Linking Ecological and Development Objectives: Trade-offs and Imperatives

Janusz Kindler

Ecological Applications, Vol. 8, No. 3 (Aug., 1998), 591-600.

Stable URL:
http://links.jstor.org/sici?sici=1051-0761%28199808%298%3A3%3C591%3ALEADOT%3E2.0.CO%3B2-U

Ecological Applications is currently published by The Ecological Society of America.

Ecological Applications, 8(3), 1998, pp. 591–600

LINKING ECOLOGICAL AND DEVELOPMENT OBJECTIVES: TRADE-OFFS AND IMPERATIVES

JANUSZ KINDLER

Institute of Environmental Engineering Systems, Warsaw University of Technology, ul. Nowowiejska 20, 00-653 Warsaw, Poland

Abstract. This paper addresses the too often separated insights of ecologists and resource managers, linking the biophysical and socioeconomic dimensions of some freshwater issues. It begins with a brief exposure of fundamentals of the method of multi-objective analysis, underlining that evaluation of trade-offs between objectives is never a purely mathematical or quantifiable undertaking. To varying degrees, it is based on subjective value judgments reflecting economic, social, cultural, and aesthetic preferences accorded by a society to different objectives. But how far can different objectives be traded? I attempt to answer this question using as an example the environmental and economic problems of the Aral Sea Basin in Central Asia. Simple water balance calculations are presented to illustrate the specific situation of the basin. Next, a few critical issues of the Aral Sea Basin are discussed to show that linking environmental and economic objectives is not an easy task if one takes a short time perspective.

Key words: Aral Sea Basin; ecology; economic development; institutional improvements; multi-objective analysis; natural environment; poverty reduction; trade-off; transboundary resources; water; water conservation; wetlands.

INTRODUCTION

Throughout most of history, the interactions between water and its natural environment as well as between water and development have been rather straightforward and of a local character. But the complexity of these interactions is increasing. What were once well understood questions of nature preservation vs. economic growth, now involve complex economic and environmental linkages. As pointed out more than ten years ago by Clark (1986), humanity has entered an era of a large-scale interdependence between economic development and the natural environment. This interdependence will intensify as the number of people on earth, the demand for agricultural products, and industrial production increase. A major challenge for the coming years is to learn how to manage our freshwater resources in such situations.

This paper is concerned with the economic and environmental dimensions of water resources management, which are complementary and mutually reinforcing in the long term. However, difficult choices between them must often be made in short and medium terms. My purposes are to introduce some fundamentals of multi-objective analysis, discuss the case of the Aral Sea, and comment on the linking of economic and environmental objectives.

Manuscript received 6 February 1997; revised 21 October 1997; accepted 21 October 1997; final version received 5 December 1997. For reprints of this Invited Feature, see footnote 1, page 569.

THE FUNDAMENTALS OF MULTI-OBJECTIVE ANALYSIS

Water as well as environmental issues and problems are characterized by multiple objectives, mutiple criteria, multiple decision makers and multiple constituencies. An "objective" is what a decision maker seeks to accomplish or obtain by means of a decision. A "criterion" is a rule or standard against which to measure the extent to which an objective has been met or to rank the alternative courses of action.

The choice of socially relevant objectives is a difficult task. It requires judgment by all involved in the decision-making process: decision makers, managers, environmentalists, scientists, and other stakeholders. In the past, engineers responsible for water resources planning and managing often considered this to be a technical issue primarily in their domain, and to be decided by them. With changing social and environmental attitudes this perception is changing rapidly.

At present, objectives identified as important for analysis of water problems include: economic efficiency, environmental quality, distributional (equity) effects, regional growth and stability, national self-reliance, and risk considerations of robustness, resilience, and other measures of system performance. Three observations seem to be appropriate. Firstly, most objectives are not defined using the same units of measure;

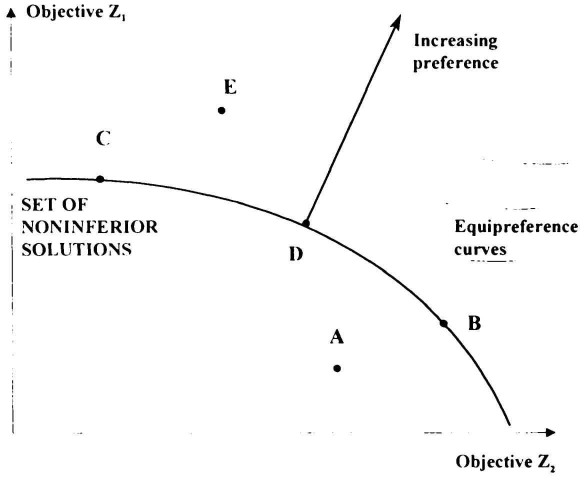

FIG. 1. Fundamentals of multi-objective analysis.

they are noncommensurate. Secondly, priorities among objectives depend on the particular problem setting. For example, societies affected with widespread malnutrition and disease, high infant mortality, low life expectancy, high illiteracy level, and endemic unemployment are not likely to place the same value on degradation of the natural environment as societies where such problems have been overcome. Thirdly, the presence of multiple objectives usually promotes conflict. Objectives conflict when the solution satisfies one objective but differs from the solution that best satisfies another objective.

