, 2000. (in Russian)

Zuev, Viktor., “Aral'skii tupik: khozhenie za odno more”, Moskva : Prometei, 1991. (in Russian)

Articles

Abdullaev, Iskandar., "Preventing Conflicts through Water Management in Central Asia", *Transition Newsletter*, 2001. http://www.worldbank.org/transitionnewsletter.htm

Adams, W.M., "Irrigation, Erosion and Famine", In Leach, M. and Mearns R. (eds.) "*The lie of the land: challenging received wisdom on the African Environment*", James Currey, Oxford, 1996.

Aladin, N V., "The Changes in the Aral Sea Ecosystems during the Last Thirty Years", paper presented at International Conference on *The Aral Sea Crisis: Environmental Issue in Central Asia*, Indiana University, Bloomington, Indiana, 1990.

Aladin, N V and et al., "The Aral Sea: Desiccation and Possible Ways of Rehabilitating and Conserving its Northern Part", *Environmetrics*, Vol. 6, 1995.

Aladin, N.V. & Kotov, S.B., "Natural state of the Aral Sea and its change under anthropogenic impact", In: *Hydrological problems of the Aral Sea*, Leningrad, 1989. (in Russian)

Alekperov, I. I., "Current problems of the industrial hygiene of cotton growers", *Gig. Santi*., Vol. 45(10), 1980, pp.38-40.

Alibekov, Lapas and Sadiq Nishanov., "Aral fajeasining aqibatlari", *Fan wa turmush*, 1994, No. 3. (in Russian)

Allenov, I., "Na osnove sotrudnichestva." *Sel'skoe khoziaistvo Uzbekistana*, 1993, No. 5. (in Russian)

Altan, Turker., "An Exhausted Environmental Legacy: Environmental Problems in Central Asia beyond borders, and destruction of Natural Resources", *Eurasian Studies*, Vol. 2(1), Spring, 1995, p. 37.

Akmansoy, Sandra., "Water Rights in the Aral Sea Basin", Center for Research in Water Resources, Civil Engineering Department, University of Texas at Austin, 1997

Antipova, Elena, Daene McKinney and Andre Savitsky., "Optimization of Syr Darya Water and Energy Uses", *Water International*, Vol. 27 (4), 2002, pp.504–516.

Aslov, S.M., "IFAS Initiatives in the Aral Sea Basin", the 3rd World Water Forum, Regional Cooperation in Shared Water Resources in Central Asia, Kyoto, March 18, 2003

Ataniyazova, Oral A., "Health and Ecological Consequences of the Aral Sea Crisis", the 3rd World Water Forum, Regional Cooperation in Shared Water Resources in Central Asia, Kyoto, March 18, 2003.

Barghouti, S. and G. Le Miogne., "Irrigation and the Environmental Challenge", *Finance and Development*, Vol. 28(2), June, 1991, pp. 32-33.

Barbier, E. B., et al., "Sustainable Agricultural Development and Project Appraisal", *European Review of Agricultural Economics*, Vol. 17(2), 1990, pp. 181-96.

Barthold, W., "K istorii orosheniia Turkestana", in *Sochineniia*, Vol. 2, Moskva: Nauka, 1965. (in Russian)

Batirov, B., "Ekologicheskie voprosy melioratsii zemel'." *Obshchestvenye nauki v Uzbekistane*, 1993, no. 2. (in Russian)

Batchelor, C., "Improving water use efficiency as part of integrated catchment management", *Agricultural Water Management*, Vol. 40(2), 1999, pp. 249–263.

Batygin, A.G. and Musienko, I.V., "Formirovanie territorial'no-proizvodstvennykh kompleksakh na zemliakh novogo orosheniia." *Obshchestvennye nauki v Uzbekistane*, 1981, No. 1. (in Russian)

Bedford, D. P., "International water management in the Aral Sea basin", *Water International*, Vol. 21, 1996, pp. 63-69.

Bektasov, Marstal., "Vodnyi balans na regional'nom urovne." *Aziia - ekonomika zhizn'*, 1996, No. 6 (30). (in Russian)

Bel'gibaev, M.E., "On geochemical migration of substances on the dried up coast of the Aral Sea", In *Biochemical cycle of substances*, pp. 49-51, Nauka, Moscow, 1982. (in Russian)

Blake, Roxanna., "Central Asia's Ecological Crisis: The Aftermath of the Cotton Monoculture", Harvard Asia Quarterly, Sept 2002.
http://www.fsk.harvard.edu/~aisacr/haq/199903/9903a011.htm

Blinov, L.K., "Hydrochemistry of the Aral Sea", *Gidrometeoizdat*, Leningrad, 1956. (in Russian)

Bobilev, Sergei., "Potential Solutions to the Aral Sea Crisis", *Environmental Policy Review*, Vol. 7 (1), 1993.

Bogdanova, N.M., Vostokova, T., Ostrovskiy, I.M. & Rubanov, I.V., "Conditions of formation of salt accumulations in the South Aral Region" Izvestiya AN SSSR, *Ser. Geogr*, 3, 1981, pp. 98-106. (in Russian)

Boisson de Chazournes, L., "Elements of a legal strategy for managing international water courses: The Aral Sea Basin", in: Salman, S. and Boisson de Chazournes, L. (eds.) International Watercourses: Enhancing Co-Operation and Managing Conflict, World Bank Technical Paper, No. 414, World Bank, Washington D.C.,1998.

Bortnik, V.N., "Salt budget of the Aral Sea at lowering of its level", In: *Transactions of State Oceanographic Institute*, Vol. 143, 1979, pp. 18-25, Gidrometeoizdat, Moscow. (in Russian)

Borovsky, V.M., "The Drying Out of the Aral Sea and Its Consequences." *Soviet Geography: Review and Translation*, Vol. 21 (2), 1980.

Bourne, C., "The International Law Association's contribution to International Water Resources Law", *Natural Resources Journal*, Vol. 36, 1996, pp.155–216.

Brill, Jennifer., "Shrinking Sea a Disaster in Asia", April 1998. http://www.disasterrelief.org

Briscoe, J., "The Financing of Hydropower, Irrigation and Water Supply Infrastructure in Developing Countries", *Journal of International Water Resources Development*, Vol. 15(4), 1999, pp. 459-491.

Broecker, W. S., "Unpleasant surprises in the greenhouse?", *Nature*, 328, pp. 123-126, 1998.

Brown, L.R., "The Aral Sea - Disaster Area and Interdisciplinary Solution", *Interdisciplinary Science Reviews*, Vol. 16 (4), 1991.

Budrin, A., "Freshening of a lake, Izvestiya sobraniya int. putei soobshcheniya", Vol. 12, 1915. (in Russian)

Bugaev, V.A., "Formation of jet currents in the atmosphere under impacts of the mountains of Middle and Central Asia", *Meteorologiya i gidrologiya*, Vol. 5, 1958, pp.3-11. (in Russian)

Cai, Ximing, Daene C. McKinney and Mark W. Rosegrant., "Sustainability Analysis for Irrigation Water Management in the Aral Sea Region", International Food Policy Research Institute, Washington DC, and Department of Civil Engineering, University of Texas, Austin.

Cai, X., D. C. McKinney, and L. Lasdon., "Solving nonlinear water management models using a combined genetic algorithm and linear programming approach", *Advances in Water Resources*, Vol. 24(6), 2001, pp. 667–676.

Cai, Ximing, Daene C. McKinney, and Leon S. Lasdon., "Integrated Hydrologic-Agronomic-Economic Model for River Basin Management", *Journal of water resources planning and management*, Vol. 129 (1), January 2003.

Cai, Ximing, Daene C. McKinney, and Mark W. Rosegrant., "Sustainability analysis for irrigation water management: concepts, methodology, and application to the Aral Sea region", EPTD discussion paper no. 86, Environment and Production Technology Division, International Food Policy Research Institute, Washington, December 2001.

Cai, Ximing and Daene C. McKinney., "Multi-objective Optimization Model for Water Allocation in the Aral Sea Basin", Environmental and Water Resources Engineering Program, Department of Civil Engineering, University of Texas at Austin, Austin, Texas, USA.

Cai, Ximing, Daene C. McKinney and Leon S. Lasdon., "A framework for sustainability analysis in water resources management and application to the Syr Darya Basin", *Water Resources Research*, Vol. 38 (6), 2002.

