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**TITLE: THE WATER MANAGEMENT CRISIS IN
 SOVIET CENTRAL ASIA**

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EXECUTIVE SUMMARY

Synopsis

Soviet Central Asia has a grave water management crisis. Located in the most southern part of the USSR, this region has an extremely arid climate. Nevertheless, water resources here are substantial owing to two rivers, the Amu and Syr Dar'ya, that flow from surrounding well-watered mountains across the deserts and into the Aral Sea, a vast saline lake. Consequently, irrigation has been extensively developed and is the primary support for the region's large and rapidly growing population. However, river discharge has been exhausted by heavy consumptive withdrawals for this activity. Water is used inefficiently and improvements in irrigation, which are underway, could free resources for further expansion of it and other water using sectors. But the potential for water savings is limited and a successful efficiency program in irrigation likely will allow only modest further growth in the irrigated area.

If this weren't enough, the Aral Sea is fast disappearing. Inflow to it has been reduced to almost nothing because of withdrawals for irrigation. The sea's recession has had far-reaching ecological and economic repercussions that are steadily worsening. Long neglected, the problem in recent years has become the focus of national attention. In September 1988, a rescue plan for the sea was decreed by the Party and Soviet government. Although a step in the right direction, it may be too little, too late.

Local water resources are probably inadequate to meet the needs of Central Asia's rapidly growing population and save the Aral Sea. Thus, the Communist Party and Soviet government are faced with hard choices. They can continue to force the region to try and survive on its own water resources with all the attendant adverse economic, demographic, ecological, and political ramifications if this policy fails. On the other hand, they can resurrect the much condemned and now halted project for large-scale water transfers into the region from Siberia. This could probably provide, along with implementation of local water saving measures, enough water to preserve the Aral in a usable form and provide for future legitimate water supply needs.

Making rational policy development more difficult, water management in Central Asia has become the center of a bitter national debate over who is responsible for the problems and how to resolve them. Russian nationalist writers and other representatives of northern regions, some scientists, Soviet environmentalists (i.e. "Greens"), and even many Central Asian writers and social critics claim irrigation and water management agencies should bear full guilt for the situation. They also contend most difficulties can be solved by careful, rational use of local water resources. On the other hand, Central Asian water managers are unwilling to admit to the level of mismanagement with which they have been charged. Furthermore, they, along with many other experts on water management in this region, contend that local measures alone will be insufficient and a realistic long-

term solution will probably have to include some level of water transfer into Central Asia from Western Siberia. Emotions are high and positions rigid in the controversy. The policies chosen at the highest levels of the Party and Government to try and resolve the issue will have major implications for the Soviet Union far into the future.

More details

Central Asia has 40% of the USSR's irrigated area. It contributes 95% of national cotton production. Irrigation is the basis of food production and the prime contributor to employment in the region. The assumed further growth of irrigation is now in grave doubt because of the regions severely strained water situation. The problem is compounded by a large (34 million in 1987) and rapidly growing population. Means must be found to ensure an adequate water and food supply as well as employment opportunities for future generations. If water supplies are exhausted, precluding any significant expansion of irrigation, how will this be done? Large-scale emigration to other parts of the USSR where water shortages are not a problem and workers are needed is one solution. But most ethnic Central Asians have no desire to move to these regions with a climate, language, and culture so different from their native lands.

What can be done locally to improve the situation? Using water more carefully is an obvious strategy. Water usage in irrigation accounts for around 90% of withdrawals and over 80% of

consumptive use and, hence, is where major savings are possible. Irrigation in Central Asia has historically been inefficient. In the late 1970s, 56% of water withdrawn for irrigation in the Amu and Syr Dar'ya basins may have been lost to noncrop (i.e. nonproductive) uses. Major efforts have been made in Central Asia since 1982 to improve irrigation efficiency. Substantial gains have already been made. Average per hectare withdrawals may have fallen as much as 27% between 1980 and 1986. The Gorbachev regime has renewed efforts to improve water use in the region. Reconstruction of old irrigation systems, improvements in water application technologies, automation, computerization, and telemechanization, and shifts from higher to lower water consuming crops are being stressed. Water pricing in irrigation, a very promising means to promote efficiency, is to be introduced nationally in 1991.

How much additional water can be saved in Central Asia? Critics of irrigation contend the potential savings are enormous - more than enough to meet regional needs far into the future. Water management specialists see only modest quantities of water being freed, perhaps a net gain as small as 10 km³/yr (less than 10% of present withdrawals for irrigation) and at enormous cost, certainly tens-of-billions of rubles. Water management experts appear closer to the truth than their opponents in this debate.

There are additional local means to deal with the water supply problem here. Exploitable water supplies could be increased somewhat, for example, by greater use of ground water,

reuse of irrigation drainage, and more regulation of river flow. The economic structure of Central Asia could be fundamentally altered away from dependence on water intensive irrigation and toward low water use industries (e.g. electronics). This would require massive investment and retraining of the populace and would not solve the problems of increasing local food production.

The problem of the Aral Sea greatly exacerbates an already strained water resource situation. This huge lake has been steadily shrinking since 1960. By 1987, its level had fallen 13 meters, area decreased 40%, volume diminished 66% and salinity risen from 10 to around 27 grams/liter. If preventive measures are not taken, the Aral will shrink to several residual brine lakes in the next century. The sea's desiccation has had severe adverse impacts. Salt and dust have been blown from the dried bottom hundreds of kilometers inland, rising salinity has destroyed the sea's biological productivity and decimated its fishery, ecosystems of the deltas of the Amu Dar'ya and Syr Dar'ya have been severely degraded, and the climate around the sea has grown more extreme as the moderating influence of the waterbody diminished. Living conditions around the Aral have become much more difficult as water supplies have disappeared or become polluted, medical and health conditions deteriorated, and employment opportunities vanished. Owing to this, districts adjacent to the Aral Sea are experiencing large-scale emigration. There are no accurate estimates of aggregate losses from the Aral's desiccation but they must already have accumulated into

the tens-of-billions of rubles.

The Council of Ministers and Central Committee issued a decree on the Aral in October 1988. It lays out a comprehensive program to stabilize sea level 5 m below its current standing by 2005 and to ameliorate the problems induced in the surrounding region. The measures specified in the decree will not only be difficult to implement and enormously costly, but would result in a polluted waterbody with a salinity higher than the ocean and only 40% of its size in 1960.

Hopes to resolve Central Asia's water problems previously rested on future massive water transfers from Siberian rivers. It was proposed to transfer 27 km³/yr initially, possibly rising to 60 km³ in the next century. The project was in the final engineering design phase and was scheduled for construction by the late 1980s or early 1990s. However, after Gorbachev's rise to leadership in 1985, the plan, along with a similar scheme for the European USSR, was halted pending further study. Central Asia was told it would have to survive on its own water resources.

The Siberian scheme is likely to be resurrected in some form. There would be a reasonably good chance to resolve water problems associated with irrigation in the absence of the Aral sea's difficulties or vice versa. To adequately deal with both these issues simultaneously without water importation seems extremely difficult if not impossible. Consequently, hard choices are ahead for the Soviet government. Dependent on only local water resources, irrigation expansion, in spite of

efficiency measures, will have to stop in the 1990s. To provide the amount of water the Aral needs to remain viable, irrigation would have to be substantially reduced. The first may cause severe social and economic disruption and necessitate large-scale emigration and the last certainly would. This, in turn, would provoke long-lasting enmity toward the Central Government and Communist Party that could have unpredictable consequences. It would seem a rational Soviet power structure would be unwilling to take this risk.

On the other hand, diversion of as little as 10 to 15 km³ annually from Siberian rivers into the Aral sea along with implementation of some local measures could preserve the sea near its current level and area while lowering salinity to ecologically tolerable levels without any cut-back in irrigation. Furthermore, this could be defended on the ecological grounds of saving the Aral - arguably outweighing the environmental harm caused in Western Siberia. The Soviet government could, as a condition of the "deal", stipulate that no Siberian water be used in irrigation, encouraging Central Asian water managers to make every effort to use the resource carefully, since expansion of irrigation and other water uses would be possible only from water freed by this means.

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INTRODUCTION

Water is biologically essential to all life. Without an adequate supply plants and animals soon perish. But an abundant and assured supply of fresh water is also an economic and social necessity to modern, industrial societies which withdraw prodigious amounts of it chiefly for industrial, agricultural, and municipal purposes. Massive water withdrawals are particularly essential in arid regions where irrigation has been extensively developed. However, since irrigation is a heavily consumptive use of water (i.e., a large proportion of water withdrawn is not returned), sources of supply such as rivers and ground water suffer significant depletion with attendant ecological, economic, and social consequences.

How to effectively manage limited water resources in an arid environment with major consumptive usage, including balancing competing economic and ecological demands is a complicated and not easily resolved task. Americans with an interest in water management are well aware of the difficulties from our own experience in the southwestern region of the U.S. The Colorado River has been depleted to a trickle in its lower reaches by large consumptive withdrawals, ground water levels have been severely depressed by overdrafting, irrigation is in decline because of rising costs and competition for water from cities, and conflicts between water users are growing more bitter (1).

But serious as is the situation in the American southwest, it pales in comparison with water management problems in a large region of the USSR. Known as Soviet Central Asia, it is situated in the most arid zone of the country. Intensive development of irrigation here has so depleted river flow into the Aral Sea, a huge saline lake, that it is

drying at a rapid pace with accompanying severe ecological consequences. The Soviet government until recently proposed to "solve" the region's water management problems by large-scale, long-distance water importation from Siberian rivers far to the north. This project, for economic, ecological, and political reasons, is in abeyance. Local means of resolving water management problems are being pursued. However they may fail. If so, Central Asia will suffer severe ecological, economic, and social consequences. To avoid these, the Soviet government may be compelled to resurrect the Siberian water transfer plan.

This report, after a brief introduction to Soviet Central Asia, investigates the two main aspects of the water crisis in Central Asia: irrigation development and the Aral Sea Problem. The latter section includes discussion of the Siberian water diversion project.

1. CENTRAL ASIA

1.1. Location

Central Asia lies in the extreme south-central part of the Soviet Union, between the Caspian Sea on the West and the chain of mountains (Kopet-Dag, Pamir, and Tyan' Shan) on the south and east (Fig. 1). Traditionally, the area has been designated "Central Asia" by the Russians and "Soviet Central Asia" by foreigners to distinguish it from adjacent lands outside the USSR. For purposes of this study, Central Asia is defined to include the Uzbek, Tadzhik, Kirgiz, and Turkmen soviet socialist republics (SSRs) which constitute administrative Central Asia as well as two of the southern oblasts of the Kazakh SSR (Kzyl-Orda and Chimkent) (Fig. 2). On water management grounds it is logical to include the two oblasts since they fall within the drainage basin of the Aral Sea, the key hydrologic feature of the region, as does most of administrative Central Asia. Hence, the region has a commonality in terms of water management problems.