The fundamentals of multi-objective analysis are illustrated graphically in Fig. 1 (Munasinghe, 1994). Assume that a project or policy has two noncommensurable and conflicting objectives, Z_1 and Z_2. Z_1 could be hydropower production in the upstream river reaches and Z_2 some index of ecological "health" in the downstream delta. Assume that alternative projects A, B, and C have been identified. Point B is better than A in terms of both Z_1 and Z_2, because B produces more hydropower and provides for a more ecologically healthy delta relative to A. Thus, alternative A may be discarded. More difficult is the choice between solutions B and C, because B is superior to C with respect to objective Z_1 but inferior with respect to Z_2. Solutions such as B and C form a set of noninferior solutions, which sometimes are also called nondominated, polyoptimal or Pareto optimal solutions.

The characteristic feature of each noninferior solution is that it cannot increase satisfaction of one objective without decreasing satisfaction of other objectives. But which one of a set of noninferior solutions should be selected as "best"? This involves choices among different objectives and the degrees to which each of them is satisfied. Because many of the objectives are noncommensurate, value judgments must be involved in evaluating trade-offs among objectives and selecting the best compromise. Choosing the best compromise solution requires additional information on trade-offs among objectives. Articulating this information is difficult and usually based on subjective judgment reflecting economic, social, cultural, and other preferences and the associated criteria of individuals and groups involved in the problem-solving process. Information on trade-offs may be given in different form, such as functional relations between different objectives (utility or preference functions), hierarchy of objectives, preferred proportion curves, etc. In my example (Fig. 1), the best compromise solution that provides the greatest utility (preference) occurs at the point of tangency D between the best preference curve and the curve of noninferior solutions.

How far can different objectives be traded? Satisfying some objectives at least at a minimum level is imperative, especially when dealing with the basic life support systems such as freshwater aquatic environments. A commonsense notion is that minimum requirements exist for many things in life. Our bodies need some minimum input of water if we are to survive. Many production processes likewise have irreducible minimum input levels, e.g., as fossil fuel in electricity generation. But in water projects, water volumes relevant to minimum requirement levels are seldom articulated or discussed. The true "requirements" for agriculture and industry are usually only a small portion of observed or planned water use and are less than large projects are built to supply.

At higher water use levels, several activities can *substitute* some other input for water. In industrial cooling, physical capital can be substituted for water by construction of closed cooling systems with non-evaporative towers. In agriculture the irrigation system can be improved by lining the canals, changing from flooding to sprinkler or drip methods and investing in the optimal timing of water application to match plant needs and soil moisture. The notion of a minimum water requirement should not ignore the possibilities of substitution and adjustment that can be implemented as water demands and costs go up.

Linkages between different objectives are discussed below using as an example the problems of the Aral Sea Basin in the Central Asia. Discussion is based on the preparatory work undertaken for the development of a regional water management strategy in the Aral Sea Basin. The work is administered and coordinated by the Executive Committee of the International Fund to save the Aral Sea (EC of IFAS) with the support of The World Bank, United Nations Development Programme (UNDP), the Global Environmental Facility (GEF), the European Union (WARMAP Project), and several bilateral donors. More detailed analysis, involving application of multi-objective modeling methods to provide policy makers with decision guidance will most probably be initiated in 1997.

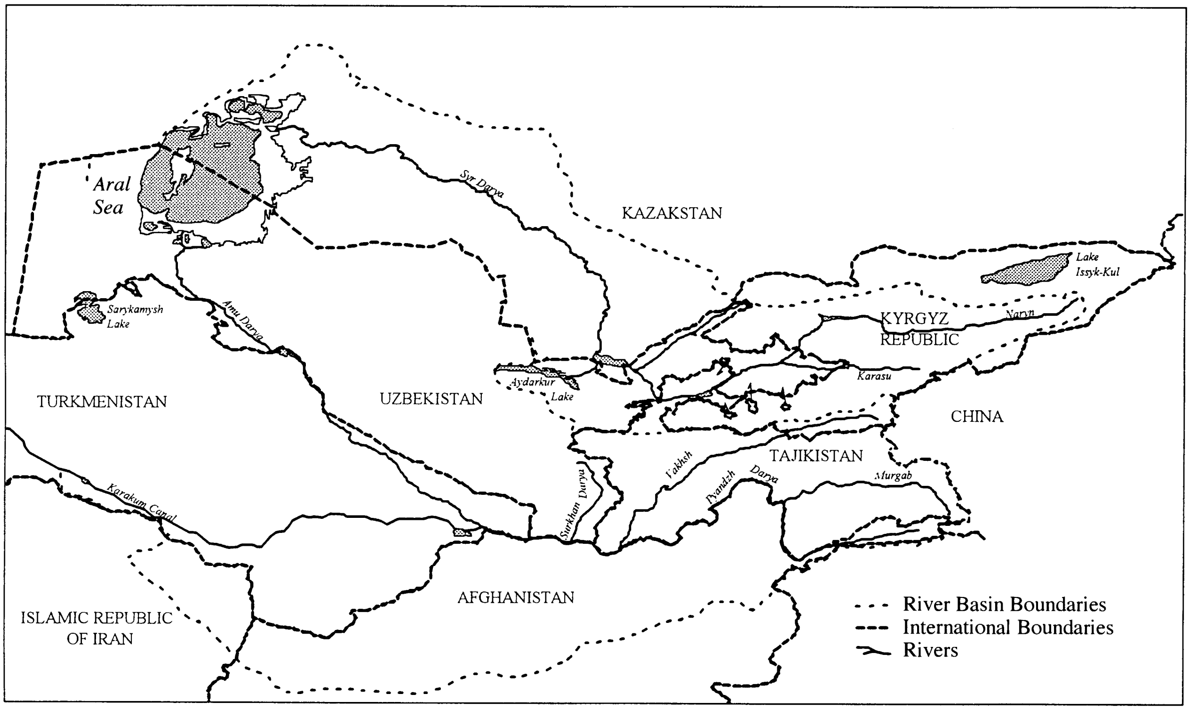

FIG. 2. The Aral Sea Basin.