Carley, Patricia, M., "Ecology in Central Asia: The Price of the Plan, Perception of Cotton and Health in Uzbekistan and Turkmenistan", *Central Asian Survey*, Vol. 8(4), 1989, pp. 21-49.

Carlisle, D. S., "The Uzbek power elite: Politburo and Secretariat (1938-83)." *Central Asian Survey,* Vol. 5 (3/4), 1986, pp. 91-132.

Chebanov, M.S., "System analysis of water and heat regime of delta lakes", *Gidrometeoizdat*, Leningrad, 1989. (in Russian)

Chembarisov A.I., "Returnable waters of basin", The bulletin of Aral, Vol. 1, *Water resources*, Tashkent, 1996.

Chernenko, I.M., "Water and salt budget and use of the drying up Aral", *Problemy osvoeniya pustyn'*, Vol. 3, 1983, pp. 18-25 (in Russian)

Clark, Miles., "A Russian Voyage: From the White to the Black Sea", *National Geographic*, June 1994, pp. 115-138.

Craumer, Paul., "Rural & Agricultural Development in Uzbekistan", Brookings Institution, *Former Soviet-South Papers*, October 1995.

Cunha, L.Veiga da., "The Aral Sea Crisis: A Great Challenge in Transboundary Water Resource Management", NATO Advanced Research Workshop on Transboundary Water Resource management: Technical and Institutional Issues, Skopelos Greece, May 1994.

Darkoh, M.B.K., "The Nature, Causes and Consequences of Desertification in the Drylands of Africa", *Land Degradation & Development*, Vol. 9 (1), 1998, pp. 1-20.

Davydov, M. M., "The Ob' will enter the Caspian: The Yenisey-Ob'-Aral-Caspian water connection and energy problem" *Sibirskiye ogni,* No. 2, 1949, pp. 102-110.

De Bardeleben, Joan.," Economic Reforms and Environmental Protection in the USSR", *Soviet Geography,* Vol. 31(4), 1990, pp. 237-56.

De Sherbinin, A., "Climate change impacts on agriculture", *Environment,* Vol. 42(2), 2000, p. 3.

Dinar, Ariel and J. Letey., "Agricultural Water Marketing, Allocative Efficiency, and Drainage Reduction" *Journal of Environmental Economics and Management,* Vol. 20(3), May, 1991, pp. 210-223.

Djalalov, A., "Rational Water Resources Use in Market Economy Conditions", the 3rd World Water Forum, Regional Cooperation in Shared Water Resources in Central Asia, Kyoto, March 18, 2003.

Döös B. R., "Why is environmental protection so slow?", *Global Environmental Change,* Vol. 4(3), 1994, pp. 179-184.

Dorman, Shawn., "Who Will Save the Aral Sea?", *Environmental Policy Review,* Vol. 5 (2), 1991.

Draper, Stephen., "International Duties and Obligations for Transboundary Water Sharing", *Journal of Water Resources Planning and Management,* Nov/Dec 1997.

Dukhovny, V & V I Sokolov., "Integrated Water Resources Management in the Aral Sea Basin", Scientific Information Centre for the Inter-state Commission for Water Coordination in the Aral Sea Basin, 2000.

Dukhovny, V. et al., "Drainage and water strategy for the Aral Sea basin", paper presented at the 6th Workshop on Drainage and the Environment, ICID, Ljubljane, Slovenia, 1996.

Dukhovny Viktor and Vadim Sokolov., "Lessons on cooperation building to manage water conflicts in the Aral Sea basin", UNESCO, 2003.

Dukhovnyi, Viktor., "Voda dlia regiona." *Zvezda vostoka,* 1986, No. 2. (in Russian)

Dukhovny V. and Sokolov V., "Inter-state Water Legislation in the Aral Sea Basin", Proceedings of IX World Water Congress, International Water Resources Association, Canada, September 1997, pp. 655-657.

Dukhovny V. and Sokolov V., "Water and Salt Management Strategies in the Aral Sea Basin", In: L.S. Pereira and J.W. Gowing (eds.) Water and the Environment: Innovation Issues in Irrigation and Drainage, E & FN Spon, London, 1998, pp. 415-421.

Dukhovny V.A., Proposals on IPTRID Network Development: Proc. The Learning Society and the Water-Environment - La societe cognitive et les problèmes de l'eau. Paris, 2-4 June, 1999.

Dukhovny V. and Ruziev U., "River Basin Management in the Aral Sea Basin", Technical Documents in Hydrology, Int. Hydrological Programme, No.31, 1999, UNESCO, Paris.

Dukhovny, V.A., Rozakov, R.M,, Rudnev, I.B. & Koshnazarov, K.A., "Aral Sea problem and nature conservation measures", *Problemy osvoeniya pustyn'*, Vol. 6, pp.3-15 (in Russian)

Dukhovny, V. A., "Integrated Water Resources Management in the Aral Sea Basin", the 3rd World Water Forum, Regional Cooperation in Shared Water Resources in Central Asia, Kyoto, March 18, 2003.

Dyukov, Oleg. "An Ecological Portrait of the Commonwealth", *Russian Life*, Summer 1993, pp. 23-25.

Dzhalilov (Jalilov), S., "Perspekitvy vnedreniia kapel'nogo orosheniia v Uzbekistane", *Sel'skoe khoziaistvo Uzbekistana*, 1996, No. 1.Economy of the Uzbek SSR in 1987-1988. Uzbekistan, Tashkent. (in Russian)

Elhance, Arun P., "Conflict and Cooperation over Water in the Aral Sea Basin", *Studies in Conflict and Terrorism*, April-June 1997.

Ellis, William. "The Aral: A Soviet Sea Lies Dying." *National Geographic*, No. 2, February, 1990, p. 83.

Elpiner, L. I., "Medical-ecological problems in the eastern Aral region", Paper presented at University of Indiana conference on "*The Aral Sea Crisis: Environmental Issues in Central Asia*," Bloomington, Indiana, 1990.

Engelman, Robert. "Mother Russia Struggles with Mother Nature", *Safety & Health,* June 1993, pp. 34-36.

Elpiner, L. I., "Public health in the Aral Sea coastal region and the dynamics of changes in the ecological situation." In: M. H. Glantz (eds.), '*Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin*', Cambridge: Cambridge university Press, 1998.

Eustis, Mark and Philip Micklin., "Anatomy of a Disaster", *Earthwatch*, May/June 1993, pp. 14-15.

Falkenmark, M., "The Ven Te Chow Memorial Lecture: Environment and Development: Urgent need for a Water Perspective", *Water International*, Vol.16 (4), 1991.

Farshad, A. and Zinck, J. A., "Seeking Agricultural Sustainability", *Agriculture, Ecosystems and Environment*, Vol. 47, 1993, pp. 1-12.

Fergus, Michael., "The Aral Sea Environmental Crisis: Problems and a Way Forward" *Asian Affairs*, February 1999.

Fiering, M. B., "Alternative indices of resilience", *Water Resources Res*earch, Vol. 18(1), 1987, p. 3339.

Frederick, K. D., "The disappearing Aral Sea", *Resources*, Winter, 1991, pp. 11-14.

Freeman, William E. "Environmental Assistance to the Newly Independent States", *Environmental Science & Technology*, Vol. 27(4), 1993, pp 608-609.

Fresco, L O. and S. B. Kroonenberg., "Time and spatial scales in ecological sustainability", *Land Use Policy 9,* 1992, pp. 155-168.

Glantz, Michael. H, Alvin Z. Rubinstein, and Igor Zonn., "Tragedy in the Aral Sea Basin: Looking Back to Plan Ahead," in *Central Asia: Its Strategic Importance and Future Prospects*, Edited by Hafeez Malik, New York: St. Martin's Press, 1994.

Glantz, M. H., "Creeping environmental phenomena: Are societies equipped to deal with them?" Paper presented at "*Creeping Environmental Phenomena and Societal Responses to Them*," Boulder, Colorado, 7-10 February, 1994.

Glantz, M. H. and I. Zonn., "A quiet Chernobyl", *The World & I*, September, 1991, pp. 324-329.

Glantz, M. H., A. Z. Rubinstein, and I. Zonn., "Tragedy in the Aral Sea basin: Looking back to plan ahead?" *Global Environmental Change*, Vol. 3(2), 1993, pp. 174-198.