1.2. Physical Character

Central Asia encompasses 1.6 million km² - 7.3% of the USSR's territory (Table 1). The region is mainly lowland (plains) desert but has mountains on the extreme south and in the southeast (with peaks over 7000 m) which are characterized by foothill-steppe, mountain-steppe, and high mountain desert climates (Fig. 3) (2, pp. 76,87,206-213,243-254 and folded end maps). Annual average precipitation in the lowland desert is from less than 100 millimeters (mm) in the Kara-Kum and Kyzyl-Kum south and east of the Aral Sea to near 200 mm approaching the foothills of the southeastern mountains. Potential evapotranspiration (PET) for the desert zone ranges from 1000 mm in the north to over 2250

FIGURE 1. LOCATION OF CENTRAL ASIA

FIGURE 2. CENTRAL ASIA: ADMINISTRATIVE DIVISIONS

TABLE 1. CENTRAL ASIA: AREA AND POPULATION CHARACTERISTICS

Administrative unit	area (000's of sq. km)	population on 1/1/87 (millions)	% total pop.	1986 rate of natural increase (%)
Uzbek SSR	447.4	19.03	56.64	3.08
Kazakh SSR(1)	344.4	2.41	7.14	1.81(2)
Kzyl-orda Obl. (228.1)		(0.63)	-	-
Chimkent Obl. (116.3)		(1.78)	-	-
Tadzhik SSR	143.1	4.81	14.25	3.52
Kirgiz SSR	198.5	4.14	12.26	2.55
Turkmen SSR	488.1	3.36	9.96	2.85
Total	1621.5	33.75	100.00	2.97(3)

Compiled from 16, pp. 393-394;406-407.

(1) two southern oblasts in the Aral Sea drainage basin

(2) rate for entire Kazakh Republic

(3) weighted average rate

FIGURE 3. CENTRAL ASIA: PHYSICAL FEATURES

mm in the extreme south, resulting in severely arid conditions with moisture coefficients (precipitation divided by PET) below 0.10 common. The foothills and valleys of the mountainous south and southeast are substantially less arid. Here precipitation ranges from 200 to over 500 mm PET is around 1500 mm at the desert margins but declines markedly with altitude. Moisture coefficients range from around 0.2 to over 0.6. The high mountain areas of the Pamirs and Tyan-Shan ranges are humid with average annual precipitation from 800 to 1600 mm and PET levels from 1000 to below 500 mm. The marked surplus of moisture here results in large permanent snow fields and glaciers that feed the two major rivers, The Amu Dar'ya and Syr Darya, which flow out across the desert and ultimately reach the Aral Sea.

Thermal conditions for plant growth in Central Asia are the best in the USSR. The sum of temperatures for the growing season rises from 3,000 C° (centigrade-degrees) in the north to over 5,000 C° in the south of the desert zone (3, p. 100). In the foothills and valleys of the mountains, temperature totals range from 2000 to over 4000 C°. Hence, conditions are favorable for raising heat loving crops such as grain corn, sorghum for grain, rice, and soy over all of the deserts and much of the mountain foothills and valleys of Central Asia and for growing cotton in the desertic plains and foothills over all but the northern part of the region (4).

A variety of soils are found here: serozem (desert), gray-brown desert, meadow, alluvial, sand, takyr (clay-pan) and heavily salinized (solonets and solonchak) (3, p. 104). Although fragile and thin, these soils (with the exception of the heavily salinized) are able to support a productive crop agriculture with the application of supplementary

water. The area "needing" irrigation in the Aral Sea basin, which is nearly coterminous with Central Asia as defined here, has been set in excess of 50 million ha (5). A more modest estimate is that 27 million ha are suitable for irrigation in the basins of the Amu Dar'ya and Syr Dar'ya - the region's two largest rivers (6)

1.3. Water Resources and Water Use

Although most of Central Asia is desert, it has substantial water resources. This owes to the high mountains on its south and southeast that capture plentiful moisture and store it as snow and ice. The runoff from these mountains, heaviest during the spring thaw, feeds the region's rivers. Estimated average annual river flow in Central Asia, as defined for this study, is 122 km³/yr (Fig. 3; Table 2). The Aral Sea drainage basin accounts for 90% (110 km³) of this. It includes the two largest rivers, Amu Darya (73 km³/yr) and Syr Darya (37 km³/yr), in Central Asia (dar'ya in Turkic means river). Discharge is maximum where rivers exit the mountains but decreases rapidly as they cross the deserts. The mountain zone has a strongly positive moisture balance (i.e. precipitation well in excess of evaporation) and, consequently, heavy surface runoff. The desert zone, on the other hand, has opposite conditions, contributing essentially nothing to river flow while inducing rapid water loss owing to high evaporation, large transpiration losses from phreatophytes (water loving plants) growing along the banks and in the deltas of rivers, and bed losses to filtration. Smaller rivers such as the Zeravshan, Tedzhen, and Murgab completely disappear as they flow into the desert. The Amu and Syr Dar'ya (until the 1960s) lost around half their flow before reaching the Aral Sea (7, p. 235). Usable supplies of ground water (i.e. that are not hydraulically

TABLE 2. CENTRAL ASIA: DRAINAGE BASIN CHARACTERISTICS

Characteristic	Drainage Basins					Aral Sea	Central
	(1)	(2)	(3)	(4)	Caspian	Basin	Asia
	Amu Dar'ya	Syr Dar'ya	Kara-Kum Canal	Lake Issyk-Kul	Sea east coast (5)	(drainage basins (1,2,3)	(drainage basins 1-5)
Area (000's of sq. km)	692.30	493.00	182.20	43.50	138.50	1367.50	1549.50
% of Aral Sea Basin	50.63	36.05	13.32	-	-	100.00	-
% of Central Asia	44.68	31.82	11.76	2.81	8.94	88.25	100.00
Population in 1975 (millions)	9.5779	12.6817	1.2450	0.3493	0.2951	23.5046	24.1490
% of Aral Sea basin	40.75	53.95	5.30	-	-	100.00	-
% of Central Asia	39.66	52.51	5.16	1.45	1.22	97.33	100.00
Population in 1980 (millions)	11.2224	14.0954	1.4044	0.3589	0.3207	26.7222	27.4018
% of Aral Sea basin	42.00	52.75	5.26	-	-	100.00	-
% of Central Asia	40.95	51.44	5.13	1.31	1.17	97.52	100.00
Irrigated area in 1975 (000's of hectares)(1)	2281.90	2885.30	340.70	150.00	8.00	5507.90	5665.90
% of Aral Sea basin	41.43	52.38	6.19	-	-	100.00	-
% of Central Asia	40.27	50.92	6.01	2.65	0.14	97.21	100.00
Irrigated area in 1980 (000's of hectares)(1)	2555.60	2883.80	544.40	158.80	10.00	5983.80	6152.60
% of Aral Sea basin	42.71	48.19	9.10	-	-	100.00	-
% of Central Asia	41.54	46.87	8.85	2.58	0.16	97.26	100.00
Average annual flow (cu-km)	72.80	36.70	0.25	12.10	-	109.75	121.85
% of Aral Sea basin	66.33	33.44	0.23	-	-	100.00	-
% of Central Asia	59.75	30.12	0.21	9.93	-	90.07	100.00
Low flow in cu-km (95% exceedance)(2)	58.40	25.40	0.16	9.60	-	83.96	93.56
% of Aral Sea basin	69.56	30.25	0.19	-	-	100.00	-
% of Central Asia	62.42	27.15	0.17	10.26	-	89.74	100.00
Usable groundwater resources, not connected with river flow (cu-km)	9.00	7.40	0.30	1.10	0.10	16.70	17.90
% of Aral Sea basin	53.89	44.31	1.80	-	-	100.00	-
% of Central Asia	50.28	41.34	1.68	6.15	0.56	93.30	100.00
Total average annual water resources (cu-km)	81.80	44.10	0.55	13.20	-	126.45	139.75
% of Aral Sea basin	64.69	34.88	0.43	-	-	100.00	-
% of Central Asia	58.53	31.56	0.39	9.45	0.10	90.48	100.00

Compiled and calculated from 7a, pp. 182-183; 226-231 and 7, p. 227.

(1) Land actually provided with water.

(2) Flow for which the exceedance probability in any year is 95%.

connected with river flow) are estimated at 18 km³/yr. Thus, aggregate average annual water resources for Central Asia are around 140 km³/yr, with 90% found in the Aral Sea drainage basin.

However, river flow varies from year-to-year because of the natural interannual variation of precipitation, temperature, evaporation and other climatic variables. For the Syr and Amu Dar'ya, hydrological statistical analysis indicates that whereas their combined average annual flow is around 110 km³ in their mountain zones of formation, there is a 95% probability (termed the exceedance probability) in any given year that flow will be more than 84 km³ and a 5% chance that it will be less (7, p. 227). In other words, over the long term we could expect 19 of 20 years to have river discharge above 84 km³ and 1 in 20 years below. On the other hand, there is a 5% probability the discharge of these rivers will be more than 141 km³ in any given year and a 95% chance it will be less. Thus, over many years we could expect more than 141 km³ 1 out of 20 years and less 19 of 20 years. This probabilistic variability of river flow adds greatly to the complexity of water management planning, particularly in arid regions such as Central Asia where adequate supplies of water in a given year are critical. It also points up the fallacy of using average annual flows as the main indicator of a region's surface flow resources. Indeed, low flow conditions (90 or 95% exceedance probability) are more critical for proper water management planning in arid zones.

Water use in the study region is large. Unfortunately, detailed data are lacking; it is likely even Soviet water management experts do not have a truly accurate idea of it. However, the Institute of Water Problems of the Soviet Academy of Sciences has published a comprehensive

and consistent water usage data set by water resource region and drainage basin for the whole country for 1980. These data have been used to construct a water usage profile for Central Asia for 1980 (Table 3). Water withdrawals for the entire region were estimated at 134 km³ with consumptive use (water lost to evaporation and transpiration or incorporated into plants, animals, or other products) of 80 km³ (59% of withdrawals). The balance of 75 km³ (41% of withdrawals) constituted return flows which consist of such things as leakage from canals and pipes; surface runoff, infiltration, and accumulation in drainage networks of water applied to irrigated tracts or other objects; and end discharges of canals or pipes. The distinction between consumptive use and return flows is blurred particularly for irrigation since some of this water is quickly evaporated or transpired rather than returning to rivers or adding to the ground water reservoir. Central Asia accounted for 39% of withdrawals and 49% of consumptive use nationally in 1980 (7a).