THE ARAL SEA BASIN

Background

Water plays a vital role in the economic and social life of the arid Aral Sea Basin in Central Asia. Over the last 35 years, intensive cotton farming in the 1.55 $\times$ 10^6 km^2 basin has diverted so much water from the two main rivers, the Amu Darya and Syr Darya (Fig. 2), that the shoreline of the Aral Sea (large freshwater lake) has retreated by more than 120 km in places. Vast salted tracts appeared on the former seabed over an area of $\sim$2 $\times$ 10^6 ha. Salt deserts have replaced marshes and freshwater lakes over an area of 50 000 ha in the Amu Darya delta alone. Benthos biomass decreased on average from $\sim$200 g/m^3 to 13 g/m^3. Mean zooplankton contents was reduced from 160 g/m^3 to 15 g/m^3. Only patches of Tugay woods and bushes remained in the Amu Darya and Syr Darya deltas. They were replaced by moss, which in turn was replaced by turang grasses. Most of the nesting grounds of migratory birds have disappeared. Local wildlife and climate have been altered.

The environmental degradation due to the excessive use of water and related land resources extends over the entire Basin. Since the 1960s the upper Basin has lost $\sim$50% of its forest cover. Soil erosion has intensified to reduce agricultural productivity and silt reservoirs. Massive discharges of drainage water from irrigated lands drastically increased water salinity. Soil salinization and waterlogging is a serious problem throughout the Basin (Micklin 1991, 1992, Glazovsky and Mainguet 1992).

Environmental problems began to build from 1927 to 1960 as irrigated lands increased from 2 to 5 $\times$ 10^6 ha (Interstate Council 1996). Water withdrawals from the rivers increased, groundwater levels rose in irrigated areas, and chemicals began to accumulate both in the soil and the sea. But the problems were not apparent during those years and irrigated lands again were expanded by one-third after the mid-1960s. Water withdrawals nearly doubled and water and soil salinity substantially increased. By the late 1980s, the Aral Sea Basin exhibited perhaps the most serious environmental problems in the world—environmental degradation in the upper and middle watershed, desiccation of the Aral Sea, and destruction of wetlands which had served as an important habitat for wildlife. These changes led to a loss of livelihood and gradual increases in poverty and illness, especially for the 3.5 $\times$ 10^6 people living in the two river deltas and in the coastal zone.

The average population density in the basin is only in the range of 20 persons per 1 km^2, but a very high percentage of the basin is empty desert. In the irrigated land, population density is much higher, on the order of 300 persons per 1 km^2. Population growth is a major issue in the social and economic structure of the basin (Interstate Council 1996). In the 1960s and 1970s, the population growth rate in the five countries averaged 2.7% per year; Turkmenistan experienced a growth rate of 3.4% per year. Between 1990 and 1994 these growth