Glantz, M.H. and R.M. Figueroa, "Does the Aral Sea merit heritage status?" *Global Environmental Change*, Vol. 7(4), 1997, pp. 357-380.

Glazovskiy, N F, "Ideas on an Escape from the Aral Crisis", *Soviet Geography*, Vol. 32(2), 1991, pp. 73-92.

Glazovsky N.F. & A. S. Shestakov, "Environmental migration caused by desertification in Central Asia and Russia", Institute of Geography, Russian Academy of Sciences. http://www.cis.lead.org

Gleason, G., "The Struggle for Control Over Water in Central Asia: Republican Sovereignty and Collective Action", Radio Liberty Research, pp. 11-19, June 21, 1991.

Gleason, G., "The Struggle over Water: Republican Sovereignty and Collective Action." *RFE/RL Report on the USSR*, June 21, 1991.

Gleason, G., "Fashioning a New Water Regime: Theoretical and International Considerations," in Social Science Research Council, Aral Sea Basin Workshop, Tashkent, Uzbekistan, May 19-21, 1998.

Gleason, G., "The struggle for control over water in Central Asia: republican sovereignty and collective action", RFE/RL Report on the USSR, June 21st, 1991.

Gleason, G., "Uzbekistan: from statehood to nationhood", in I. Bremmer& I. Tazar (eds.), Nations and Politics in the Soviet Successor States, Cambridge University Press, Cambridge, 1993.

Gleick, P. H. "Water and Conflict: Fresh Water Resources and International Security", *International Security*, Vol. 18(1), 1993.

Goble, Paul and Bruce Pannier., "A Watershed in Central Asia", *Central Asia Monitor*, No. 5, 1997.

Goble, P & B. Pannier., "A watershed in Central Asia", *RFE/RL Newsline*, 1, 82/1, 1997.

Gorodetskaya, M. Ye. and A. S. Kes., "Alma-Ata conference on the environmental impact of a drop in the level of the Aral Sea", *Soviet Geography*, Vol. 19(10), 1978, pp. 728-736.

Green, Peter., "Turning a Sea into Toxic Soup", *U.S. News & World Report*. 13 April 1992: p. 47.

Green, Eric. "Poisoned Legacy: Environmental Quality in the Newly Independent States." *Environmental Science & Technology*, 1993, Vol. 27(4), pp. 590-595.

Gerardi, LA., "Transfer of the runoff of Siberian rivers southward (river Ob' - Aral - Caspian)", *Bulleten' po vodnomu khozyaysvu*, 1972, 10. (in Russian)

Gerasimov, I.P, Kuznetsov, N.T, Kes',A.S. &Gorodetskaya, M.E., "The problern of the Aral Sea and anthropogenic desertification of the Aral Region", *Problemy osvoeniya pustyn'*, Vol. 6, 1983, pp. 22-33 (in Russian)

Glazovsky, N.F., "Water and ion ground runoff to the Aral, Caspian, and Black Sea", *Doklady AN SSSR*, Vol. 227(4), 1976, pp. 961-964 (in Russian)

Glazovsky, N.F., "Wind-energy conditions of substance migration in the arid zone of the USSR", *Doklady AN SSSR*, Vol. 279(5), 1984, pp.1225-1229 (in Russian)

Glazovsky, N.F., "Microelements in landscapes of the Ustyurt Plateau", In: *Problems of development of the Ustyurt Desert*, 1985, pp. 71-82, Mokhnat, Tashkent (in Russian)

Glazovsky, N.F. & Golubov, B.N., "On the problem of regulation of the Caspian Sea regime", Izvestiya AN SSSR, *ser. geogr.*, 6, 1973, pp. 49-52 (in Russian)

Gleick, P. H., "The changing water paradigm: a look at twenty-first century water resources development", *Water International*, Vol. 25(1), 2000, pp. 127-138.

Goble Paul, 'Central Asia: analysis from Washington – a watershed in Central Asia', (Washington, 25 July 1997, Radio Free Europe) (19 August 1998). www.rferl.org/nca/features/1997/07/F.RU.970725144746.html

Gorodetskaya, M.Y and A S Kes., "Alma Ata Conference on the Environmental impact of a Drop in the level of the Aral Sea Basin", *Soviet Geography*, Vol. 19 (10), 1978, pp. 728-736.

Grigoriev, A.A. & Lipatov, V.B., "Dust storms in the Aral Region by space survey data", In: *Development and transformation of environment*, 1979, Leningrad. (in Russian)

Grigoriev, A.A. & Lipatov, V.B., "Dynamics and sources of dust storms in the Aral Region in accordance with by observations from space", Izvestiya AN SSSR, ser. geogr., 5, 1982, pp. 93-98. (in Russian)

Gryaznova, G.P., "Processes of relief formation on the drying up bottom of the Aral Sea in the region of the ancient Kazalin delta of the Syr Darya", *Geomorphologiia*, 1, 1986, pp. 47-54. (in Russian)

Gustafson, Thane., "Transforming Soviet Agriculture: Brezhnev's Gamble on Land Improvement." *Public Policy*, Vol. 25 (3), 1977.

Hansen, J., "Forcings and chaos in inter annual to decadal climate change", *Journal of Geophysical Research*, Vol. 102(D22), 1997, pp. 25679-25720.

Harris, P.G., "Affluence, poverty and ecology: Obligation, international relations and sustainable development", *Ethics and the Environment*, Vol. 2(2), 1997, pp. 121-138.

Harris, P.G., "Environment, history and international justice", *Journal of International Studies*, Vol. 40, 1997, pp. 1-33.

Hasanov, Rasulmat., "Yetakchi yonalishlar (dehqanchilikning hazirgi ahwali wa uni rivajlantirishning bash yonalishlari)", *Ozbekistan qishlaq khojaligi*, 1996, no. 1. (in Russian)

Hashimoto, T., J. R. Stedinger, and D. P. Loucks., "Reliability, resiliency, and vulnerability criteria for water resources system performance evaluation", *Water Resources Research*, Vol. 18(1), 1982, p 1420.

Hollis, G.E., "The Falling Level of the Caspian and Aral Seas", *Geographical Journal*, Vol. 144 (1), 1978.

Horsman, Stuart., "The Environmental-Nationalist Linkage in Post-Soviet Central Asia: Causes and Implications", *Environmental Politics in Central Asia*, University of Sheffield.

Hollis, G.E., "The Falling Levels of the Caspian and Aral Sea", *The Geographical Journal*, Vol. 144(1), 1978, pp. 62-80.

Hutchens, A. O., and P. C. Mann., "Review of water pricing policies, institutions and practices in Central Asia", Technical Report, U.S. Agency for International Development, Environmental Policy and Technology Project, Central Asia Regional EPT Office, 1998, Almaty, Kazakhstan.

Ilkhamov, Alisher., "Shirkats, Dekhqon Farmers, and Others: Farm Restructuring in Uzbekistan", *Central Asian Survey*, Vol. 17 (4), 1998.

Ilkhamov, Alisher., "Divided Economy: Kolkhoz System vs. Peasant Subsistence Economy in Uzbekistan." *Central Asia Monitor*, 2000, no. 4.

Ingram, H., "Water and equity: A direction for research", *The Common Property Resources (CPR) Forum*, No. 43, 1997.

International Research Institute for Climate Prediction, "The drought and humanitarian crisis in Central and Southwest Asia: A climate perspective", Nov 2001.
http://www.reliefweb.int

Ishaqov, A.I. and Qasimov, Sh. A., "Pakhtakar ayallar mehnati gigienasi," in *Qishlaq khojaligi khadimlari mehnati gigienasi.* Edited by T.I. Iskandarov. Tashkent: Uz SSR "Meditsina," 1988. (in Russian)

Izahara, T., "Raw cotton of the USSR", *Spinning Monthly Report,* June 1990, pp. 32-50 (in Japanese).

Izumi, S., "The present state of the textile industry of the USSR", *Japan Spinning Monthly*, 1960, Vol. 166, pp. 2-22. (in Japanese).

Jamieson, D. 1991., "The epistemology of climate change: Some morals for managers", *Society and Natural Resources*, Vol. 4, pp. 319-329.

Janauer, G.A., "Eco-hydrology: fusing concepts and scales", *Ecological Engineering*, Vol. 16 (1), 2000, pp. 9-16.