Withdrawals in 1980 were 144% of low flow (95% exceedance), 110% of average annual flow and 96% of average annual water resources (average annual surface flow + usable ground water) in Central Asia (Tables 2 and 3). It would appear water resources here are completely exhausted. The corresponding figures are even worse for the Aral Sea basin: 157%, 120%, and 104%. However, withdrawals are not a good measure of water shortage since the same flow, as long as it is returned to the source of withdrawal, can be used repeatedly - this is the case in Central Asia. A better gage is the total of consumptive use plus evaporation from reservoirs since this water is largely lost to the source from which it is taken (a small portion of the evaporated and transpired water may be

TABLE 3. CENTRAL ASIA: WATER USE BY SECTOR IN 1980 (cubic kilometers)

Water consuming sectors	Drainage basins										Aral Sea Basin [drainage basins 1,2,3]	%	Central Asia [drainage basins 1-5]	%
	[1]		[2]		[3]		[4]		Caspian					
	Amu Dar'ya	%	Syr Dar'ya	%	Kara-Kum Canal	%	Lake Issyk-Kul	%	Sea east coast [5]	%				
Municipal														
withdrawal	0.4637	100.00	1.1044	100.00	0.1039	100.00	0.0131	100.00	0.0080	100.00	1.6720	100.00	1.6931	100.00
return	0.2218	47.83	0.7332	66.39	0.0459	44.18	0.0030	22.90	0.0018	22.50	1.0009	59.86	1.0057	59.40
consumptive use	0.2419	52.17	0.3712	33.61	0.0580	55.82	0.0101	77.10	0.0062	77.50	0.6711	40.14	0.6874	40.60
withdrawals as % of drainage basin total		0.75		1.95		0.75		0.82		1.15		1.27		1.26
Industry														
withdrawal	0.7690	100.00	1.7380	100.00	0.2430	100.00	0.0030	100.00	0.1010	100.00	2.7500	100.00	2.8540	100.00
return	0.5790	75.29	1.3620	78.37	0.1750	72.02	0.0020	66.67	0.0770	76.24	2.1160	76.95	2.1950	76.91
consumptive use	0.1900	24.71	0.3760	21.63	0.0680	27.98	0.0010	33.33	0.0240	23.76	0.6340	23.05	0.6590	23.09
withdrawals as % of drainage basin total		1.25		3.08		1.75		0.19		14.55		2.08		2.13
Thermoelectric														
withdrawal	0.9331	100.00	2.5152	100.00	0.7059	100.00	-	-	0.3749	100.00	4.1542	100.00	4.5291	100.00
return	0.8456	90.62	2.3752	94.43	0.6922	98.06	-	-	0.3703	98.77	3.9130	94.19	4.2833	94.57
consumptive use	0.0875	9.38	0.1400	5.57	0.0137	1.94	-	-	0.0046	1.23	0.2412	5.81	0.2458	5.43
withdrawals as % of drainage basin total		1.51		4.45		5.09				54.01		3.15		3.37
Irrigation														
withdrawal	57.8030	100.00	49.3320	100.00	12.6390	100.00	1.5040	100.00	0.2000	100.00	119.7740	100.00	121.4780	100.00
return	23.3160	40.34	16.2920	33.03	6.1930	49.00	0.7070	47.01	0.0090	4.50	45.8010	38.24	46.5170	38.29
consumptive use	34.4870	59.66	33.0400	66.97	6.4460	51.00	0.7970	52.99	0.1910	95.50	73.9730	61.76	74.9610	61.71
withdrawals as % of drainage basin total		93.81		87.30		91.21		94.69		28.81		90.75		90.48
Rural settlements														
withdrawal	1.1551	100.00	1.1318	100.00	0.1121	100.00	0.0379	100.00	0.0089	100.00	2.3990	100.00	2.4458	100.00
return	0.1514	13.11	0.1583	13.99	0.0147	13.11	0.0049	12.93	0.0012	13.48	0.3244	13.52	0.3305	13.51
consumptive use	1.0037	86.89	0.9735	86.01	0.0974	86.89	0.0330	87.07	0.0077	86.52	2.0746	86.48	2.1153	86.49
withdrawals as % of drainage basin total		1.87		2.00		0.81		2.39		1.28		1.82		1.82
Livestock														
withdrawal	0.1100	100.00	0.1559	100.00	0.0166	100.00	0.0068	100.00	0.0013	100.00	0.2825	100.00	0.2906	100.00
return	0.0056	5.09	0.0078	5.00	0.0008	4.82	0.0003	4.41	0.0001	7.69	0.0142	5.03	0.0146	5.02
consumptive use	0.1044	94.91	0.1481	95.00	0.0158	95.18	0.0065	95.59	0.0012	92.31	0.2683	94.97	0.2760	94.98
withdrawals as % of drainage basin total		0.18		0.28		0.12		0.43		0.19		0.21		0.22
Fish rearing ponds														
withdrawal	0.3815	100.00	0.5327	100.00	0.0368	100.00	0.0236	100.00	-	-	0.9510	100.00	0.9746	100.00
return	0.2705	70.90	0.4124	77.42	0.0241	65.49	0.0228	96.61	-	-	0.7070	74.34	0.7298	74.88
consumptive use	0.1110	29.10	0.1203	22.58	0.0127	34.51	0.0008	3.39	-	-	0.2440	25.66	0.2448	25.12
withdrawals as % of drainage basin total		0.62		0.94		0.27		1.49				0.72		0.73
Drainage basin total														
withdrawal	61.6154	100.00	56.5100	100.00	13.8573	100.00	1.5884	100.00	0.6941	100.00	131.9827	100.00	134.2652	100.00
return	25.3899	41.21	21.3409	37.76	7.1457	51.57	0.7400	46.59	0.4594	-	53.8765	40.82	55.0759	41.02
consumptive use	36.2255	58.79	35.1691	62.24	6.7116	48.43	0.8484	53.41	0.2347	-	78.1062	59.18	79.1893	58.98
Evaporation from reservoirs	2.7020		2.5160		5.6400		0.0000		0.0208		10.8580		10.8788	
Total including evaporation from reservoirs														
withdrawal	64.3174	100.00	59.0260	100.00	19.4973	100.00	1.5884	100.00	0.7149		142.8407	100.00	145.1440	100.00
return	25.3899	39.48	21.3409	36.16	6.7116	34.42	0.7400	46.59	0.4594		53.4424	37.41	54.6418	37.65
consumptive use	38.9275	60.52	37.6851	63.84	12.7857	65.58	0.8484	53.41	0.2555		89.3983	62.59	90.5022	62.35

Compiled and calculated from 7a, pp. 212-215.

returned to its source as precipitation).

Consumptive use and reservoir evaporation (totalling 91 km³) were 97% of low flow, 74% of average annual flow, and 65% of average annual water resources in Central Asia. For the Aral Sea basin, the figures were 106%, 81%, and 71%. However, even this measure understates the actual losses of water since a significant portion of so-called return flow is lost to evaporation and transpiration and does not recharge ground water or reach the major rivers in Central Asia. One authoritative estimate is that of the 34 km³ of irrigation drainage water generated annually in the drainage basins of the Amu and Syr Dar'ya, in the early 1980s, only 21 km³ (62%) returned to these rivers or their tributaries (8). Adding the balance (13 km³) to consumptive use brings the percentages for the Aral Sea basin to 123%, 94%, and 82% of low flow, average annual flow, and average annual basin water resources. Indeed, the combination of anthropogenic and natural losses of flow to the region's two major rivers, Syr and Amu Dar'ya, had diminished the flow in their lower reaches (and into the Aral Sea) to practically nothing by 1980 (9).

Irrigation is by far the dominant use of water in Central Asia (Table 3). In 1980 it accounted for 90% of withdrawals, 95% of consumptive use (excluding reservoir evaporation), and 84% of return flows. It predominates in all drainage basins except the Caspian Sea east coast where thermoelectric uses are primary. Thus it is accurate to state that the water management crisis in Central Asia is a crisis of the use of water for irrigation. Although there are clearly water saving opportunities in other sectors their contribution is limited by the insignificance of other water users compared to irrigation. Indeed,

even small relative water savings in this sector could provide enough water to more than meet any future needs of other economic sectors in Central Asia.

1.4. Population

The estimated population of Central Asia was 34 million on January 1, 1987, 12% of the USSR total (Table 1). The rate of natural increase (births minus deaths) was in excess of 2.9% in 1986 compared to a national rate of 1.0%. This is the highest of any region in the USSR and comparable to rates of the world's fastest growing developing countries (10). Fertility among the indigenous Muslim peoples, although falling, remains high. W. Ward Kingkade of the U.S. Bureau of the Census estimates that total fertility for the Uzbeks, Kirgiz, Tadzhiks, Turkmen, and Kazakhs was 5.7, 5.8, 6.6, 6.1, and 4.0, respectively, in 1983-84 (11). These compare with rates of 2.4 for the USSR as a whole and 2.1 for the Russians and Ukrainians - the two largest nationalities.

Efforts to induce Central Asian Muslims to emigrate to labor-short regions of the country (industrial centers and the nonchernozem zone of the European USSR and resource development projects in Siberia and the Far East) have so far met with a notable lack of success (12;13;14). High fertility, the young age structure, and minimal out-migration, make rapid population growth for Central Asia a near certainty well into the next century. A recent study has detected increasing out-migration from the Central Asian republics during the 1980s (14a). However, it is still small (-0.2%) compared to rates of natural growth here and largely Russian in ethnic composition. If the rate of increase (births minus deaths plus or minus net migration) in the study region averaged only 2.5% until 2000, population would rise to 47 million - 38% above 1987.

Assuming a 1.5% average rate for the first decades of the next century, it would grow to 63 million by 2020 - 85% above 1987.

2. IRRIGATION DEVELOPMENT IN CENTRAL ASIA

2.1. Irrigation in the USSR

The southern tier of the Soviet Union, the part of the country with the most favorable heat and soil conditions for crop raising, is arid and semi-arid. Consequently, irrigated agriculture has been extensively developed in this zone. Irrigation not only greatly increases yields but dampens their interannual variability. The USSR holds fourth place in the world in irrigated area, after China India, and the U.S. In contrast to the U.S. where irrigated lands have been shrinking since the late 1970s (a function of declining crop prices, water shortages, and rising water costs), they have continued to grow in the USSR. After Gorbachev's rise to leadership in March 1985 and the introduction of his program of perestroika (economic restructuring) which emphasizes efficiency, economic accounting, and intensive rather than extensive development, there has been a shift in stress and investment away from irrigation and toward alternative soil reclamation measures. Dry farming techniques such as erosion control, soil fertility enhancement, snow retention, proper crop rotation, and shelterbelt planting are receiving particular promotion as cheaper, more effective, and less environmentally harmful means of increasing agricultural production (15).

Nevertheless, the final guidelines for the 12th Five Year Plan 1986-1990) schedule the irrigated zone to grow by 3.3 million hectares from its 1985 level of 20 million ha - an increase of 14% (16, p. 245;17, p. 47). The long-term reclamation program (to the year 2000), which was approved at the October 1984 plenary meeting of the Communist Party, and, as yet, has not been rescinded, projected irrigation to reach as much as 32 million ha by the end of the century (18). Given

the de-emphasis of irrigation by the Gorbachev regime, the Five Year Plan target will not be met and it is highly unlikely that irrigation in the year 2000 will be anywhere near 32 million ha. However, the momentum of existing investment and project commitment as well as the vast reclamation planning and construction infrastructure will power the growth of irrigation, although at a considerably slower than previously planned pace, for at least another decade.

2.2. Distribution and Use of Irrigated Lands

Central Asia is the most important region of irrigation in the USSR. Irrigation has been a mainstay of agriculture in Central Asia for thousands of years (19). Archaeological research has unearthed ancient irrigation systems along and between the Syrdar'ya and Amudar'ya rivers that provided water to several million ha beginning some 3500 years ago (20). Since the consolidation of Soviet power in Central Asia in the early 1920's, irrigation has steadily expanded. By 1984 (the most recent year for which detailed irrigation data for both the Central Asian republics and the two oblasts of Kazakhstan included in the study region are available), the area served by irrigation facilities operated by state enterprises encompassed 7.2 million ha, 38% of the national total (21, pp. 272-275; 22, pp. 97-100).