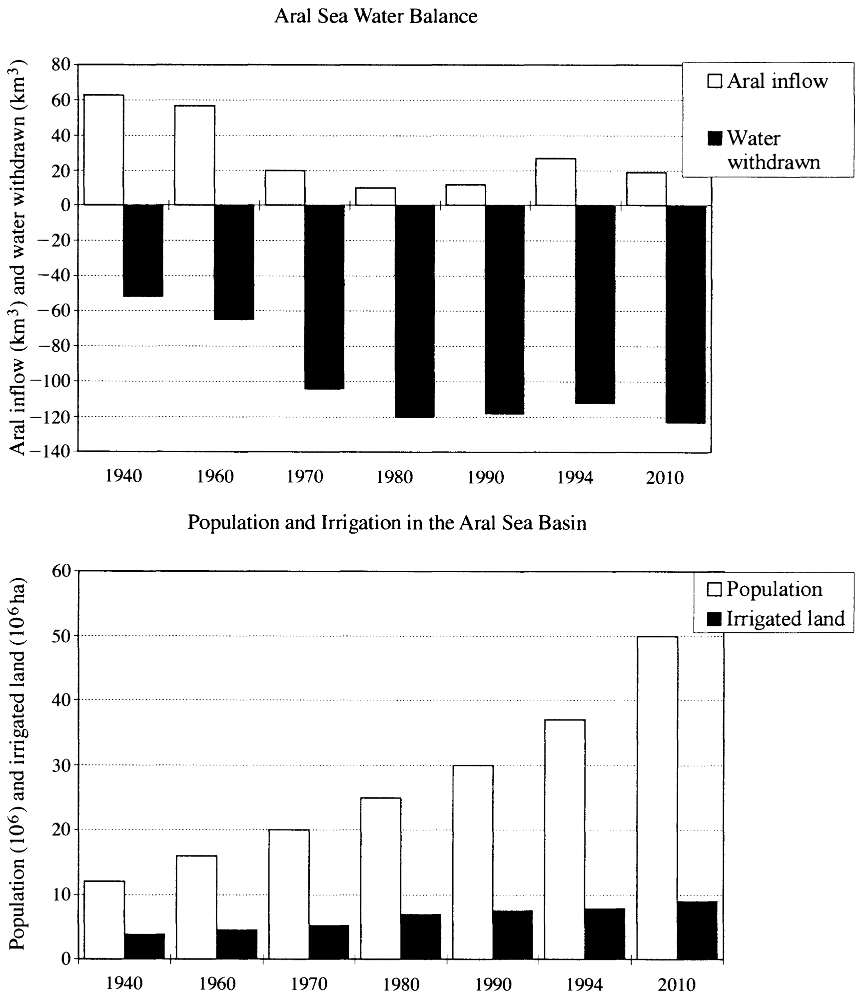

FIG. 3. Water balance and population and irrigation growth rates in the Aral Sea Basin.

rates dropped almost by one-half. The two main factors for the decline have been emigration and a lower birth rate owing to the deteriorating economic situation. Even so, by 2010 the population is expected to approach 50×10^6, compared to $\sim 37 \times 10^6$ in 1994 and 16×10^6 in 1960 (Fig. 3). Provision of adequate food to the growing population is a major consideration in national agricultural plans.

The basin is primarily an agricultural area. About 92% of total water use irrigates $\sim 8 \times 10^6$ ha (Interstate Council 1996). In terms of the surface area, this is one of the world's largest irrigation systems; twice that of Egypt and one-half that of the Indus system in Pakistan.

At present, the economic and social situation in the Basin states is difficult. The past was marked by economic inefficiencies, legislation without adequate enforcement, and a number of ineffective institutional arrangements. Independence in 1991 has brought the prospect of greater national self-sufficiency and governance, but also contributed to a decline in economic integration among the former republics of the USSR. Increased customs barriers, new obstacles to fund transfers, rupture of procurement and supply contracts, and a sharp rise in transportation tariffs are features of the region. Since the Aral Basin states became independent, in some years their economies experienced inflation rates well over 100%, serious credit shortages, and declines in GDP (Gross Domestic Product) from 15% (Uzbekistan) to >50% (Tajikistan).

While effective water management is critical, it competes with other priorities for human and financial resources. Timely action on some water issues, especially those related to agriculture, ultimately may assist the stabilization process and benefit the basin as a whole. Water decisions must be made rationally given the severe institutional, human resource, and financial constraints over coming years while the basin's economies strive to recover their former levels.

Recognizing the severity of social and environmental concerns, the heads of state from Kazakstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan met in January 1994; they approved an Action Plan to

TABLE 1. Water balance in the Aral Sea Basin in cubic kilometers (Interstate Council 1996).

	1990 Actual	1994				2010 Calculated
		Actual			Calculated	
	Total Aral Sea Basin	Amudarya River Basin	Syrdarya River Basin	Total Aral Sea Basin	Total Aral Sea Basin	Total Aral Sea Basin
Resources						
Surface water resources	112.7	80.3	41.2	121.5	121.5	115.6
Groundwater resources (recharge)	11.6	6.2	7.8	14.0	14.0	18.0
Return drainage water	41.2	31.3	14.6	45.9	45.9	40.0
Interbasin transfer	1.0	0.0	1.0	1.0	1.0	1.0
Total resources	166.5	117.8	64.6	182.4	182.4	174.6
Uses						
Unaccounted losses from river channels	9.8	7.0	3.2	10.2	10.2	10.2
Surface flow losses due to groundwater withdrawal	7.0	4.2	3.3	7.5	7.5	10.6
Unused discharge of vertical drainage water	2.2	1.6	1.0	2.6	2.6	4.0
Transfer to other basins	1.0	1.0	0.0	1.0	1.0	1.0
Summary withdrawal by all economic sectors	117.5	66.0	45.7	111.7	151.8	160.0/131.6†
Diversion of return waters to Aral Sea and natural depressions	14.5	13.6	2.8	16.4	16.4	12.0
Water withdrawal by Afghanistan	2.0	2.0	0.0	2.0	2.0	5.0
Discharge into Aral Sea by main streams	12.3	21.7	9.8	31.5	31.5	19.0
Total uses	166.3	117.1	65.8	182.9	223.0	221.6/193.2
Balance	+0.2	+0.7	−1.2	−0.5	−40.6	−47.0/−18.6

† The value of 160.0 km^3 corresponds to water demands of Uzbekistan calculated in 1993. In 1996, Uzbekistan revised its future irrigation water demands, bringing the total demands in the basin to 131.6 km^3.

improve the environmental situation for social and economic development over the next three to five years. Following the request of the five Basin states for assistance in implementing the plan, the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank supported them in the preparatory phase for developing the Aral Sea Basin Program (ASBP). The Program established in 1994 will lead to strategy formulation, priority actions, and pilot projects, all aiming at basin-wide impacts and requiring regional cooperation and coordination.