Jickling, B., "A future for sustainability?", *Water Air and Soil Pollution*, Vol. 123 (1-4), 2000, pp. 467-476.

Joffe, Muriel., "Autocracy, Capitalism, and Empire: The Politics of Irrigation", *The Russian Review*, Vol. 54, July 1995.

Juurokuhara, T., "The present cotton situation of the USSR - the slump in the cotton harvest", *Spinning Monthly Report*, September 1985, pp. 50 56 (in Japanese).

Kadamov M., "Tajikistan as one of the main sources of the Central Asian regional water resources formation", Proceedings of International Workshop on Global Change, Sustainable development and Environment management in Central Asia, Environmental Programme of the Government of Uzbekistan supported by UNDP, 2004.

Kamilov, A., "Internal conflicts in Soviet Central Asia: Causes and Consequences", in Rupersinge, et. al. (eds.), *Ethnicity and Conflicts in a Post-Communist World: The Soviet Union, Eastern Europe and China*, New York, 1992.

Kayumov O., & Ikramova M., "Development of the operative measures on water shortage control for the lower part of the Amu Darya River", Proceedings of International Workshop on Global Change, Sustainable development and Environment management in Central Asia, Environmental Programme of the Government of Uzbekistan supported by UNDP, 2004.

Katanov, D. and E. Lian., "Kapel'nomu orosheniiu - shirokoe vnedrenie", *Sel'skoe khoziaistvo Uzbekistana*, 1993, No. 4. (in Russian)

Kes, A.S., "The Cause of Water level Changes of the Aral Sea in the Holocene", *Soviet Geography: Review and Translation*," Vol. 20 (2), 1979.

Khaydarova, N and et. al., "Some aspects of integrated water resources management in Central Asia", *Geophysical Research Abstracts*, Vol. 5, 14164, European Geophysical Society 2003.

Khalmetov, R. K. and L. M. Beketova., "Health status of children and adolescents in the main cotton growing region of Central Asia", *Vestn. Ross. Akad. Med. Nauk,* ISS 6, 1993, pp. 43-46.

Khakimov, Fikki I., "Pochvenno-meliorativnye usloviya opustynivahyuschikhshya del't: Tendentsii izmenii prostrant'svennaya differentsiatsia [Soil reclamation conditions of delta desertification: Tendencies of transformation and spatial differentiation]", Pushchino: Nauchoyi Tsentr biologicheskikh isseldovaniy AN SSSR, 1989.

Khamdamov, K. A., "Topographic examinations of the eye in children exposed to effects of pesticides applied agriculturally in some areas of Uzbekistan." *Oftalmol. Zh.*, Vol. 31(3), 1976, p. 226.

Khan, Azizur Rahman., "The Transition to a Market Economy in Agriculture," in *Social Policy and Economic Transformation in Uzbekistan*, Edited by Keith Griffin, Tashkent: UNDP, 1995.

Khrustalev, Yu.P. & Reznikov, S.N., "Main sources of sedimentation material income to the Aral Sea", *Izvestiya VGO*, Vol. 108 (5), 1976, pp. 434-438 (in Russian)

Khusainova, N.Z., "Kultulcs of the eastern shore of the Aral Sea and their life", *Vestnik AN KazSSR*, Vol. 6, 1960, pp. 34-42 (in Russian)

Klotzli, Stefan., "The Water and Soil Crisis in Central Asia – A Source for Future Conflicts?" *ENCOP Occasional Paper No. 11*, Zurich: Centre for Security Policy and Conflict Research, 1994. http://www.fsk.ethz.ch/fsk/encop/11/en11-con.htm.

Kolbasov, O.S., "Legislation on Water Use in the USSR: Problems of Perfecting Soviet Legislation on the Use of Water Resources", in *Water Resources Law and Policy in the USSR*, Edited by Irving Fox, Madison: University of Wisconsin Press, 1971.

Kondratiev, K.Ya, Grigoriev,A.A. & Zhvalev, V.F., "Impacts of powerful duat storms on the radiation energy of atmosphere and deserts", In: *Natural resources of deserts and their development*, 1986, pp. 27-31, Ashgabad. (in Russian)

Korzhenko, V.A. et al., "Scientific bases of environmental forecasts of desertification of hydro-morphic landscapes", *Problemy osvoeniya pustyn'*, 1983, 2. (in Russian)

Kotov, S.V. & Frumin, G.T., "New data on ion composition oft he Aral Sea water", In: *Results of expedition on the Aral problems in 1991*, 1991, pp.10-17, St. Petersburg. (in Russian)

Kotlyakov, V.M. et al., "Concept for preserving and restoring the Aral Sea and normalizing the ecological, public health, and socio-economic situation in the Aral Region", *Post-Soviet Geography*, Vol. 33(5), 1992, pp. 283-295.

Kotylyakov, V.M., "The Aral Sea Basin: A Critical Environmental Zone", *Environment*, Vol. 33 (1), 1991.

Krenke, A.N., "Mass exchange in glacial systems on the territory of the USSR", *Gidrometeoizdat*, Leningrad, 1982. (in Russian)

Kuksa, V.I., "Iuzhnyi moria (Aral'skoe, Kaspiiskoe, Azovskoe i Chernoe) v usloviiakh antropogennogo stressa", *Gidrometeoizdat*, Sankt-Peterburg: 1994. (in Russian)

Kulmatov R., "*Problems of monitoring, use and management of the rivers of basin of the Aral Sea*", Proceedings of International Workshop on Global Change, Sustainable development and Environment management in Central Asia, Environmental Programme of the Government of Uzbekistan supported by UNDP, 2004.

Kuptsov, V.M., Rubanov, I.V. & Zel'dina, B.B., "Radiocarbon dating of bottom sediments of the Aral Sea", *Izvestiya AN SSSR, ser. geogr.*, 1, 1982, pp. 103-108 (in Russian)

Kumar, Rama Sampath., "Aral Sea: Environmental Tragedy in Central Asia", *Economic and Political Weekly,* Sept 14, 2002, pp. 3797-3802.

Kundzewicz, Z. W and J. Kindler., "Multiple criteria for evaluation of reliability aspects of water resource systems", *Proceedings of a Boulder Symposium*, International Association of Hydrologic Sciences (IAHS) Pub. No. 231, 1995.

Kuznetsov, N.T. & Nikolaeva, R.V., "Geographical aspects of the possibilities of the Aral Sea water regime management", In: *Natural resources and spatial organization of economy*, 1979, pp. 79-89, Nauka, Moscow (in Russian)

Kuznetsov, N. T., "Geographical and Ecological aspects of the Aral Sea Hydrological Functions", *Post Soviet Geography*, Vol. 33 (5), 1992, p. 324.

Kuznetsov, N.T., "Geographical Aspects of the Future of the Aral Sea", *Soviet Geography: Review and Translation*, Vol. 18 (5), 1977.

Lal, D., et al., "Polar ice ablation rates measured using *in situ* cosmogenic^{14}C", *Nature,* Vol. 346, 1990, pp. 350-352.

Lee, T. R., "Managing Water Resources in Latin America" *Natural Resources Journal,* Vol. 30 (3), 1990, pp. 581-607.

Lerman, Zvi, Jorge Garcia-Garcia, and Dennis Wichelns., "Land and Water Policies in Uzbekistan", *Post-Soviet Geography*, Vol. 37 (3), 1996.

Levintanus, A., "Saving the Aral Sea", *Journal of Environmental Management*, Vol. 36 (3), 1992.

Liptovsky, Igov., "The Deterioration of the Ecological Situation in Central Asia: Causes and Possible Consequences", *Europe Asia Studies*, Vol. 47(7), 1995, pp. 1109-23.

Loucks, D. P., "Sustainable water resources management", *Water International*, Vol. 25(1), 2000, p.11.

L'vovich, M.I. & Tsigelnaya, I.D., "Aral Sea water management", *Izvestiya AN SSSR, ser. geogr.*, 1, 1978, pp. 42-54 (in Russian)

L'vovich, M.I. and I.D. Tsigel'naya., "Management of the Water Balance of the Aral Sea." *Soviet Geography: Review and Translation*, Vol. 20 (3), 1979.