The uses of irrigated land in Central Asia in 1984 are shown in tables 4 and 5 and the location of the main irrigation zones on Fig. 4. The Uzbek SSR contained more than half of the irrigated zone, followed far behind by, in order, the Turkmen, Kirgiz, and Tadzhik SSRs and Chimkent and Kzyl-Orda oblasts of the Kazakh SSR. Eighty-seven percent of irrigated lands were under sowings by state enterprises with the residual used for gardens, orchards, and vineyards; hayfields and

TABLE 4. USE OF IRRIGABLE LAND IN CENTRAL ASIA IN 1984 (millions of hectares)

Adminis- trative unit	irri- gable land(1)	% total	irr- gated land	% of irri- gable	idle land	% of irri- gable	sown land	% of irri- gable	gardens, orchards, vineyards	% of irri- gable	hay- fields, pastures	% of irri- gable	private garden plots	% of irri- gable
Uzbek SSR	3.8143	52.65	3.7914	99.40	0.0229	0.60	3.2906	86.27	0.3026	7.93	0.0360	0.94	0.1622	4.25
Kazakh SSR														
Kzyl-Orda oblast	0.2493	3.44	0.2427	97.35	0.0066	2.65	0.2358	94.58	0.0016	0.64	0.0007	0.28	0.0031	1.24
Chimkent oblast	0.4473	6.17	0.4332	96.85	0.0141	3.15	0.3823	85.47	0.0260	5.81	0.0004	0.09	0.0181	4.05
Turkmen SSR	1.0978	15.15	1.0978	100.00	0.0000	0.00	1.0081	91.83	0.0605	5.51	0.0000	0.00	0.0292	2.66
Kirgiz SSR	0.9869	13.62	0.9845	99.76	0.0024	0.24	0.8241	83.50	0.0406	4.11	0.0608	6.16	0.0590	5.98
Tadzhik SSR	0.6484	8.95	0.6391	98.57	0.0093	1.43	0.5265	81.20	0.0631	9.73	0.0117	1.80	0.0378	5.83
total	7.2440	100.00	7.1887	99.24	0.0553	0.76	6.2674	86.52	0.4944	6.82	0.1096	1.51	0.3094	4.27

Compiled and calculated from 21, p. 273 and 22, p. 98.

(1) Land with irrigation facilities.

TABLE 5. CROPS SOWN ON IRRIGATED LAND IN CENTRAL ASIA IN 1984
(millions of hectares)

Admini- strative unit	sown area	grains	technical % sown area	crops (1)	% sown area	potatoes, vegetables, melons	% sown area	fodder crops	% sown area
Uzbek SSR	3.3162	0.4458	13.44	2.0526	61.90	0.1321	3.98	0.6857	20.68
Kazakh SSR									
Kzyl-Orda oblast	0.2380	0.1295	54.41	0.0008	0.34	0.0040	1.68	0.1037	43.57
Chimkent oblast	0.3828	0.0837	21.87	0.1411	36.86	0.0148	3.87	0.1432	37.41
Turkmen SSR	0.9837	0.1387	14.10	0.5456	55.46	0.0416	4.23	0.2578	26.21
Kirgiz SSR	0.8252	0.2512	30.44	0.0890	10.79	0.0291	3.53	0.4559	55.25
Tadzhik SSR	0.5314	0.0565	10.63	0.3134	58.98	0.0216	4.06	0.1399	26.33
total	6.2773	1.1054	17.61	3.1425	50.06	0.2432	3.87	1.7862	28.45

Compiled and calculated from 21, p. 274 and 22, p. 99.

(1) Almost entirely cotton.

FIGURE 4. IRRIGATION IN CENTRAL ASIA

■ Main Irrigation Zones

- — — proposed Siberia-Aral Sea Canal
- — — main irrigation canal
- — — planned extension of Karakum Canal

Major Irrigation Complexes

1. Kara-Kum Canal	5. Golodnaya Steppe
2. Amu Dar'ya Canal	6. Fergana Valley
3. Amu-Bukhara Canal	7. Kzyl-Kum Canal
4. Karshi Steppe	8. Kzyl-Orda Canal

pastures; and for private plots. Technical crops (almost entirely cotton) were most widely planted, followed by fodder crops (grasses, alfalfa, corn for silage), grains (corn, rice, winter wheat, barley), and potatoes, vegetables, and melons. However, there is considerable diversity within the region in terms of relative crop importance according to area planted: cotton is dominant in the Uzbek, Kirgiz, and Tadzhik republics as well as in Chimkent oblast whereas fodder crops and grains are much more important in the Kirgiz SSR and in Kzyl-Orda Oblast.

2.3. Importance of Irrigation

Irrigated agriculture in Central Asia is important to both the national and regional economy. The USSR leads the world in production of cotton with 95% of the nation's fiber raised in Central Asia (23). All the Soviet Union's cotton is irrigated. This is far and away the region's most important crop. In 1986, the Uzbek Republic led the USSR in production of raw cotton (61%), followed by the Turkmen (14%) and Tadzhik (11%) SSRs in second and third places (16, p. 229). Nearly all the raw cotton is ginned here and a portion of this goes to the local textile and clothing industry. But the largest share of the cleaned and pressed fiber is shipped to other parts of the USSR, particularly the Central Region around Moscow, for processing and manufacture (24, pp. 178-180). Central Asian cotton varies considerably in quality with the best grades (long and fine fibers) produced in the southern part of the region (Uzbek, Turkman, and Tadzhik SSRs). A portion of the harvest (713,000 tons or 9% in 1986) is exported from the USSR (16, p. 641).

Thus, cotton production in Central Asia earns foreign exchange for the USSR as well as meeting national need for this commodity. Indeed,

the current heavy emphasis on production in Central Asia is traced directly back to Lenin's may 1918 decree "About the organization of irrigation work in Turkestan" which started work on large-scale irrigation projects here in order to guarantee the USSR's "cotton independence" (25). Cotton growing is fundamentally important to the regional economy contributing to agricultural, light manufacturing, and heavy manufacturing employment (i.e. local industries supplying equipment for cotton growing, harvesting, and processing), providing clothing for indigenous needs, and also bringing in considerable export earnings since in a regional context it functions largely as a "basic industry". Cotton is frequently referred to as "white gold" in terms of its economic importance to Central Asia (26).

Irrigation is also crucial to food and fodder production in Central Asia. Forty percent of the USSR's rice, one-third of its fruit and grapes, and a quarter of its vegetable and melons are grown on irrigated lands here (23). For the four Central Asian republics (Uzbek, Tadzhik, Kirgiz, and Turkmen), in 1986, 78% and 56% of the gross harvest of grains and vegetables, respectively, came from irrigated lands (16, pp. 227,233,248). In the Uzbek SSR, with the largest population and most extensive irrigation in Central Asia, 78% of grain, 52% of vegetable, 68% of potato, and 46% of melon production was from irrigated lands in 1984 (27, pp. 114,138). In this republic, 51% of wheat, 85% of corn, and all of the rice was raised by irrigation in that same year.

Irrigation is clearly of fundamental importance to Central Asia. Reportedly, 90-99% of crop production in the region comes from irrigated lands (28). Yields from irrigated lands are much above those from unirrigated. For example, grain yields from irrigated versus unirri-

gated fields in the four Central Asian republics (Uzbek, Kirgiz, Tadzhik, and Turkmen) averaged 30.7 against 9.8 centners/ha in 1985, a ratio of over 3:1 (21, pp. 208-209, 230-231). Since 1960, the expansion of irrigation in Central Asia has allowed agricultural production to increase by 8.6 billion rubles (in constant 1973 prices) or more than two fold (29). With inclusion of related branches of industry and construction, the joint contribution to the growth of the social product has been 21.5 billion rubles and led to a 3 million increase in employment.

In light of the near certainty of continued rapid population growth in Central Asia for the foreseeable future, rapid expansion of the regional economy to provide employment and of agriculture to provide food is essential. Indeed, inadequate food supplies are a problem now in the region where for a number of basic foodstuffs, per capita consumption is significantly below average national levels (30). In the most populous republic, Uzbekistan, the per capita consumption levels of some basic foodstuffs has dropped in recent years and now lags national levels by 2.2, 2, and 2.5 times for meat, milk, and eggs (31). Problems are especially serious in rural areas of this republic where consumption of meat and meat products by collective farmers is 6 times below rational consumption norms and 7.3 times below medical standards (32). Per capita consumption of milk and milk products by collective farmers is 2.1 and 2.2 times below rational and medical norms.

Although not the only means to meet employment and food needs, irrigation has much to be recommend. It is labor intensive and many operations do not require highly skilled workers as is also true of local industries based upon irrigation such as food processing, cotton

textiles, and clothing manufacture. These are favorable characteristics for the Central Asian situation where the labor force is abundant, growing rapidly and generally unskilled (12, pp. 8-13). Indeed, the working age sector of the population in Central Asia is projected to rise from 14 to 20% of the USSR total between 1980 and 2000. Irrigation's importance to food production in this generally arid region is obvious. Crops can be grown without it on the more humid slopes of the region's foothills and mountains and animals can be raised on natural pastures. But crop yields and meat production are much lower and more variable. To satisfy rapidly growing food needs mainly by stressing these production modes would be difficult to say the least.

Until recently, continued growth of irrigation in Central Asia was assumed. The final version of the 12th Five Year Plan (1986-1990) included directives for increasing the area with irrigation facilities by 8.5%, to 7.2 million ha from 6.7 million ha in 1985, in the four Central Asian republics (Uzbek, Tadzhik, Kirgiz, and Turkmen) (17, pp. 77-84). The long-range reclamation plan also included a significant growth of irrigation. Irrigation in the four Central Asian republics was projected to rise to 8.2-9.0 million ha by the turn of the century - 23-27% above 1985 (18). Because of greater emphasis by the Gorbachev regime on alternative means of increasing agricultural production and, particularly, the dire water supply situation in Central Asia, planned irrigation expansion here has been scaled-back but not halted (28). One authoritative source states the annual increment to irrigation in Central Asia and southern Kazakhstan has been reduced from 160,000 to 50,000 ha. (33).

2.4. Water Use in Irrigation and Its Efficiency

Irrigation is the major user of water in Central Asia. For the region as a whole, it is estimated to have accounted for 90% of withdrawals in 1980 (Table 3). Irrigation is a heavily consumptive use of water (i.e., much of the flow withdrawn is lost to transpiration from plants and evaporation from the soil) and, consequently, intensive irrigation as practiced in Central Asia significantly depletes river flow. In 1980, an estimated 62% of the water withdrawn for irrigation was consumed and 38% constituted return flows. However, consumption is actually a larger share of withdrawals since a significant large portion of water considered return flow (e.g. leakage from canals and runoff from irrigated fields) is subsequently evaporated or transpired.

Many Soviet water management experts have claimed that since the early 1980s the water resources of the two primary drainage basins of Central Asia, the Amu and Syr Dar'ya, are fully utilized owing to heavy withdrawals for irrigation. A recent estimate put total withdrawals for irrigation around 100 km³ in these two river basins with 35 km³ lost to filtration (in main, inter-, and intrafarm distribution networks and at the fields where the water is applied) (25). Of total filtration losses, 14 km³ was ultimately consumptively used, suggesting 21 km³ (35-14), or 21% of withdrawals constituted water returned to rivers and 79 km³ or 79% overall consumptive use. A study analyzing the degree of stress on the water resources of different river basins in the USSR for 1985 and 1986 determined that the Syr Dar'ya and Amu Dar'ya had, respectively, the first and second most strained water balances of any of the USSR's major drainage basins (34). This study placed the ratio of consumptive water use to average annual natural flow at 0.92 and 0.96

for the Syr Dar'ya and Amu Dar'ya, respectively, during 1985 and at 1.00 and 0.97 in 1986, meaning the flow of the two rivers was essentially entirely consumed.