The water balance calculations

In spite of the difficulty of collecting and standardizing data, the preparatory phase of the project has produced several water balances for the Aral Sea Basin, including balances for 1990 (a dry year) and 1994 (a wet year), and some projected balances for the year 2010. To present the overall water situation in the basin, the balance for 1994, based on actual data, is presented and discussed below in more detail (see column 1994 Actual in Table 1).

On the resources side, total resources available consist of four elements: surface water, groundwater recharge, drainage water returning to the system (return water) and interbasin transfers. The surface water resources in 1994 were equal to 121.5 km^3. Based on the national reports, some 14.0 km^3 were available in 1994 (groundwater recharge). Return drainage water is significant in the Aral Sea Basin. Return water of 45.9 km^3 in 1994 is the sum of drainage water collected from irrigation (42.7 km^3) and wastewater discharged by industrial enterprises and municipalities (3.2 km^3). A large volume of the collector-drainage water (~36% or 16.4 km^3) is totally lost (see Table 1: *Uses*); it is discharged into natural depressions and evaporates. The extent of water reuse (that is, irrigation water reuse and drainage water discharged into rivers) ranges from 45% in Turkmenistan to 100% in the Kyrgyz Republic and Tajikistan.

Taking into account relatively small interbasin transfer, the total resources in the basin were ~182.4 km^3 in 1994 (the mean annual water availability is ~176 km^3). Total uses, according to Table 1, were some 182.9 km^3, for a slight deficit.

The first major categories of water use in the basin are water losses, whether from river channels, groundwater withdrawal, or drainage water. A considerable amount of water is lost in riverbeds, although the

TABLE 2. Water use in cubic kilometers by five Aral Sea Basin states, 1990 and 1994.

Country	1990	1994	Change	Change (%)
Kazakhstan	11.9	10.9	−1.0	−8.4
Kyrgyz Republic	5.2	5.1	−0.1	−0.02
Tajikistan	13.3	13.3	0.0	0.0
Turkmenistan	24.4	23.8	−0.6	−2.4
Uzbekistan	63.3	58.6	−4.7	−7.4
Total	118.1	111.7	−6.4	−5.4

Note: There is a slight discrepancy between the 118.1 km^3 total water use for 1990 given in these figures and the 117.5 km^3 total use reported in the 1990 regional water balance.

amount is difficult to estimate, especially for certain sections of the two main rivers Amu Darya and Syr Darya. Observations of high water losses are not supported by climatic and hydrological factors.

Of the total water use by all economic sectors in 1994 equal to ~111.7 km^3, ~91.6% was for irrigated agriculture, 3.6% for domestic and household purposes, 1.9% for industry, 1.6% for rural water supply, 0.8% was used for fisheries, and 1% was given to other uses. The importance of irrigated agriculture in both water use and economies in the region makes consideration of irrigation and land use patterns essential to a regional water resources management strategy.

Of the 155.4 × 10^6 ha in the Aral Sea Basin, some 32.6 × 10^6 are considered suitable for irrigation while ~7.9 × 10^6 ha are actually irrigated. Cotton still dominates the agricultural crops in the area, followed by cereals and fodder. For a wide variety of reasons, including the high cost of inputs, increasing soil salinity, and disrupted markets, the levels of both yields and production of major crops have fallen significantly in every country since 1990.

Out of the total net irrigated area of 7.9 × 10^6 ha in the Aral Sea Basin, >5 × 10^6 ha requires man-made drainage, but only ~4.4 × 10^6 ha has such drainage. At the end of 1990, the total length of collector-and-drainage networks was ~174 572 km, with >9262 tube wells. Of this total length, ~89% is on farms, with 11% on inter-farm networks. Closed horizontal drainage is used for ~11.3 × 10^6 ha, mostly on newly irrigated lands.

The two major land quality problems in the basin are the interrelated issues of salinity and waterlogging caused by high groundwater levels. Only ~50% of the land in the basin is classified as nonsaline. The extent of the problem varies; in the upper reaches of the Amu Darya and Syr Darya, <10% of the land has average or strong salinity, while in downstream parts of the basin ~95% of the land is saline. Salinity is of course closely tied to drainage conditions. Moreover since 1985, a growing water shortage, lower water quality, and the decay of enterprises responsible for the drainage system has resulted in secondary soil salinization.

The final use of water in the basin mentioned in Table 1 is discharge into the Aral Sea of 31.5 km^3 in 1994. This was a huge increase of flow into the sea over the relative trickles in the late 1980s and early 1990s, which were comparatively dry years. In 1990, this figure was put at 12.3 km^3.

In Table 1, the 1994 water balance (wet year) is contrasted with the 1990 balance (dry year) for an overall picture of developments in the four years since independence. Total resources in 1990 were reported at 166.5 km^3 vs. 182.4 km^3 in 1994, and total uses at 166.3 km^3 vs. 182.9 km^3 in 1994. On the use side, the most relevant figures for comparison are the economic withdrawals of water (mostly for irrigation), which were ~5.8 km^3 lower in 1994 than in 1990. Most interesting in this regard was a 2.4% decrease in water use in Turkmenistan (Table 2) despite a 31% increase in irrigated area (Table 3). Uzbekistan reduced its water consumption by 7% with a slight increase in irrigated area. The decrease in water use in 1994 in these countries was largely because of a switch from cotton to cereal cultivation that was mandated by policy.