Maja Schlütera, Andre G. Savitskyb, Daene C. McKinneyc & Helmut Lietha, "Optimizing long-term water allocation in the Amu Darya river delta –A water management model for ecological impact assessment", Institute of Environmental Systems Research, University of Osnabrueck, Osnabrueck, Germany.

Marchisio, S., "Sustainable Management of Water Resources and International Law", *Water Science and Technology*, Vol. 42(1-2), 2000, pp. 241-247.

Martin, Keith., "Central Asia's Forgotten Tragedy", *RFE/RL Research Report*, Vol. 3 (30), 1994.

Medvedev, Z A., "The Environmental Destruction of the Soviet Union", *The Ecologist*, Vol. 20(1), 1990, pp. 24-29.

McCaffrey, S., "An assessment of the work of the International Law Commission", *Natural Resources Journal*, Vol. 36, 1996, pp.297–318.

McCaffrey, S. and Rosenstock, R., "The International Law Commission's draft articles on international watercourses: an overview and commentary', *RECIEL*, Vol. 5, 1996, p.89.

McKinney, Daene C., "Basin-Scale Integrated Water Resources Management in Central Asia", Third World Water Forum, Regional Cooperation in Shared Water Resources in Central Asia, Kyoto, March 18, 2003.

McKinney, Daene C., "Cooperative management of transboundary water resources in Central Asia", in *the Tracks of Tamerlane-Central Asia's Path into the 21st Century*, D. Burghart and T. Sabonis-Helf (eds.), National Defense University Press, 2003.

McKinney, Daene. C., Ximing. Cai, M. W. Rosegrant, C. Ringler, and C. A. Scott., "Modelling water resources management at the basin level: Review and future directions", SWIM Paper No. 6, International Water Management Institute, Colombo, Sri Lanka, 1999.

McKinney, Daene C., "Sustainable water management in the Aral Sea Basin", Department of Civil Engineering, The University of Texas, Austin.

McKinney, Daene C. and Amirkhan K. Kenshimov., "Optimization of the use of water and energy resources in the Syr Darya basin under current conditions", University of Texas, Austin.

McKinney, Daene C., “Basin-Scale Integrated Water Resources Management in Central Asia”, the 3rd World Water Forum, Regional Cooperation in Shared Water Resources in Central Asia, Kyoto, March 18, 2003.

McKinney, Daene C. and Ximing Cai., “Linking GIS and water resources management models: an object-oriented method”, *Environmental Modelling & Software*, Vol. 17, 2002, pp. 413–425. www.elsevier.com/locate/envsoft

Micklin, Philip. P., “The Water Management Crisis in Soviet Central Asia”, The Carl Beck Papers in Russian and Eastern-European Studies No. 105, University of Pittsburgh, Center for Russian and Eastern European Studies, 1991.

Micklin, Philip. P., “The Aral Crisis: Introduction to the Special Issue”, *Post-Soviet Geography*, Vol. 33(5), 1992, pp. 269-282.

Micklin, Philip. P., “The shrinking Aral Sea”, *Geotimes*, Vol. 38(4), 1993, pp. 14–18.

Micklin, Philip P., "Touring the Aral: Visit to an Ecological Disaster Zone," *Soviet Geography: Review and Translation*, Vol. 32 (2), 1991.

Micklin Philip., “Desiccation of Aral Sea: A Water Management Disaster in the Soviet Union”, *Science*, Vol. 241(4870), 1988, pp. 1170-76.

Micklin, Philip P., "No More Çaviar", *The Economist*, October 15, 1994.

Micklin, Philip P., “International and Regional Responses to the Aral Sea Crisis: An Overview of Efforts and Accomplishments,” in Social Science Research Council. Aral Sea Basin Workshop, Tashkent, Uzbekistan, May 19-21, 1998.

Micklin, Philip P., "The Aral Crisis: Introduction to the Special Issue", *Post-Soviet Geography*, Vol. 33 (5), 1992.

Micklin, Philip P., “Soviet Geography Studies in Our Time”, L. Holzner and J. M. Knapp, (eds.), Univ. of Wisconsin Press, Milwaukee, 1987, pp. 229-261.

Micklin, Philip P., "Ideas on an Escape from the ‘Aral Crisis’", *Soviet Geography*, Vol. 32, 1991, No. 2.

Micklin, Philip P., "The Fate of the 'Sibaral': Soviet Water Politics in the Gorbachev Era," *Central Asian Survey*, Vol. 6 (2), 1987.

Micklin, P., “Irrigation and its future in Soviet Central Asia: A preliminary analysis”, in I. Holzner & J. M. Knapp (eds.), *Soviet Geography Studies in our Time*: A Festscrift for Paul E. Lydolph, 1987.

Mikhaylov, N.I., V.A. Nikolayev, and Ye. Timashev., "Environmental Protection Issues and the Southward Diversion of Siberian Rivers" *Soviet Geography: Review and Translation*, Vol. 20 (1), 1979.

Mirzaev S.Sh., Razakov R.M., Nasonov V.G., "The future of the Aral Sea basin in flourishing oasis or fruitless desert", Collection of scientific articles: Water resources, the Aral problem and environment, Tashkent University, 2000.

Moriarty Patrick, Charles Batchelor and Christine van Wijk., "Trends in watershed management in arid and semi-arid regions", DGIS Policy Supporting Paper, IRC, Delft, July 2001.

Molosnova, T.I., Subbotina, O.I. & Chanysheva, S.G., "Climatic consequences of economic activity in the Aral Sea zone", Gidrometeoizdat, 1987, Moscow. (in Russian)

Morozov, N.P., "Lithium and rubidium in internal sea water", *Okeanologiya*, 8, 4, 1968, pp. 612-615. (in Russian)

Morozova, M.I., Petrosyants, M.A. & Chernyshova, O.N., "Mean wind field over the mountain systems of Middle and Central Asia", In: Transactions of V.I. Romanovsky Institute of mathematics, Vol. 25, 1962, pp. 23-44. (in Russian)

Mozhaitseva, N.M. & Nekrasova, TF., "Method of estimation salt removal by wind from the dry bottom of the Aral Sea", *Problemy osvoeniya pustyn'*, Vol. 6, 1983, pp. 15-21. (in Russian)

Muhammadjanov, M., "Suw ambarlari wa ekologiya." *Sharq yulduzi*, 1989, No. 10. (in Russian)

Nagar, Rusi., "Reflection on the Aral Sea Tragedy in the National Literature of Turkmenistan", *Central Asian Survey*, Vol. 8(1), 1989, pp. 21-49.

Nanni, M., "The Aral Sea Basin: legal and institutional issues", *RECEIL*, Vol. 5, 1996, pp.131–132.

Nikitin, A.M., "Morphometry and morphology of lakes of Central Asia", In: Transactions of SARNIGMI, Vol. 50 (131), 1977, pp. 22-30, Tashkent. (in Russian)

Nikitin, A.M. & Bondar', V.A., "Dynamics of lakes in Amu Darya delta", In: Transactions of SARNIGMI, Vol. 25 (106), 1975, pp. 79-90, Tashkent. (in Russian)

Nikitin, A.M. & Lesnik, Yu. N., "Estimation of dynamics of lowland lakes of Central Asia by space images", In: Transactions of SARNIGMI, Vol. 87 (168), 1982, pp. 49-56. (in Russian)

Nikol'sky, G.V., "The fish of the Aral Sea", MOIP, 1940, Moscow. (in Russian)

Novikova, N., "Creeping environmental changes in the pre-Aral ecosystems under the Aral Sea crisis", In: M. H. Glantz (ed.), Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin. Cambridge: Cambridge University Press. 1998.

Novikova, N.M., "Impacts of anthropogenic changes of river runoff upon ecosystems of present delta plains of arid regions", *Problemy osvoeniya pustyn'*, 4, 1983, pp.18-24. (in Russian)

Novikova, N.M., "Vegetation dynamics of delta plains of arid regions due to anthropogenic transformation of river runoff", In: Bio-geographical aspects of desertification, 1985, pp. 32-40, Moscow. (in Russian)

Novikova, N.M. & Zaletaev, V.S., "Water management as a factor of transformation of natural ecosystems", In: Bio-geographical aspects of desertification, 1985, pp. 4-12, Moscow. (in Russian)

Novikova, N. M., and V. S. Zaletayev., "Vodnoye khozyeistvo kak faktor transformatsii prirodnykh ekosistem [Water economics as a factor in the transformation of natural ecosystems]", In *Biogeograficheskiye aspekty opustynivaniya* [Bio-geographical aspects of desertification], (eds.) Oleg A. Kibal'chich, Anatolii G. Voronov, and D. D. Vishyvkin, 1985, pp. 4-12. Moscow: Moskoviskii filial Geograficheskoe obshchestvo SSSR.