Clearly, Central Asia faces a water crisis which is an irrigation crisis as well. Irrigation is the backbone of the economy but this activity has so depleted local water resources that its continued expansion is jeopardized. The situation is by no means hopeless. A variety of technical and economic-institutional measures are available that, if widely and successfully implemented, could free a certain amount of water for further irrigation and other purposes.

However, water management in Central Asia and its improvement has become a controversial issue. Much criticism of irrigation in Central Asia has been heard in recent years. The most strident opponents, most of whom have no professional training in the water management field, contend that water wastage in irrigation here is enormous and maintain that large amounts of water can be freed without great difficulty or cost that will be sufficient to meet regional needs far into the future (35;36). Water management specialists, on the other hand, are much more cautious, alledging the amount of water that can be freed is much less than the optimists believe, will somewhat alleviate but by no means "solve" regional water problems, and that the process of implementing the measures necessary will be lengthy, costly, and complicated.

There is general agreement that, first and foremost, water use efficiency in irrigation must be improved. Soviet water managers employ a measure known as the efficiency of the irrigation system (koeffitsient polesnogo deystviya orositel'noy sistema), typically referred to as the KPD of the system, to gauge efficiency. Usually, this is calculated as

the ratio of water arriving at the field to water withdrawn at the source ($W[\text{field}]/W[\text{withdrawn}]$) and is simply the product of the efficiencies of the main canal, interfarm canal, and intrafarm canals which bring the water to field side. Thus, if the respective efficiencies for these are 0.9, 0.8, and 0.7, the aggregate KPD would be 0.5 or 50% (38, pp. 108-110).

Accurate calculation of the efficiency of irrigation systems in Central Asia is difficult because of the absence of reliable data on water withdrawals and losses in the delivery networks of the major irrigation systems (34). A commonly cited figure for the Aral Sea basin which has some 97% of the irrigated area in Central Asia is 60% and for systems in the Uzbek Republic which has over 50% of the irrigated area in Central Asia efficiency has been said to range from 52 to 61% (23;38). These figures, characteristic of the early 1980s, indicate that at least 40% of the water withdrawn in Central Asia for irrigation was lost before it reached the fields, primarily to filtration from earthen canals. Based on the 1980 estimate of 121 km³ withdrawn for irrigation (Table 3), this equals 50 km³.

A more accurate measure of water use efficiency in irrigation than the ratio of water arriving at the field to withdrawals is the ratio of water used productively by irrigated crops (i.e. necessary for their growth and survival) to water withdrawn at the source, since it takes into account unproductive losses of water during the irrigation process (e.g. percolation of applied water downward into the ground water zone and surface runoff of water from the field into adjoining lands). However, the latter is considerably more difficult to calculate than the former. Recently, with the growing concern for water management in

Central Asia, attempts have been made to calculate more precisely the structure of water usage in irrigation, including the amount of water used productively by crops. A detailed evaluation has been done for the main irrigation zones of the Amu Dar'ya and Syr Dar'ya basins for 5 year periods running from 1960 to 1980 (39).

This study writes the irrigation water use equation in the following form:

$$W[\text{withdr}] = W[\text{prod}] + W[\text{ret}] + W[\text{unprod}] + W[\text{drain}],$$

where $W[\text{withdr}]$ is water withdrawn at the headworks for irrigation; $W[\text{prod}]$ is the amount of withdrawn water used productively by crops; $W[\text{ret}]$ is the volume of return flow from irrigated areas that re-enters the river network by surface and ground water flow; $W[\text{unprod}]$ is the quantity of withdrawn water that is lost to unproductive evaporation in unirrigated lands within irrigated massives that have ground water lying at shallow depths and in the transit zones that lie between irrigated areas and the rivers from which water is taken and to which it is returned; and $W[\text{drain}]$ is the amount of irrigation water collected in and evaporated from lowlands and irrigation drainage water lakes formed around the periphery of irrigated areas.

According to this research, withdrawals for irrigation rose from 30.8 to 55.5 km³/yr between 1960-65 and 1976-80 in the Amu Dar'ya basin and from 30.7 to 37.6 km³/yr in the Syr Dar'ya basin between 1960-65 and 1976-78. Total withdrawals for the two basins thus rose from 61.5 km³ for the early period to 93.1 during the later. Irrigation withdrawals from the Amu Dar'ya are understated in the study because diversions for this purpose to the Kara-Kum Canal, which grew from 4 to 11 km³/yr between 1960 and 1980, are not included (40).

In spite of this limitation, the study data are very interesting. They show, irrigation withdrawals per hectare rising from 18,700 to 24,500 m³ in the Amu Dar'ya basin between 1960-65 and 1976-80 but dropping in the Syr Dar'ya basin from 15,700 to 14,700 m³/ha between 1960-65 and 1976-78. Combining data for the two basins, withdrawals rose from 17,088 to 19,283 m³/ha from the early 1960s until the late 1970s. Irrigation area and water use data from tables 2 and 3 (section 1.3) indicate 23,216 m³/ha were withdrawn for irrigation from the Kara-Kum Canal in 1980. Including this as part of the Amu Dar'ya basin (since the water comes from that river), slightly lowers the per hectare rate here to 24,300 m³/ha and somewhat raises the rate for the Amu Dar'ya and Syr Dar'ya basins together to 19,682 m³/ha. There is great regional variation in withdrawal rates with the lowest in the Amu Dar'ya basin found in Samarkand Oblast (Zeravshan River basin) (12,600 m³/ha in the late 1970s) and the lowest in the Syr Dar'ya basin found in the Chirchik-Akhangaran- Kelesskiy water management region (located near Tashkent) (10,200 m³/ha in the late 1970s). These contrast sharply with the highest withdrawal rates in the late 1970s of 39,700 and 27,200 in the lower reaches of the Amu Dar'ya and Syr Dar'ya, respectively.

Productive use of irrigation water, W[prod], was 51% in the Amu Dar'ya basin (excluding the Kara-Kum Canal) in the early 1960s but had declined to 41% by the late 1970s. This resulted from major drops in irrigation water use efficiency in all but the upper part of the basin. In the Syr Dar'ya basin, efficiency showed modest improvement over the period, rising from 47 to 49%. The combined basins showed a decline from 49.4 to 44.3% over the period. Thus, for the two basins by the late 1970s, nearly 56% of irrigation water withdrawn (52 out of 93 km³)

did not go for the growth or maintenance of irrigated crops but was "lost" to filtration and evaporation in the irrigation water delivery system before it reached the fields or to unproductive filtration, evaporation, and runoff once it was applied to the fields. However, not all this water was lost to further use. A sizable portion, 13.9 km³ or 25% of withdrawals in the Amu Dar'ya basin and 12.9 km³ or 34% of withdrawals in the Syr Dar'ya basin, constituted return flows (W_{ret}) and re-entered the river network by surface or ground water routes. Thus, water actually lost was not 52 but around 25 km³ (52 minus 26.8) in both basins.

The above analysis suggests that as of the late 1970s there were major opportunities for improving the efficiency of irrigation in Central Asia and by this means freeing sizable amounts of water that could be used to further expand irrigation and for other purposes. Ideally, it would be desirable to raise the KPD of an irrigation system to 1. This is, of course, technically impossible and economically unjustifiable. Soviet water management experts have variously set the average efficiency target for irrigation systems in Central Asia as low as 72% and as high as 80% (33;42;43). This refers to the simpler measure of system efficiency as the ratio of water arriving at field side to withdrawals. Accepting the average KPD here in 1980 as 60% and that withdrawals for irrigation were around 120 km³ (Table 3), raising average system efficiency to 72% and 80% would have allowed irrigating the same area with 20 and 30 km³ lower withdrawals, respectively.

Victor Dukhovnyy, one of the leading experts on irrigation in Central Asia and director of the Central Asian Institute for Irrigation Research (SANIIRI), has attempted to determine a feasible level of

improvement for the more useful measure of efficiency, the ratio of productive use of water by crops to withdrawals (43). He estimates that average withdrawals for irrigation in Central Asia (probably characteristic of the early 1980s) were 16,700 m³/ha with the productive use of water 39% of withdrawals. Modern irrigation systems here withdrew 11,000 m³/ha and had a productive use/withdrawal ratio averaging 59%. Dukhovnyy foresees the possibility to reduce the average withdrawal in the future to 8,000 m³/ha and raise the efficiency to 65%. These water use improvements would be brought about mainly by reducing losses in the water delivery and distribution network (the main, interfarm, and intrafarm canals), at the fields, and through reductions in water used for flushing salt from the fields.

The improvement of irrigation efficiency in Central Asia has been a priority since 1982 when because of the very tight water supply situation strict limits were placed on water consumption (44, p. 22). It has received additional emphasis under the Gorbachev regime as part of the general program for agricultural intensification and has been given the highest priority by N.F. Vasil'yev, the USSR Minister of Reclamation and Water Management, for the 12th Five Year Plan (28;46).

The effort to raise irrigation efficiency in Central Asia has had results. In Uzbekistan by 1986, irrigation canals on 1.3 million ha had been rebuilt, the levelling of fields had been completed on 634,000 ha, and 2.2 million ha had received lesser reclamation improvements (42). As a result, the KPD of irrigation systems in Uzbekistan rose from 48% (at an unspecified earlier date) to 62%. Dukhovnyy states that renovation of old irrigation systems on some 4 million hectares in the Aral Sea basin between 1982 and 1988 raised their average KPD from 48% to 64%

and lowered the average withdrawal rate for them by 5,000 m³/ha (30). He also indicates that average withdrawals in the Central Asian region have dropped from 18,700 m³/ha in 1980 to 13,700 m³/ha in 1986 (44, p. 22). However, 1986 was a very low flow year which necessitated especially strict limits on water use in irrigation and, thus, use of the figure for this year may exaggerate the permanent improvement in withdrawals (34). For example, another source implies a rate of 15,952 m³/ha for 1985 (46).

Nevertheless, it appears that considerable improvement in irrigation efficiency over levels of the late 1970s-early 1980s have already been made in Central Asia. Water withdrawals for irrigation likely peaked during this period at no more than 120 km³ (Table 3). The significant improvements in efficiency since then have allowed around a 20% increase in the irrigated area (from 6.2 million to around 7.4 million ha by 1988) with a decrease in water withdrawals, using Dukhovnyy's figures for average withdrawals per hectare in 1980 and 1986, from 116 to 101 km³. Using Dukhovnyy's 1980 number and the perhaps more realistic figure of 15,952 m³/ha characteristic of 1985, implies a slight increase in withdrawals, from 116 to 118 km³.

Critics of water management and irrigation in Central Asia, and there are many of them, seem to be drawing their data and conclusions about efficiency levels and potential water savings here from the state of affairs characteristic of a decade ago when efficiencies were lower and per hectare withdrawals higher (44, p. 15). Furthermore, they seem to have a simplistic view of the potential for water savings in irrigation systems, equating it to all the water lost enroute to the fields plus that lost during the process of irrigation (i.e., not used

productively by crops). In reality, potential net water savings are considerably less than this. In the first place, even in the most technically sophisticated irrigation systems some water loss in transport from source to fields is unavoidable. Secondly, as the KPD of the delivery system is raised, there are diminishing returns: the cost of each additional increment of saved water rises steeply. Thus, there is economic justification only to increase system efficiency and decrease water losses to a certain point. That is why Soviet water management experts have set 72% to 80% as the goal for improvement of the average KPD for irrigation water delivery systems in Central Asia. Finally, as explained earlier, only a portion of the water nominally lost in irrigation is actually removed from further use. Part of the water that filters from canals and runs off or infiltrates downward from irrigated fields returns by surface and subsurface routes to the rivers from which the water was originally taken. These return flows are substantial in Central Asia, amounting in the early 1980s to more than 20 km³, and estimates of potential savings must be adjusted downward accordingly (8).