Another interesting difference between 1990 and 1994 is the volume of water discharged into the Aral Sea. In 1990 this was only 12.3 km^3 in 1994, it was 31.5 km^3. It is apparent that in the dry years, while irrigation use remains fairly constant, the Aral Sea receives far less water. The relatively wet period in the first years of independence has masked the continuing desiccation of the sea, which has been treated as a residual, rather than an active, user of water.

In addition to 1990 and 1994 actual water balances, Table 1 presents calculated balances for 1994 and 2010. Comparison of the balances for 1994, shows that the calculated summary demand of all economic sectors (taken from the national reports) is 40.1 km^3 higher than the actual withdrawal. This is the additional volume of water that according to the national reports would be needed in 1994 to supply all the existing irrigation systems at a level compatible with the present national norms of specific water use per hectare per year. Providing actual water withdrawals in 1994 are at the level of those calculated, the water shortage in the basin would approximate 40 km^3. Since ~92% of the total demands are irrigation water demands, reassessment of irrigation norms is fundamental for the next stage of investigations for the regional water strategy.

TABLE 3. Irrigated area in thousands of hectares of five Aral Sea Basin states, 1990 and 1994.

Country	1990	1994	Change	Change (%)
Kazakhstan	781.8	786.22	4.4	0.6
Kyrgyz Republic	423.7	429.9	6.2	1.4
Tajikistan	709.1	719.2	10.1	1.4
Turkmenistan	1329.3	1744.1	414.8	31.2
Uzbekistan	4222.0	4286.0	64.0	1.5
Total	7465.9	7965.4	499.5	6.6

Regarding future water demands, Table 1 shows two alternative estimates depending on the irrigation water use in Uzbekistan. Still, even under the lower demand scenario (that can be achieved at a cost which has not been defined so far), the shortage of water in the basin is in the order of 18.6 km^3/yr (assuming very low inflow to the Aral Sea, which cannot sustain the sea even at the present level). All estimates of available resources and future water demands will be subject to further investigations in the next stage of work on the regional strategy.

Even with the current imperfect information, it is clear that there is not enough water in the basin to meet the requirements of all the states. With the exception of Kazakhstan, every country in the region plans to expand irrigated agriculture by the year 2010, by a total for the basin of $>1 \times 10^6$ ha demanding additional water on the order of 18 km^3. The countries of the region seem to recognize the problem of shortages by frequently raising the issue of importing at least 20 km^3 from outside the Aral Sea Basin (transfer from the northern Siberian rivers). The difficulties of importing this vast amount of water are well known. The basic alternatives appear to be either conserving water in a variety of ways or revising national social and economic goals and policies (or both).

Water conservation generally means on the one hand reducing losses, and on the other, conserving as much from use as possible. The countries of the region estimate that overall, 12.7–18 km^3 can be saved in the basin. This level is substantial, but it would come at a cost, involving large amounts of money which would be a substantial burden on any national budget in the region. Therefore, countries and regional organizations must carefully set priorities for water conservation, rather than covering a wide number of solutions with inadequate funding for any one program.

Conserving water should begin by improving the efficiency of the present irrigation networks and introducing better irrigation practices. Of $\sim 7.9 \times 10^6$ irrigated hectares, $\sim 2.5 \times 10^6$ ha have new systems in good technical condition, but the rest were built 25–30 years ago and are coming to the end of their lifespan. During the first years of independence, budget problems meant that funds for operation and maintenance of irrigation systems declined every year. The basic question is what can be done to avoid irreversible damage to these irrigation and drainage systems when over the next five to six years the overall economic situation will still be difficult? According to national estimates, reconstruction or modernization of the irrigation and drainage networks may cost ~$3000/ha. Again, considering budget limitations, priorities must be established.

All national reports recognize the importance of economic incentives that must be introduced for any effective water conservation. One of the reasons for inefficient use of water is that it is still a free good. All of the basin countries have introduced charges for municipal and industrial water supplies, but introducing charges for irrigation water is much more difficult. Experiments so far in the region indicate that the main problems are (1) the lack of flow measuring devices, (2) the lack of appropriate laws and regulations, and (3) the lack of appropriate institutional arrangements to implement and enforce a system of charges for water. The model under discussion across the Basin is a two-rate tariff, consisting of a basic per hectare fee and in addition a progressive fee per cubic meter of water above an assigned volume. This issue is closely related to reforms in the agricultural sector.

The question of whether any potential savings in water via increased irrigation efficiency should be available to countries or to the Aral Sea has been raised. The riparian countries have agreed that the Aral Sea will be regarded as an independent water consumer. Its share of regional water is to be determined according to a mutually approved strategy. National reports have not presented any quantitative assessments of the environmental demand for water, but preliminary estimates indicate that the minimum demand for water by the Aral Sea and its coastal regions in the near future is in the order of 30 km^3/yr, of which 22 km^3/yr might come from the Amu Darya and 8 km^3/yr might come from the Syr Darya. Table 1 indicates, however, that in dry years (such as 1990) such an inflow to the Aral Sea could be secured only at the expense of reducing irrigation water withdrawals.