Nurushev, A., "Crisis of the Aral Sea", *Himalayan and Central Asian Studies*, Vol. 3(2), 1999, pp. 50-58.

Ohlin, G., "The population Concern", *Ambio*, Vol. 21(1), 1992, pp. 6-9.

O'Hara, Sarah., "Agriculture and Land Reform in Turkmenistan Since Independence" *Post Soviet Geography and Economics*, Vol. 38 (7), 1997.

O'Hara, Sarah., "Managing Turkmenistan's Kara Kum Canal: Problems and Prospects" *Post-Soviet Geography and Economics*, Vol. 39 (4), 1998.

O'Hara, Sarah., "Water and Conflict in Central Asia", Environmental Politics in Central Asia, University of Nottingham, UK.

O'Hara, S & T. Hannan., "Irrigation and water management in Turkmenistan, Central Asia: past systems, present problems and future scenarios", (unpublished manuscript).

O'Dy, S., "La voix du désert d'Aral", *L'Express*, August 1991, pp. 52-55. (in French)

Orechkine, D., "La mer d'Aral menacée de disparition" *La Recherche*, 226 21, November, pp. 1380-1388. (in French)

Palm, R. I., "Introduction to the study of natural hazards", In: R. I. Palm, Natural Hazards. Baltimore, Md: Johns Hopkins University Press, 1990, pp. 1 17.

Pannier, B & S. Aioubov, 'Central Asia: Tajik and Uzbek Presidents Meet' (Prague, 6 January 1998, Radio Free Europe) (19 August 1998). www.rferl.org/nca/features/1998/01/F.RU.980106134242.html

Parisi, P. and M. H. Glandz., "Deforestation and public policy" *The World & 1*, November, 1992, pp. 270-277.

Peck, S., "Managing and Protecting Our Water Resources", *Water Air and Soil Pollution*, Vol. 90(1-2), 1996, pp. 11-20.

Petterson, J., "The social component of (adaptive) ecological characterizations", Memo presented at NOAA Scientific Advisory Meeting on Adaptive Ecological Management, National Center for Atmospheric Research, Boulder, Colorado, 1995, 9-10 March.

Pearce, Fred., "Neighbours Sign Deal to Save Aral Sea", *New Scientist*, 22 Jan. 1994, p. 10.

Pope, Victoria., "Poisoning Russia's River of Plenty", *U.S. News & World Report*, 13 April 1992, p. 49.

Prihodko, V.G., "What will happen with Aral Sea basin in 2020?", Proceedings of International Workshop on Global Change, Sustainable development and Environment management in Central Asia, Environmental Programme of the Government of Uzbekistan supported by UNDP, 2004.

Pshenin, G.N,, Steklenkov, A.P. & Cherkinsky, A.E., "Origin and age of pre-Holocene terraces of the Aral Sea", *Doklady AN SSSR*, 276, 3, 1984, pp. 675-677. (in Russian)

Pryde, Philip R., "Observations on the Mapping of Critical Environmental Zones in the Former Soviet Union" *Post-Soviet Geography*, 1994, Vol. 35(1), pp. 38-49.

Rafikov, A., "Vodnoe khoziaistvo i rynochnaia ekonomika" *Sel'skoe khoziastvo Uzbekistana*, 1993, No. 3. (in Russian)

Rafikov, A.A., "Environmental Change in the Southern Aral Sea Region in Connection With the Drop in the Aral Sea" *Soviet Geography: Review and Translation*, Vol. 24 (5), 1983.

Raskin, P., E. Hansen, Z. Zhu, and D. Stavisky., "Simulation of water supply and demand in the Aral Sea Region", *Water International*, Vol. 17, 1992, pp. 55–67.

Rawat, A., "Technological change and environmental management in industry", *International Journal of Environment and Pollution*, Vol. 6(2-3), 1996, pp.172-184.

Palm, R. I., "Introduction to the study of natural hazards", In: R. I. Palm, Natural Hazards. Baltimore, Md: Johns Hopkins University Press, 1990, pp. 1 17.

Pannier, B & S. Aioubov, 'Central Asia: Tajik and Uzbek Presidents Meet' (Prague, 6 January 1998, Radio Free Europe) (19 August 1998). www.rferl.org/nca/features/1998/01/F.RU.980106134242.html

Parisi, P. and M. H. Glandz., "Deforestation and public policy" *The World & 1*, November, 1992, pp. 270-277.

Peck, S., "Managing and Protecting Our Water Resources", *Water Air and Soil Pollution*, Vol. 90(1-2), 1996, pp. 11-20.

Petterson, J., "The social component of (adaptive) ecological characterizations", Memo presented at NOAA Scientific Advisory Meeting on Adaptive Ecological Management, National Center for Atmospheric Research, Boulder, Colorado, 1995, 9-10 March.

Pearce, Fred., "Neighbours Sign Deal to Save Aral Sea", *New Scientist*, 22 Jan. 1994, p. 10.

Pope, Victoria., "Poisoning Russia's River of Plenty", *U.S. News & World Report*, 13 April 1992, p. 49.

Prihodko, V.G., "What will happen with Aral Sea basin in 2020?", Proceedings of International Workshop on Global Change, Sustainable development and Environment management in Central Asia, Environmental Programme of the Government of Uzbekistan supported by UNDP, 2004.

Pshenin, G.N,, Steklenkov, A.P. & Cherkinsky, A.E., "Origin and age of pre-Holocene terraces of the Aral Sea", *Doklady AN SSSR*, 276, 3, 1984, pp. 675-677. (in Russian)

Pryde, Philip R., "Observations on the Mapping of Critical Environmental Zones in the Former Soviet Union" *Post-Soviet Geography*, 1994, Vol. 35(1), pp. 38-49.

Rafikov, A., "Vodnoe khoziaistvo i rynochnaia ekonomika" *Sel'skoe khoziastvo Uzbekistana*, 1993, No. 3. (in Russian)

Rafikov, A.A., "Environmental Change in the Southern Aral Sea Region in Connection With the Drop in the Aral Sea" *Soviet Geography: Review and Translation*, Vol. 24 (5), 1983.

Raskin, P., E. Hansen, Z. Zhu, and D. Stavisky., "Simulation of water supply and demand in the Aral Sea Region", *Water International*, Vol. 17, 1992, pp. 55–67.

Rawat, A., "Technological change and environmental management in industry", *International Journal of Environment and Pollution*, Vol. 6(2-3), 1996, pp.172-184.

Razzaqov, Abdukhalil. "Melioratsiya: mish-mish wa haqiqat." *Hayat wa iqtisad*, 1992, No. 1. (in Russian)

Razzakov, Abdukhalil., "Water shortage in Central Asia and re-routing of Siberian rivers to Central Asia", Biweekly briefing, *Central Asia-Caucasus Analyst*, Wednesday/June 6, 2001.

Reteyum, A. U., "Letter in Overview Section", *Environment*, Vol. 33(1), 1991.

Rosegrant, M. W., and C. Ringler., "Impact on food security and rural development of transferring water out of agriculture", *Water Policy*, Vol. 1(6), 2000, pp. 567–586.

Rosegrant, M.W., C. Ringler, D.C. McKinney, X. Cai, A. Keller, and G. Donoso., "Integrated economic-hydrologic water modeling at the basin scale: the Maipo River basin", *Agricultural Economics*, Vol.24(1), 2000, pp.33-46.

Rosegrant, M. W., and R. S. Meinzen-Dick., "Multi-country research program: Water resource allocation: Productivity and environmental impacts (MP-10)", Program statement and methodology. Washington, D.C.: International Food Policy Research Institute, 1996.