No one questions that water use efficiency in Central Asia can be further improved (47). Using Dukhovnyy's figures for 1986 of 13,700 m³/hectare as the average current withdrawal and 8,000 m³/ha as a target, suggests it might be possible to irrigate 7.4 million ha with withdrawals around 60 km³ - a saving of some 43 km³. This appears to imply much water could be freed for expansion of irrigation and other purposes. However, with such an efficiency improvement, consumptive use of water would become a much larger share of withdrawals and return flows significantly diminish, so that the net gain of water would be

much less. Furthermore, lowering withdrawals to 8,000 m³/ha may be too optimistic a goal. Other experts have set 10,000 m³/ha as the minimum necessary average consumptive use figure for irrigation in the Aral Sea basin (48). This refers to water used at the field and doesn't delivery network losses. Assuming an average delivery system KPD of 80% and that all the water arriving at field side was used productively (no wastage), which is unlikely, would imply an average withdrawal rate of 12,500 m³/ha - only 1200 m³/ha lower than in 1986. This is close to a recent estimate that withdrawals in the Syr Dar'ya basin need not exceed 12,000 m³/ha and in the Amu Dar'ya 13,600 m³/ha (49). Assuming 12,500 m³/ha as the lowest feasible withdrawal rate would mean that 7.4 million ha could be irrigated with only 8 km³ lower withdrawals compared to the 1986 rate (93 vs 101 km³).

Soviet water management experts forecast modest savings from further irrigation efficiency improvement measures in Central Asia compared to the level of aggregate withdrawals for this purpose. Dukhovnyy and Razakov estimate that a major effort could reduce withdrawals in the Aral Sea basin by 18 km³/yr by 2000, even assuming modest expansion of irrigated lands to 8.4 million hectares, (30). But taking into account the accompanying reduction of return flows, the net addition to water supplies would be only 10 km³ - only 10% of current irrigation withdrawals. The results of other analysis are not markedly different. A. Rafikov, a water management expert from the Geography section of the Uzbek Academy of Sciences, sees water savings in the Aral Sea basin of 12 km³, assuming a raising of the average KPD for irrigation water delivery systems to 78-80% (42).

A blue-ribbon commission for the study of the nation's water

resources, headed by Vice-President of the Academy of Sciences, V.A. Kaptyug, reported in late 1987 that reconstruction of irrigation systems in Central Asia along with other refinements of irrigation technology would only save 10 out of 100 km³ withdrawn for this purpose (44, p. 7). Finally, N.R. Khamrayev of the Uzbek Council for the Study of Productive forces, has recently estimated that 60 km³ are lost in the Aral Sea basin: 40 km³ to evaporation from irrigated lands, 15 to 20 km³ to evaporation from river flood plains and hollows flooded by drainage from irrigated zones and in collector-drainage systems and other discharges, and 2 km³ from reservoir evaporation (41). However, only 9 out of the 40 km³ is considered unproductive evaporation whereas it is feasible to reuse about 10 km³ of collector-drainage water. Thus, maximum water savings from reducing unproductive evaporation and reusing irrigation drainage water are around 20 km³. Actually, they would be somewhat less since some of the 10 km³ of collector-drainage water already constitutes return flows to rivers.

2.5. Irrigation Water Use Improvement Measures

2.51. Reconstruction of old systems. There are a variety of measures and strategies that are or could be used to improve the water use situation in Central Asia. Rebuilding of older irrigation systems to reduce water losses from them has received and continues to receive the greatest stress. Given the long history of irrigation development here, a larger share of the irrigated area is served by antiquated and inefficient irrigation systems than in any other part of the USSR. Irrigation facilities on 4 million hectares were built prior to 1950, with a number of complexes dating from prerevolutionary times (30). These systems were built with earthen canals, crude water withdrawal

facilities, and had infrequent drainage channels of an open (surface) type. Consequently, they suffer from low water use efficiencies.

To provide the large funds required for reconstruction of old systems, the introduction of new irrigated lands is being slowed in Central Asia and the freed capital devoted to the renovation effort. Reconstruction of irrigation systems nationally now is reported to be receiving 45% of all investment in reclamation compared to 18% in the 11th Five Year Plan (1981-85) whereas the figure rises to 70% in Central Asia (25;28;30). In the Uzbek SSR a minimum of 100,000 ha/yr are to be renovated (38). This program, it is claimed, will result in the bringing up to modern standards of all old irrigation systems in Central Asia by the early 1990s (28).

Reconstruction involves implementation of a complex of measures. Of fundamental importance is the reduction of filtration and evaporation from main and distributary canals. A recent estimate is that 35 km³ are lost to the former from irrigation canals in the basins of the Amu and Syr Dar'ya (28). Filtration can be reduced by lining earthen canals, extensive in Central Asia, with concrete, clay, polymer films or plastic sheeting, and various chemical coatings whereas both types of losses can be diminished by substituting flumes and pipes for canals where feasible. Dramatic efficiency improvements are possible. For example, concrete lining of canals reduces filtration losses 85-90%, flumes can reduce water losses compared to dirt channels up to 95% and even simple clay coatings diminish leakage by 50-70% (50, p. 68).

However, lining and other anti-filtration measures are not cheap. Concreting medium size canals in Central Asia costs 250,000-400,000 rubles/km (51). Considering there are 165,000 km of interfarm irri-

gation canals in only the Uzbek SSR, long stretches of which are still unlined, gives some idea of the magnitude of the task (47). Counter filtration measures, in general, are reported to run 800-2000 rubles/ha (43). Because of the high cost and also a shortage of concrete, a universal policy of lining earthen canals is not considered economic in Central Asia (51). Small and medium capacity canals with KPDs of 60-70% should in most cases be lined. But medium and large capacity canals with little slope and KPDs above 70% have such long capital cost recovery periods (18-30 years) that their lining is not normally justified. Filtration and evaporation can also be reduced by consolidation (shortening) of both the interfarm and intrafarm water distribution networks and this is being pursued as part of the reconstruction effort (41).

Another very important aspect of the reconstruction effort is the installation or upgrading of collector-drainage facilities. These are necessary to remove excess water from fields in order to maintain the water table level (around 3 meters below the surface) and to prevent waterlogging and soil salinization caused by the deposition of salts as saline ground water evaporates from the surface (52, pp. 114-127). Most of the older irrigation systems in Central Asia either lack engineered drainage networks entirely or have crude open channels, frequently choked with weeds, that do not effectively remove water. Technically modern systems can be of a closed horizontal or vertical character. The former consist of perforated metal or plastic pipes laid in a regular pattern beneath the surface of the field. The latter are wells spaced at even intervals over the field. Excess soil and ground water collects in the pipes and wells and is reused for irrigation and

soil flushing or conveyed away from the irrigated zone. Where vertical drainage is employed, pumps are required to lift the water from the wells to the surface.

Proper drainage is not only essential in preventing waterlogging and soil salinization but directly contributes to the lowering of water usage by greatly reducing the amount of water necessary to flush excess salts from the soil. In some parts of Central Asia, the volume of water used for flushing soils during the spring is greater than that expended during the subsequent growing season (43). By 1985, 22%, of irrigated lands in Uzbekistan, 23% in the Tadzhik SSR, and less than 5% in the Turkmen and Kirgiz republics possessed modern collector-drainage facilities. However, a major campaign has been mounted to correct the problem. In the Uzbek SSR alone, 26,000 km of surface drainage pipe is to be laid over 390,000 ha of irrigated lands in the 12th Five Year Plan (1986-1990) (47).

2.52. Improvements in water application technologies. Upgrading methods of water application at the field is an essential element for raising the efficiency of water use. In the early 1980s, 98% of irrigation in Central Asia was by surface methods, where water flows from a canal or flume directly onto the fields (52, pp. 16-27). Application of water into furrows is the most widely used surface technique in Central Asia; other methods are the complete shallow flooding of levelled and walled sectors (known as liman irrigation and used for rice cultivation), and the flooding of flat-bottomed strips. The efficiency of furrow irrigation is generally low: more water is delivered than is needed by crops and, consequently, much is lost to filtration, unproductive evaporation, and end discharges. However, its

efficiency can be raised substantially through the use of automation and mechanization of water deliveries in combination with the use of flumes, siphons, hoses, and movable and rigid pipes to provide more precise control of the volume and distribution of supplied (33;43). Dukhovnyy estimates that the KPD at the field of furrow irrigation (the ratio of the design application norm to the actual amount of water applied) in Central Asia could be raised from an average figure of 62-65% to 82% by implementation of these measures (43). Precise levelling of fields, often utilizing laser technology, to ensure the even distribution of applied water is also an important means of improving the efficiency of furrow as well as other types of surface irrigation (52, p.19). Experts believed it possible to cut unproductive losses at the field associated with surface methods of irrigation from their present 30% to 16% (i.e., to raise the KPD at the field from 70% to 84%) by 2010 (33).

There are more modern, efficient irrigation technologies than surface application such as sprinklers, drip, and intersoil whose use could be expanded to some degree in Central Asia. Sprinkler irrigation has expanded rapidly in the USSR and was used on 43% of irrigated lands in 1986 (28). It has advantages over surface methods such as ease of mechanization and automation, generally higher efficiencies of water use, high labor productivity, more even water application rates, less land loss to water delivery facilities (e.g. canals, flumes, pipes, ditches, furrows), and can be used on somewhat uneven terrains (52, pp. 9-15,47-92). On the other hand, sprinkler systems are usually more expensive and energy consumptive than surface and are not adapted for flushing salts. Also, the efficiency of sprinklers is highest (KPD at the field from 75-85%) where relative humidities are reasonably high

(55-65%), such as the dry steppe of southern and southeast European Russia (43). Consequently, sprinklers are used on a limited basis in Central Asia where obtaining the energy to run them can be difficult, the need to flush irrigated soils to control salinization is widespread, and, most importantly, atmospheric humidity is typically 30-45%, limiting the maximum KPD at the field to 65-70%. Innovative sprinkling methods adapted for desert regions hold promise such as so-called near surface application where the sprinkler heads are mounted as close to the ground as possible significantly reducing evaporative losses and raising the KPD to 80% (52, pp. 88-93).

Drip irrigation applies water at the base of the plant whereas intersoil delivers it to the root zone (52, pp. 97-113). They can markedly reduce water use compared to more traditional irrigation methods because of the ability to provide the right amount of water where it can best be utilized by the crop. The basic problem with intersoil irrigation is the high capital cost of laying the water delivery pipes below the fields and its inability to prevent soil salinization. Drip irrigation is costly and feasible only for high-value row crops (grapes, fruit, and vegetables). Its water savings are 20% to 30% compared to surface methods. It is to be widely employed on gardens and vineyards planted on sloping lands of the piedmont zones in Central Asia (33). Because of the limitations of sprinkling, intersoil, drip and other newer methods, surface irrigation will remain the most important water application technology in Central Asia (33;43).