Trade-offs Between Objectives

The root cause of all environmental problems in the Aral Sea Basin is similar throughout the entire area: the unsustainable development practices adopted in the past. The irrigation system was expanded beyond the ecologically sound potential of Amu Darya and Syr Darya rivers (UNEP [United Nations Environment Programme] 1992). It confirms that economic, social, and environmental objectives of the regional water management are so inextricably linked that none of them can be considered in isolation from the others. For instance, although >90% of water is used in irrigation, this sector cannot be looked at alone. The poor quality of drainage water has serious consequences on practically all facets of life in the basin. Thus social welfare and health are intimately linked to irrigation and drainage practices. Similarly, the disputes between upstream states that are primarily interested in operating storage reservoirs for hydropower production and the downstream states interested primarily in irrigation water supplies appear to be an interstate two-sectoral issue, but each specific solution or alternative has a number of consequences that extend well beyond these two sectors.

The regional water management strategy is beyond the scope of this paper, which is based on the results of the preparatory work carried out by the Interstate Council and funded by GEF. More detailed analysis will come later. Thus, the purpose of this section is only to reflect on the strategy objectives and their linkages. Discussed below are a few examples of the difficult choices that must be made in the Aral Sea Basin. Restoration of environmental vitality of the sea and of its basin must be seen as a multi-objective problem characterized by a number of challenges and constraints.

The Aral Sea.—By 1994/1995, the level of the sea had dropped by 15 m and lost ~50% of its surface. Water salinity had increased from ~10 g/L in 1960 to almost 30 g/L, as volume had declined to about one-third of its 1960 level. As shown in Table 1, an excessive volume of irrigation water withdrawn from its tributaries, which approximately doubles the pre-1960 withdrawals, is clearly the leading cause of the sea's demise (there was a series of wet years in the early 1990s and the Aral Sea inflows somewhat increased as shown in Table 1). Increased water use efficiency is an obvious need. In this respect, it should be recognized that during the last fifteen years, per hectare irrigation water use decreased substantially, from 18 200 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ in 1980 to 12 200 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ in 1994. This decrease was achieved primarily by limiting water use by the Interstate Commission for Water Coordination. Because of the shortage of funds, limiting water use was not accompanied by necessary technological improvements. Introduction of economic incentives (payment for water) was proposed several times, but it was (and still is) difficult to implement under the prevailing economic conditions.

The per hectare water use reduction has not caused any dramatic reduction of the total irrigation water use in the Basin. This is largely due to the expansion of irrigated farming area. Furthermore, deterioration of drainage facilities demands that more water must be used for soil leaching (desalination) purposes. This is a direct consequence of the deterioration of the overall economic conditions and lack of adequate funds for operation and maintenance of drainage facilities. The potential for further water savings in the Aral Sea Basin is estimated at the level of 15%–20% of the current use (combined effect of economic, regulatory and technological incentives). This level is substantial, but it would come at a cost. It is clear that money needed for implementation of any large-scale water conservation program would be a substantial burden on any national budget in the region.

Unfortunately, saving 20% of the current irrigation water use is insufficient for restoration of the Aral Sea to its former levels (although it is of great importance for other water uses in the basin, including instream ecological requirements). Even preserving the sea at a present level would call for regular water inflows ~3 × higher than the dry year inflow under the present conditions (~12 km^3). Such level of inflow is rare, except in wet years, and would require the commitment of Basin states to treat the Aral Sea as a water user at this level of "consumption" (~30 km^3/yr). Such a commitment is unlikely because of the population growth, calling for an increase of water supply and local food production as well as for creation of new employment opportunities in the region. Theoretically, the problem could be solved by economic restructuring of the region at least partially away from irrigated farming. This would, however, require substantial investment outlays and probably too much time for any definite reversal of deterioration processes currently at force. Furthermore, reduction of local food production is politically always difficult to justify in the situation of rapidly growing population. It is anticipated that if the current water use patterns in the basin continue, in ~20 yr the sea will be little more than a few highly saline lakes.

The long-distance water transfer options (e.g., from the Siberian rivers) are beyond the scope of this paper. The potential environmental effects and economic costs make them very unlikely. For the foreseeable future, the basin has no choice than to rely on its own water resources.

With reference to the multi-objective analysis discussed in the beginning of this paper, decision makers in the region face a difficult task involving articulation of trade-offs between restoration of the sea and food production, i.e., the extent of irrigated farming. Identification of the minimum levels of food production (imperatives) will most probably be left to the political process (see, for example, Lubin 1995, Starr 1996), where the responsibility properly resides.

Coastal wetlands.—The desiccation of the Aral Sea has caused the degradation of the wetlands in the deltas of both Amu Darya and Syr Darya. These deltas have historically been the biologically richest parts of the Aral Sea ecosystem. While the Aral Sea cannot be restored to a healthy ecosystem in the foreseeable future, many of the detrimental effects of the sea desiccation can be mitigated by creating a wetland belt in the most ecologically and sociologically important river deltas. A wetland belt would halt the desertification in the delta; provide opportunities for the sustainable use of natural resources, particularly fishing; and restore the functioning of the region as an important staging and breeding ground for migratory birds.

Wetland creation and rehabilitation has been recognized as a priority in the Aral Sea Basin for quite a long time. It is an important way to create new employment opportunities for the local population. Furthermore, it will help to preserve international biodiversity, including a highly endangered species of migratory birds. Establishing a wetland buffer zone is also an efficient and innovative way of combating desertification.