Rototaeva, O.V., "Construction of fields of alimentation and accumulation altitude of for the glacial system of the Gissaro-Alay", MGI, Khronika obsuzhdeniya, 35, 1979, pp. 42-51. (in Russian)

Rozanov, Boris G. "Zemelnye resursy aridnogo poyasa SSSR, ikh ratsional'-noye ispozovaniye i okhrana [Lands of the arid belt of the USSR, their rational use, and protection]". *Problemy osvoyeniya paistyn 5*, 1986, pp. 22-28. (in Russian)

Rubanov, I.V. & Bogdanova, N.M., "Quantitative estimations of salt deflation of the drying up bottom of the Aral Sea", *Problemy osvoeniya pustyn'*, 3, 1987, pp. 9-16 (in Russian)

Rubinova F.A., "Change of the runoff of the Amu Darya river under influence of land-improvements in its basin", *SARNIGMI*, issue 106 (187), Gydrometeoizdat, 1085.

Rudenko B., "Solenye Peski Aralkum (The Salty sands of the Aral)", *Nauka I zhizn*, Vol. 10, October 1989, p. 44. (in Russian)

Rumer, Boris., "Central Asia's Cotton: The Picture Now", *Central Asian Survey*, Vol. 6(4), 1987.

Rupert, James., "Tragedy of the Aral: How the Soviets Destroyed a Sea", *Surviving Together*, No. 4, 1992.

Rudenko, B., "Solenye Peski Aralkum [The salty sands of the Aral]", *Nauka i zhizn*, Vol.10, October, 1989, p. 44.

Ryabtsev, A.D., "10 Years of Regional Collaboration in Shared Water Resources Management of Central Asia", the 3rd World Water Forum, Regional Cooperation in Shared Water Resources in Central Asia, Kyoto, March 18, 2003.

Sadikova, S. S. et al., "Indicators of iron metabolism and cellular immunity in healthy children and in those with iron deficiency anemia in relation to ecological conditions" *Pediatriia,* ISS 8, 1990, pp. 41-44.

Sadoff, Claudia W. and David Grey., "Beyond the river: the benefits of cooperation on international rivers", *Water Policy*, Vol. 4, 2002, pp. 389–403.

Seckler, D., Upali, Amarasinghe, Molden D., Ridhika de Silva, and Barker R., "World Water Demand and Supply, 1990 to 2025: Scenarios and Issues", International Water Management Institute, Research Report 19, Colombo, 1998.

Seckler, D., "The new era of water resources management: From "dry" to "wet" water savings", Research Report, No. 1, 1996, Colombo, Sri Lanka: International Water Management Institute (IWMI).

Seliunin, V., "The time to act", *Novy Mir*, 5, 1989, pp. 231-241. (in Russian)

Sharmanov, T. S., "Nutrition and health in relation to ecology" *Vest. Akad. Med. Nauk* SSSR, 1989, pp. 27-30.

Shokhkhuzhaev (Shahkhojaev), F., "Kompleksnomu obsluzhivaniiu vnutrikhoziaistvenykh gidromeliorativnykh sistem - dogovornyie tseny" *Sel'skoe khoziaistvo Uzbekistana*, No. 4, 1993. (in Russian)

Shaporenko, S.I., "Effects of hydrological regime upon fish productivity of salinized pools (on the example of the Aral sea, lakes of Arnasay system, and Sarykamysh)", Review of dissertation, Moscow, 1987. (in Russian)

Simonovic, S. P., "Risk in sustainable water resources management", In *Sustainability of water resources under increasing uncertainties*, IAHS Pub. No. 240, 1997.

Sinnott, Peter., "The Physical Geography of Soviet Central Asia and the Aral Sea Problem", in; Lewis, Robert A. (eds.), "*Geographical Perspectives on Soviet Central Asia*", London, New York, 1992.

Smith, David, R., "Salinization in Uzbekistan", *Post Soviet Geography*, Vol. 33 (5) Jan. 1992, pp. 21-32.

Smith, David R., “Change and Variability in Climate and Ecosystem Decline in the Aral Sea Basin Deltas”, *Post-Soviet Geography*, Vol. 35 (3), 1994, pp. 142-165.

Smith, David R., “Climate Change, Water Supply, and Conflict in the Aral Sea Basin”, *CIS Environmental Watch*, No. 6, Spring 1994.

Smith, David R., “Environmental Security and Shared Water Resources in Post-Soviet Central Asia” Post-*Soviet Geography*, Vol. 36 (6), 1995.

Smith, David., “Water and Cities in Arid Central Asia”, *Arid Lands Newsletter*, Vol. 45, Spring/Summer, 1999. http://ag.arizona.edu/OALS/ALN/aln45/central-asia.html

Sokolov V., “Integrated Water Resources Management in the Republic of Uzbekistan”, *Water International*, Vol. 24(2), 1999, pp. 104-115.

Sokolov V.I., “Definition of boundaries of water collection basins of Trans bordering, local and mixed types of surface water resources in the basin of the Aral Sea and quantitative assessment”, Collection of scientific works of SRC ICWC, pp.35-53 Tashkent, Issue 2, 2000

Solov'eva, N.F., “Salt and biogenic runoff of the Syr Darya”, In: Transactions of Laboratory of Lake Researches, Vol. 8, 1959, pp. 84-112 (in Russian)

Spoor, Max., “The Aral Sea Basin Crisis: Transition and Environment in Former Soviet Central Asia”, *Development and Change*, Vol. 29(3), 1998, pp. 409-435.

Stepanov, N.N., “Real possibilities to save the Aral and Aral Region”, *Vestnik Kara-Kalpakskogo filiala AN UzSSR*, Vol. 1, 1990, pp. 3-17 (in Russian)

Sultangazin, U. M. and T. Tsukatani., “Modelling of the Kazakhstan Economy and Environment” Discussion Paper No. 416, 1995, Kyoto University, Japan.

Svendsen, M., “Sustainability in irrigated agriculture”, International Irrigation Management Institute (IIMI), Working Paper No. 4, Colombo, Sri Lanka, 1987.

Terekhina, A.N. & Timoshhuk, L.A., “Results of the All-Union "Aral" competition”, *Izvestiya AN SSSR, ser. geogr.*, Vol. 4, 1991, pp.132-137. (in Russian)

Thurman, Michael., "Irrigation Management in Uzbekistan: Economic Inefficiencies, Costs, and Possible Solutions", *Central Asia Monitor*, 1995, no. 4.

Timashev, I.E., “Landscape forecast analysis at development of regional water management systems (methodological approach)”, In: *Rational use of water resources*, Vol. 12, Nauka, Moscow, 1988. (in Russian)

Tishkov, V. A., "The Soviet Empire before and after Perestroika", *Theory and Society*, Vol. 20(5), 1991, pp. 603-629.

Tolkacheva G.A., Aksenova L.A., Konuhov V.G., "The monitoring of atmospheric fallings-out in Central Asia region", Works of III International symposium Complex, global monitoring of biosphere condition, -L.: Gydrometeoizdat, 1986.

Tolkacheva G.A., Aksenova L.A., "A role of atmospheric fallings-out in migration of polluting ingredients and influence of them on pollution of lands in the Central Asia region", Migration of polluting substances in lands and contiguous environments. Works of the V All-Union meetings, - L.: Gydrometeoizdat, 1991, pp. 176-186.

Tolkacheva, G.A., Aksenova, Syrlibaev T.S., Gluhova E.M., "Comparative study of chemical structure of dry atmospheric fallings-out in Priaralie", Monitoring of natural environment in the basin of the Aral sea, Materials of scientific - coordinating meetings. - L.: *Gydrometeoizdat*, 1991, pp. 176-186.

Tolkacheva G.A., "To the question about possible scales of wind consumption of salts from drained part and water areas of the Aral sea", Works of SANIGMI, An estimation of pollution of natural environment of the Central Asia region. - Iss.151 (132), Tashkent, 1995, pp. 13-18.

Tolkacheva G.A., Covalevskaya U.I., Vasichkina I.E., "Influence of atmospheric fallings-out (precipitations, dry) in industrial zones on pollution of ground vegetation / an Estimation of influence of industrial emissions on ground vegetation", Works of the interstate conference, Tashkent, 1993, p. 27-36.

Tolkacheva G., Zinoviev P., Aksenova L., Toranikova R., Aliev R., "Development of modern technologies for environment pollution monitoring of Central Asia Region", Abstract on WMO International conference on Meteorological and Hydrological Management MTEOHYTEC XXI, Geneva, 22-26 May, 1995, pp. 57-60.

Tolkacheva G.A., "Assessment of opportunities to use remote sensing methods for Environment pollution monitoring in the Aral Sea Basin", NRI know how Fund Environmental monitoring project. Tashkent, 19-20 June 1996, pp.132-135.