Besides saving water, the various irrigation improvements discussed above also contribute to better soil and crop growth conditions contributing to increased yields and to the reduced loss of irrigated land

owing to deterioration beyond the point where it is economically usable. Reconstruction allows better control of water applications rates so that they are more attuned in volume and timing to plant growth needs. It also provides effective means for draining excess water from the fields. More finely tuned water application methods and effective drainage aid in combatting the widespread, serious problems of erosion, waterlogging, leaching and secondary salinization typical of the older irrigated zones in Central Asia. (53;54). From 40 to 50% of irrigated land in Central Asia suffers from salinization with yields in Uzbekistan reduced 20-25% from this (37, p. 36;55).

2.53. Automation, computerization, and telemechanization. Automation, computerization, and telemechanization of large irrigation systems is being promoted as one of the most important means of substantially improving water use efficiency (38;56-59). The basis of the program is the installation of water measurement and regulating devices along main and distributary canals to provide accurate data on and control over the amount of water delivered and used in irrigation (51). Such information is still woefully inadequate; rectification of this deficiency is considered fundamental to improved water management planning in the future (34). The water measurement and control equipment transmits data to and is directed by a central facility. The most sophisticated systems employ mainframe, mini, and micro computers to process meteorological, hydrological, and crop information via mathematical models and provide a set of operating instructions for the complex.

Irrigation systems in Central Asia are being integrated into centralized management. In Kirgizia, 21 irrigation systems with 400 km

of main and distributary canals have been automated. Plans are to add an additional 1200 km of canals in the near future with attendant water savings (compared to pre-existing conditions) of 15 to 20%. In Uzbekistan, 40 telemechanically operated and 25 remotely controlled water management systems are in use. The largest irrigation facilities in the republic, which distribute a total of 20 km³ of water, are automated. However, they account for only 40% of the 50 km³ used for irrigation in the republic. The process of combining separate, partially automated systems into fully integrated basin-wide systems of water management (ASUB = avtomatizirovanniye sistemy upravleniya vodnymi resursami basseynov rek) is underway here and, when completed, will allow the automated distribution of water over an area of more than 1 million ha, equal to about one fourth of the land under irrigation in 1986. By 1990, it is hoped to automate the operation of all large reservoirs, serving 40 irrigation systems, in the republic.

A more comprehensive approach to the management of water resources in Central Asia is to establish in Minvodhoz USSR directorates for the water management complexes of the Syr and Amu Dar'ya basins (33;38). These would have responsibility for interrepublic and intersector allocation of river flow, determination of the water use regime of reservoirs, and technical operation of all water withdrawal facilities and pumping stations. The systems would gather and process information on estimated water resources and water needs within the basins, determine an allocation plan for water use for a year (using 10 day time steps), control the distribution of water, and keep track of actual water allocations, uses, and conditions (pollution, salinity levels, etc.). There would be heavy reliance on hydrologic, meteorologic, water use and

other data for inputs to sets of hierarchically linked simulation and optimization models to determine the optimal allocation of water. The gathering and processing of data would be automated and computerized and there would be "feedback" to the system from the monitoring of water use and conditions within the basins.

Such systems would permit a more optimal distribution and rational utilization of water resources as well as aid in the resolution of problems of interrepublic water distribution taking into account the interests of all water users. Soviet water management experts reported at the Sixth World Water Congress in June 1988 that the major principles of basin management for the Syr Dar'ya and Amu Dar'ya were worked out in 1983-85 and that separate water management authorities were created for each basin, subordinated to Minvodkhoz USSR, in 1988 (33). The management system for the Syr Dar'ya is evidently operational but the status of the Amu Dar'ya system is unclear.

Several other advanced technologies are closely linked with the implementation of complex, basin-wide water management systems in Central Asia. One of the most promising is "programmed harvests." It involves the use of linked mathematical simulation models (optimization models) for determining the appropriate operation of a set of irrigation systems based on input information about the mix of crops and "norms" of crop water requirements, soil characteristics (e.g. fertility, structure, moisture), meteorological conditions, the designs and capacities of irrigation facilities, and operational objectives (e.g. yields) and constraints (e.g. water availability and distribution limitations) (57;60). Efforts are also underway to determine appropriate irrigation norms and regimes for some parts of Central Asia based on local

climatic, soil, hydrologic, and geomorphic conditions (61). The development of a comprehensive set of differential irrigation criteria for Central Asia as a whole, taking account of variations in natural conditions, would greatly facilitate basin-wide water management and contribute to water savings in irrigation. Finally, aerial and space photography and satellite imagery is also being used, for example, to study soil and relief conditions over large areas as an aid in choosing the most appropriate sites for new irrigation facilities (62;63).

2.54. Other technical measures. There are other technical measures available to improve water use in Central Asia. A shift from high water consuming crops such as cotton and rice (withdrawals for the latter in the lower course of the Syr Dar'ya can reach 40,000 m³/ha) to lower such as vegetables and fodder plantings (corn and alfalfa) would not only lower per hectare withdrawals but contribute to the direly needed improvement of regional food crop and milk and meat supplies (51). An added advantage is higher profits: corn and other fodder crops give 130 rubles/ha in milk and meat versus 30-50 for rice (64). This shift is is going forward in Central Asia (31;65).

Cotton growing, in particular, is under severe criticism not only because of its high water requirements but owing to its role in soil deterioration, the scandals arising out of the corruption in the cotton production industry, and the conscious exaggeration of harvests in Uzbekistan during the late 1970s and early 1980s (66;67;68). Nevertheless, cotton will continue to be the dominant irrigated crop in Central Asia for the foreseeable future because of its great economic importance to the region, particularly to Uzbekistan (31). However, an optimum production model constructed for Uzbekistan by the Central Asian Re-

search Institute for Irrigation indicates the area planted to cotton should decrease from 62% of the irrigated sown area in 1986 to 37% (64). Efforts are also underway to raise yields of cotton, mainly by instituting and enforcing more frequent rotations with alfalfa to maintain soil fertility. This will indirectly contribute to lessening water use by raising the yield per cubic meter of applied water. Emphasis is also being placed on raising yields of irrigated food and fodder crops (e.g. rice, vegetables, and corn) which are very low (31;69).

Attention is also being given to research and refinement of irrigation norms (i.e., standards as to how much water should be applied to different crops) to adjust them more precisely to actual crop water consumption requirements under complex and variable environmental conditions of soil moisture, precipitation, air temperature, and relative humidity (43). Established norms, which are frequently and significantly exceeded in Central Asia, are believed above what is optimal for crop growth. A related suggestion to lower application rates is to switch to night irrigation thereby lowering evaporative losses (41). This, is contingent, however, on mechanization and automation of irrigation systems.

2.55. New sources of water. There are opportunities to develop new or currently underutilized water resources for irrigation in Central Asia. Ground water supplies are huge but little used. On the other hand, a major expansion of ground water pumping faces formidable obstacles. Much of the ground water is strongly mineralized which prevents employment for irrigation. The largest reserves also lie at great depth which necessitates expensive deep drilling and extraction costs. Furthermore, since the recharge rate for aquifers is very slow

and near surface ground water deposits are frequently hydraulically linked to rivers, heavy pumping inevitably leads to lowered ground water tables and reduced river flow. Consequently, the upper limit for exploitation of this resource may be only 17 km³/yr (Table 2).

A larger share of irrigation drainage water could be reused. The volume of it in the early 1980s was estimated at around 34 km³/year in the Aral Sea basin (8). Approximately 21 km³ (60%) returned to rivers from which withdrawn and was reused. The remaining 13 km³ ran onto fallow lands (pereloga) or into hollows adjacent to irrigated lands forming lakes. This water was transpired from noncrop plants or evaporated from the soil and lakes. Losses could be reduced by consolidating small and separated irrigation areas to reduce the amount of pereloga, by planting crops on the pereloga, and by installing interception networks around irrigated areas to collect the drainage water for reuse for irrigation or discharge to rivers (41). However, a substantial portion of the drainage water has salinities so high from leached salts that without dilution it would severely damage most crops (70). Drainage water with salinities up to 3 grams/liter could be used for irrigating rice, a salt-tolerant crop (41). It should again be stressed that the programs to improve the efficiency of irrigation water use have reduced and will continue to reduce the amount of drainage water available for reuse.

Seasonal and multiyear regulation of river flow via reservoirs allows storage of water during high flow period for use in low flow seasons and years and increases usable water resources. Reservoirs completed or under construction in the basins of the Amu and Syr Dar'ya have a usable storage capacity of 55 km³ (71, p. 118). When finished

these will allow the increase of available water resources from these rivers, compared to natural conditions, by 15 km³ during low flow years (90% flow exceedance probability, occurring, on average, one in ten years) (46). A chronic problem is the delayed completion of these. Furthermore, large reservoirs, particularly those built in the desert plains of Central Asia, have a number of disadvantages: they flood extensive areas; lose large amounts of water via evaporation, transpiration from water loving plants growing on their banks, and filtration; raise ground water levels of adjacent territory, leading to waterlogging and soil salinization; and markedly reduce the downstream flow of water, sediments, and nutrients with harmful environmental consequences, particularly for the deltas of the Amudar'ya and Syrdar'ya (72). One means of reducing evaporative, transpirative, and filtration losses from reservoirs in Central Asia is to accumulate and keep the maximum amount of water possible in deep mountain reservoirs with high ratios of volume to surface area and low rates of evaporation and filtration (41).

Finally two other means of increasing usable water resources in Central Asia deserve mention. First, Central Asia has many small, ephemeral streams as well as takyr (clay pan) basins that are dry most of the year but collect water after heavy rains. These could be exploited for the development of small-scale irrigation. Secondly, evaporation and transpiration from floodplains is still significant along the middle and upper course of rivers where their flows have not been so reduced by irrigation withdrawals. These losses could be reduced by engineering measures such as diking, bed straightening, and channelization (41).

2.56. Institutional and economic measures. Economic and institutional changes could contribute to the improvement of irrigation, including water use efficiency in Central Asia. The advent of the Gorbachev regime in 1985 has led to a new and fundamental emphasis on these under the rubrics of perestroika (restructuring) and uskoreniya (acceleration) as stimuli to improving the performance of all economic sectors. The main components of the program (khozraschyot - economic or balance sheet accounting, samookupaemost' - self capital financing, samofinansirovaniye - self-financing, and khozyaystvennaya samostoyatel'nost' - economic independence) are being introduced in the construction and operational branches of irrigated agriculture as they are in other sectors of the economy (28;45;73). The transition to khozraschyot and self-financing is supposed to be completed throughout the Soviet economy in 1989 (74).

These reforms are intended to improve performance by giving production organizations more control over their operations as well as more responsibility for the success or failure of them. In irrigation, it is hoped they will combat and alleviate a formidable array of serious problems: lagging and poor quality construction, shoddy repair work, low labor productivity, hoarding and squandering of capital resources, lack of labor discipline and low morale among workers, an overgrown and excessively bureaucratic administrative structure, etc. (28;47;75). These deficiencies have led to chronic under fulfillment of crop production plans, low and declining returns on investment, poor crop yields, excessive use of water, and large amounts of land with irrigation facilities that cannot or are not utilized. Central Asia has been singled out as being especially seriously afflicted by these

difficulties.

Specific efforts are being made to deal with these problems in Central Asia. A serious difficulty is the division of operational and repair/maintenance services for irrigation systems among a number of different organizations which has led to a lack of equipment and financial resources, inadequately trained personnel, and poor cooperation (76). A proposal to improve this situation in Uzbekistan is to consolidate multiple operational and repair organizations in each district (rayon) into one service - the district repair-operational association for reclamation and water management (77). This agency would be responsible for planning and establishing technical policies as well as operating and carrying out repair/maintenance work for irrigation systems under its jurisdiction.