But again some difficult trade-offs are involved, this time concerning reservoir release scheduling. Maximizing the value of hydropower production calls for winter reservoir releases, while biodiversity objectives in the delta requires adequate flow in the spring and the summer. Analysis of trade-offs between these two objectives presents additional difficulties since hydropower plants and delta wetlands are located in different countries.

Upstream watersheds.—The upstream watersheds of the Aral Sea Basin, which are the source of ~70% of all water resources available in the basin, are characterized by complex land and water management problems which are causing cumulative impacts in the lower watersheds as well as in the immediate area. The most important of these impacts are salinization and pollution of water bodies used for drinking and irrigation in the lower watersheds, increased peak flows and lower minimum flows due to deforestation and erosion, and siltation caused by increased erosion. The population in this area suffers from severe poverty due to the declining productivity in agriculture and industrial production. Public health problems also have intensified due to the increased environmental risks. Because all of these impacts are related to land use, improving water management in the upper watersheds will require effective land management involving all major land users and other key stakeholders.

The long-term objective is to reduce environmental degradation and promote sustainable land and water resource management in the upper watersheds of the Aral Sea Basin. Related programs can play important roles in developing national awareness of upper watershed problems and demonstrating ways to deal with them. This can only occur if they are organized as national programs. The significance of the overall effort, however, is regional; the cumulative effects of local and national efforts to manage land and water in the upper watersheds will result in downstream improvements in water quality and increased, moderated flows.

Implementation of the upstream watershed improvements is positive from the point of view of all program objectives. Improvements in land and water use efficiency will increase productivity (economic gains), reduce environmental pollution downstream (ecological gains) and benefit rural populations (social gains). The only problem is the availability of necessary funds and, if they are limited, priorities will have to be established concerning their allocation in time and geographic space. With the limited budget, allocation of funds between the upstream and downstream parts of the basin will involve difficult choices. Again, trade-off analysis will be required.

To summarize, it should be recognized that this paper reports on the results of the preliminary phase of strategy development only. At the moment, there are no formal models developed for analysis of trade-offs between different strategy objectives. There are numerous models and techniques available that are consistent with a multi-objective analysis, but their application in the unusually difficult context of Central Asia will be a real challenge. The modeling work will be carried out in the next phase of the project funded by the Global Environmental Facility.

Linking Environmental and Economic Objectives

The time to address freshwater challenges is running out. A sense of urgency must be brought to the international debates on development and environment. The fundamental question to be asked is what are the short, medium, and long-term impacts of water resources development and economic development on the biosphere. Answers to this question are not easy, especially because the scale of human activities has increased substantially and many environmental problems take time to fully unfold (30 yr in case of the Aral Sea). Impacts must be examined with the related uncertainties and risks taken into account. Values should be placed upon risks taken or not taken, and explicit statements made as to the benefits from risk reduction. Decision criteria must obviously extend beyond engineering and economics.

In the Aral Sea Basin, increasing recognition of environmental problems, in particular desiccation of the Aral Sea and the related human impacts coincided in the early 1990s with initiation of economic reforms, almost complete utilization of water resources, and population growth pressures. The problems inherited from the past had to be addressed within a radically different new political and economic setting. Under current circumstances, highest priority must be given to the policies that exploit the complementarity between poverty reduction, economic efficiency, and environmental quality. Any strategy that aims at sustainable management of earth's natural resources must build on the positive links between development and environment and seek to break the negative links. In the long run both components are essential, and the Aral Sea Basin provides a dramatic example of the economic, social, and environmental complexities involved in restoration of a freshwater system. Sustainability does not necessarily imply preservation of a natural state, but rather maintenance of the resilience and capacity of the economic, social, and ecological systems to adapt to change.

Literature Cited

Clark, W. C. 1986. Sustainable development of the biosphere: themes for a research program. Pages 5–48 *in* W. C. Clark and R. E. Munn, editors. Sustainable development of the biosphere. IIASA and Cambridge University Press, Cambridge, UK.

Glazovsky, N. F., and M. M. Mainguet. 1992. Le bassin de l'Aral: quelques aspects d'un desastre ecologique. Secheresse. Number 3, Volume 3.

Interstate Council. 1996. Fundamental provisions of water management strategy in the Aral Sea Basin. Interstate Council of the Aral Sea. Kazakhstan, Kyrgyz Republic, Tadjikistan, Turkmenistan, Uzbekistan.

Lubin, N. 1995. Central Asian take stock. Peaceworks, Number 2. United States Institute of Peace. Washington, D.C., USA.

Micklin, P. P. 1991. The water management crisis in Soviet Central Asia. The Carl Beck Papers in Russian and East European Studies. Number 905. University of Pittsburgh Center for Russian and East European Studies, Pittsburgh, Pennsylvania, USA.

———. 1992. The Aral crisis: introduction to the Special Issue. Post-Soviet Geography (formerly Soviet Geography). Volume XXXIII. Number 5.

Munasinghe, M. 1994. Economic and policy issues in natural habitats and protected areas. Pages 15–50 *in* M. Munasinghe and J. McNeely, editors. Protected area, economics and policy; linking conservation and sustainable development. World Bank and World Conservation Union, Washington, D.C., USA.

Starr, S. F. 1996. Making Eurasia stable. Foreign Affairs. Volume **75**, Number 1.

UNEP (United Nations Environmental Programme). 1992. Management of water and land resources in the Aral Sea Basin: a diagnostic report. Nairobi, Kenya.