Tolkacheva G., "Working out the methodical Scientific Basis for Atmospheric Fall-Out Monitoring in Central Asia", Abstract on Symposium Eurotrac-2, Munich, Germany, 1998, pp. 4-19.

Tolkacheva G.A., Haritonov G.G., "Recognition of pollution sources by aerosols of atmospheric Central Asia in a winter period // Research of pollution of natural environment of the Central Asian region", Iss.128 (209). - M.: Gydrometeoizdat, 1988, pp.45-57.

Tsukatani, T. and U. M. Sultangazin., "Current economy and environment of Kazakhstan in 1995", *Japanese Slavic and East European Studies*, Vol. 16, 1996, pp. 95-106.

Tsur, Y., and A. Dinar., "Efficiency and equity considerations in pricing and allocating irrigation water", Policy Research Working Paper 1460, 1995, Washington, D.C.: World Bank.

Tucker, C. J., H. E. Dregne, and W. W. Newcomb., "Expansion and contraction of the Sahara Desert from 1980 to 1990", *Science*, No. 253, 1991, pp. 299-301.

Tursunzod, Akbar., "Water shortage in Central Asia: is there a way out?", Bi-Weekly Briefing, *Central Asia-Caucasus Analyst*, Wednesday/September 26, 2001.

UN Chronicle (Online Edition), "Dry Tears of Aral", Volume XXXVI, Number 1, 1999, Department of Public Information.
http://www.un.org/Pubs/chronicle/1999/issue1/0199p38_4.htm

UNESCO Sources., "How it happens: the Aral Sea", June 06, 2001. http://www.unescosources.org/

Varis, O., "Dreams and reality in water resources management: a critical view to leading paradigms", *Global Environmental Change - Human and Policy Dimensions*, Vol. 9(4), 1999, pp. 255-259.

Vasilliev O.F, Kuzin V.I., "Hydro-physical processes of the Aral sea desiccation: historical data and modelling", Proceedings of International Workshop on Global Change, Sustainable development and Environment management in Central Asia, Environmental Programme of the Government of Uzbekistan supported by UNDP, 2004.

Veinsberg I.G., Oulst V.G. & Rose V.K., 1972., "Ancient rivers and variations of the Aral Sea level", *Voprosy Chetvertichnoy geologii*, Vol. 6, pp. 69-89 (in Russian)

Vinogradov, Sergei & Vance P E Langford., "Managing transboundary water resources in the Aral Sea Basin: in search of solution", *International Journal of Global Environmental Issues*, Vol. 1(3/4), 2001.

Weinthal, Erika., "Central Asia: Aral Sea Problem", Department of Political Science, Tel Aviv University, 2000.

Yablonskaya, Ye. A., "Research history and composition of invertebrates of the Aral Sea", In: *Atlas of invertebrates of the Aral Sea*, 1974, pp. 3-8, Pischevaya Promyshlermost', Moscow. (in Russian)

Young, M and N Ishwaran., "Human Investment and Resource Use: A New Research Orientation at the Environment/Economics Interface", Mab Digest 2, UNESCO, 1989, p. 10.

Zak, P. I. R. and T. S. Ergashev., "Experimental study of the effect of pesticide Butifos on female gonads", *Med. Zh. Uzb.* Vol. 2, 1980, pp. 48-50.

Zakhidov, S. T. et al., "The cytogenetic monitoring of the southern Aral Sea area. An evaluation of the genotoxic activity of the water", *Izv. Akad. Nauk Ser. Biol.*, ISS 1, 1993, pp. 95-101.

Zolotokrylin, A. N., "Climate fluctuations and changes in the Aral Sea Basin within the last 50 years", Chapter 5, in *Creeping environmental problems and sustainable development in the Aral Sea basin.* Glantz, M. H., (eds.) Cambridge, UK, and New York: Cambridge University Press, 1999.

Zonn I.S., "Water resources issues of the Caspian region in Central Asia", Proceedings of International Workshop on Global Change, Sustainable development and Environment management in Central Asia, Environmental Programme of the Government of Uzbekistan supported by UNDP, 2004.

SERIALS, JOURNALS

Advances in Water Resources

Agricultural Water Management

Agriculture, Ecosystems and Environment,

Agricultural Economics

Asian Affairs

Aziia - ekonomika zhizn' (in Russian)

Central Asian Survey

Central Asia Monitor

Central Asia-Caucasus Analyst

CIS Environmental Watch

Development and Change

Earthwatch

Economic and Political Weekly

Ecological Engineering

Environmental Science & Technology

Environmental Policy Review

Environment

Environmental Policy Review

Environmental Modelling & Software

Environmetrics

Ethics and the Environment

European Review of Agricultural Economics

Europe Asia Studies

Finance and Development

Geographical Journal

Geomorphologiia (in Russian)

Geotimes

Global Environmental Change

Gidrometeoizdat (in Russian)

Himalayan and Central Asian Studies

International Journal of Global Environmental Issues
International Journal of Environment and Pollution
Interdisciplinary Science Reviews
Japanese Slavic and East European Studies
Journal of Environmental Management
Journal of International Water Resources Development
Journal of water resources planning and management
Journal of Environmental Economics and Management
Journal of Geophysical Research
Journal of International Studies
Land Degradation & Development
Meteorologiya i gidrologiya (in Russian)
Nature
Natural Resources Journal
National Geographic
Nauka I zhizn (in Russian)
New Scientist
Obshchestvenye nauki v Uzbekistane (in Russian)
Post Soviet Geography and Economics
Post Soviet Geography
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Public Policy
Resources
Russian Life
Safety & Health
Science
Sibirskiye ogni (in Russian)
Soviet Geography
Society and Natural Resources
Sochineniia, (in Russian)
Soviet Geography: Review and Translation

Studies in Conflict and Terrorism

Surviving Together

The Economist

The Ecologist

The Russian Review

The World & I

The Geographical Journal

Theory and Society

Transition Newsletter

Voprosy Chetvertichnoy geologii (in Russian)

Water Policy

Water Air and Soil Pollution

Water International

Water Resources Research

Water resources

Zvezda vostoka (in Russian)

WEBSITES REFERRED

http://www.cgiar.org

http://www.sacredbalance.com

http://www.fao.org

http://www.unesco.org

http://www.adb.org

http://www.worldbank.org

http://www.icarp.org

http://www.igc.org

http://www.un.org

http://www.undp.org

http://www.unep.org

http://www.looking-glass.co.uk

http://www.rferl.org

http://www.unccd.int

http://www.transboundarywaters.orst.edu/

http://www.fpif.org

http://csis.org

http://www.eurasianet.org

http://waterpartners.geo.orst.edu

http://www.american.edu

http://www.nature.uz

http://www.irinnews.org

http://www.unu.edu

http://www.umid.uz

http://www.geology.sdsu.edu

http://www.ifas-almaty.kz

http://www.eni-environment.net

http://www.crisisweb.org

http://www.ce.utexas.edu

http://www.jica.uz

http://www.tech-db.ru

http://bpsp-neca.brim.ac.cn

http://www.reliefweb.int

http://www.disasterrelief.org

http://www.usaid.gov

http://ag.arizona.edu

http://www.ncar.ucar.edu

http://www.mikethurman.net

http://www.grida.no/aral

http://visearth.ucsd.edu

http://www.bbc.co.uk

http://bubl.ac.uk

http://www.cango.net.kg

http://iri.columbia.edu

http://www.icess.ucsb.edu

http://www.mem.dk

http://www.cde.unibe.ch

http://www.ifas-almaty.kz

http://www.intas.be

http://nailaokda.8m.com

http://www.dfd.dlr.de

http://www.livinglakes.org

http://www.msf.org

http://www.soton.ac.uk

http://www.oneworld.org

http://www.resource.nl

http://www.udel.edu

http://www.wmo.ch

http://www.aral.uz

http://www.worldwaterforum.net

http://ucsub.colorado.edu

http://www.sahra.arizona.edu

http://www.ishs.org

http://www.thirdworldcentre.org

http://www.waterinstitute-wise.ca

http://environ.chemeng.ntua.gr/wsm

http://www.wri.org

http://www.iwrm.icwc-aral.uz

http://www.ca-c.org

http://giserv.karelia.ru