Of all the economic/institutional changes being proposed to make the use of water in irrigation more rational, water pricing holds the greatest promise. Although a differential tariff (based on the adequacy of a region's water supplies) has been levied on water withdrawn by industry from surface sources (lakes and rivers) since 1982 and from ground water since 1984, water used for domestic and agricultural purposes is provided at no charge (78-80). Since 1985, arguments have been repeatedly published, mainly by critics of irrigation, that the best way to encourage efficient water use in this sector is to establish a meaningful charge for water use (78;81;82). The Ministry of Reclamation and Water Management (Minvodkhoz) and its director, N.F. Vasil'yev, were originally opposed or lukewarm at best to this idea, although some water management experts familiar with Central Asian problems, such as Dukhovnyy, favored it (43;79;81). However, it is an approach "whose

time has come" and the water management apparatus has accepted the inevitability of some kind of water tariff on irrigation.

Charges for irrigation water are not new in the USSR. In the 1920s, payments were levied to cover operating costs of water delivery systems and organizations (83;84). These payments were abolished with collectivisation in the early 1930s. Tariffs for irrigation water were reinstituted in 1949-1957 to improve water use and accelerate the tempo of irrigation system modernization. These covered operating expenses of water delivery systems but had no provisions for capital amortization or profit. In Central Asia, a fee of 0.075 kopecks/m³ was levied on water used directly for irrigation and 0.035 kopecks/m³ for water employed in flushing soils of salt. The payments were abolished in 1957 because of deleterious effects on economically weak farms.

The most recent experiment with water pricing for irrigation has been in effect in the Kirgiz SSR since 1977. The system has promoted more efficient water use and lowered waste, improved water accounting (i.e., keeping track of how much water is used in irrigation), contributed to better yields, accelerated the modernization of systems, and increased the importance of the water-use plan. Nevertheless, Soviet water management experts see fundamental flaws in the system. First of all, the tariffs cover only part of operating costs and none of capital expenses. Secondly, collective and state farms (Kolkhozy and Sovkhozy) were essentially excluded from the beneficial effects of water pricing since funds to cover water costs incurred by them were provided by the water management delivery agencies of the Kirgiz Minvodkhoz. Thus, there was little stimulus for more careful water use by the final consumer and the cost of water was not reflected in the price of

agricultural products these farms produced. Finally, the requirement that payments for water use above established norms would come from the farms' budgets backfired: rather than inducing more careful water use it stimulated agricultural enterprises to raise norms since payments for water use within norms would be covered by outside funds.

The system for pricing irrigation water now under discussion and debate is more comprehensive and far-reaching than past efforts (84). It is an attempt to introduce an automatic mechanism for implementation of the principles of economic accounting in irrigated agriculture. The basic goals are to encourage careful management of water by the organizations providing it to the farms, thrifty and appropriate use of water delivered to the farms, and cooperation between supplier and consumer to achieve these aims. It has been proposed that a rational water pricing system should include the following. (1) Full payment for water from the budgets of water users (i.e., no outside subsidies or supplements) to encourage appropriate behavior. (2) Regionally differentiated water prices, which take into account natural-climatic variability and the types of water use. (3) Inclusion of two elements in water prices: the cost of withdrawing water from sources and the cost of delivering water to users (state farms and collective farms). (4) Payment by irrigation water management agencies, which are responsible for withdrawing and delivering water to farms, for all water withdrawn according to prices established by the USSR State Committee on Prices. (5) Payment by farms receiving water to the water supplying organizations only for the volume delivered to them, with this tariff taking account of the cost of water withdrawal from the source. (6) Formulation of water tariffs for irrigation based not only on actual costs of

withdrawing and delivering water but on norms to be established for this. (7) Inclusion of profit (8% of costs has been suggested) in the price of water delivered to farms to ensure the water management agency providing it sufficient operating funds to survive under full implementation of economic accounting.

Although introduction of water prices for irrigation based on the above principles would do much to improve water use efficiency, there are attendant problems (83). Water prices levied on weak farms could worsen their economic situation and, in turn, adversely affect management organizations working under full khozraschyot and dependent on payments from the farms for water delivered for their financial survival. Water payments must be based on accurate measurements of supplied water but irrigation systems, particularly older ones in Central Asia, lack apparatus for this. To equip both interfarm and intrafarm irrigation nets with adequate facilities could easily cost 250 million rubles. Also, much greater record keeping on water usage than presently is done will be needed along with a 6,000 to 7,000 increase in personnel for this purpose. Finally, if the water tariff system is to work, prices paid by the government for agricultural products from irrigated lands must be adjusted upward to reflect the contribution of water costs in the product cost. This could substantially raise food prices, already a contentious issue in the Soviet Union. It has been suggested the government use the estimated one billion rubles saved by the transfer of irrigation water management agencies onto full economic accounting, under which they would be self-financing and not dependent on state subsidies, to raise prices for agricultural products purchased from irrigated farms.

Recognition of the above problems has led the Soviet government to introduce water pricing for irrigation on an experimental basis in three oblasts during 1988-89: Saratov (Russian Republic), Tashkent (Uzbekistan), and Dnepropetrovskiy (the Ukraine) (83). Based on this experience, it is planned to implement water charges in irrigation nationwide in 1991 (85). However, for a time after their introduction nationally, there will likely be provisions to alleviate some of the harsher consequences for water management organizations and irrigated farms such as bonuses, tied to performance, for economically weak farms and a gradual increase of water prices toward a full recovery cost level (84).

2.6. The Future of Irrigation

Irrigation in Central Asia faces an uncertain future. It is the major contributor by far to consumptive use here which has already placed severe strains on usable water resources. Soviet water management experts claim that the water resources of the Amu Dar'ya and Syr Dar'ya, constituting 90% of surface flow in Central Asia, are fully utilized and that further expansion of the irrigated area is only possible through "freeing" of water via reconstruction of existing irrigation systems to improve their efficiency (25). Irrigation technology has historically been low in Central Asia and water wasted on a grand scale. However, major efforts to raise water use efficiency have been made during the 1980s which have substantially lowered average withdrawals per hectare. Improvement measures are continuing such as renovation of older facilities, automation, computerization, and telemechanization of water management systems, employment of simulation and optimization modelling for decision making, introduction of modern

methods of irrigation, shifts from more to less water intensive crops, and refinement of irrigation norms for crops. These not only save water but alleviate secondary salinization and waterlogging and raise yields on irrigated lands.

Usable water resources can be increased somewhat more by further regulation of major rivers as well as greater use of ground water, irrigation drainage, and ephemeral streams and playa lakes forming in takyr basins. Economic and institutional change to enhance management control and responsibility at the local level is also likely to stimulate more efficient water use in irrigation. The most important economic lever to encourage careful and appropriate water usage would be institution of a meaningful pricing structure for irrigation water. The ultimate success of programs to save water in Central Asia is, however, open to question. Past campaigns to solve agricultural problems, launched with high hopes and much fanfare, such as Khrushchev's Virgin Lands and corn programs and Brezhnev's reclamation and nonchernozem development efforts fell far short of expectations. The current attempts to correct problems in the water management field are better founded, more flexible and attuned to local conditions and needs, incorporate the use of economic tools to a much greater degree, and are less dogmatic than those of the past.

Nevertheless, results still may be ultimately disappointing. Complaints about failings and deficiencies in the programs to improve irrigated agriculture and save water in Central Asia continue to be frequent (31;47;65;75). Low crop yields, failures to implement the decision to put more emphasis on food and fodder crops and less on rice and cotton, poor performance of maintenance and repair organizations,

slow introduction of water-saving technologies, lagging installation and reconstruction of drainage facilities, above norm water withdrawals, and continuing soil salinization and waterlogging are among the more serious issues.

Another threat to the success of water use improvement efforts is that they will be carried out mindlessly and uniformly, so typical of national campaigns in the Soviet Union in the past. For example, the universal lining of earthen canals in Central Asia would not only be a horrendous waste of money but could be damaging as well (5). In some localities, percolation of water from earthen irrigation canals plays a beneficial role by, for example, promoting the dense growth of canal side vegetation, thereby providing a barrier to the encroachment of sand dunes, and by serving as a buffer against the penetration of naturally saline ground water into irrigated fields. Soviet irrigation experts are warning about the folly of "universal" solutions to water management problems in Central Asia, cautioning that improvement strategies must be tailored to local conditions, but if their advice will be heeded is an open question.

Finally, the program for water use improvement in irrigation will not be cheap. Rigorous and detailed cost analyses are not available but some estimates have been made. The bill for a comprehensive program to modernize irrigation in the Aral Sea basin has been set as high as 95 billion rubles (86). Several experts have set the cost of saving one cubic kilometer of irrigation water at 2-3.5 billion rubles (48;87). Thus, the "low" estimate of future water savings here (10 km³) could run 20-35 billion rubles. However, this does not include the costs associated with loss of agricultural production from irrigated lands under-

going renovation. That the Soviet government is willing to make the very large additional investments for substantial further improvements in water use efficiency in Central Asia is far from a certainty. Thus, a Central Asian water management official recently complained that after the decision to reorient irrigation construction agencies from developing new lands to renovating old, inefficient systems, Gosplan (the State Planning Agency) slashed 200 million rubles from the budget of agencies assigned this task even though reconstruction is more expensive than new development (87).

Forecasting the limit of expansion of irrigation in Central Asia based on local water resources and in conjunction with implementation of various water use efficiency measures is treacherous. Beyond the question of how successful improvement measures will be, one would need estimates of the efficiencies of water delivery and application systems (KPDs of the system and of the field), of crop irrigation norms, of the proportion of runoff water from irrigated fields that would (or could) be reused for irrigation, of the efficiencies of use of reused water, of the amount of local water resources that must be reserved for other uses (industry, municipal, instream uses), and of the contribution of ground water and further regulation of river flow to increasing usable water supplies.

Nevertheless, some estimates by Soviet water management experts are available. As indicated in section 2.4, Dukhovnyy and Razakov believe that an intensive irrigation system reconstruction effort would allow an expansion of irrigation in the Aral Sea basin to 8.4 million ha by 2000 (30). This would represent about a 17% growth over the current irrigated area here (7.2 million ha) while at the same time freeing a net 10

km³ The 10 km³ could be used for further irrigation expansion but most of it would probably need to go for growing municipal and industrial needs, assuming it was of suitable quality.

A much more detailed exposition of the possibilities for increasing irrigation in the Aral Sea basin has been made by water management experts from the Institute of Water Problems of the Academy of Sciences (46). They first present annual flow data for the Amu Dar'ya and Syr Dar'ya for 1980-86 which show nearly the entire flow of these rivers was consumed during this period. The maximum flow of the Amu dar'ya at the head of its delta was 8.6 and the minimum 0.5 km³ in 1980 and 1986, respectively. Analogous figures for the Syr Dar'ya were 2.81 and 0.34 in 1981 and 1983. They assume usable annual average water resources of the Aral Sea basin (delimited the same as for this study, see Fig. 3 and Table 2) can be increased to 127.6 km³, of which 119.4 and 8.2 km³ will come from surface flow and ground water, respectively.

Four scenarios (variants) of irrigation development were formulated for the Amu Dar'ya. For each scenario, four future stages of irrigation expansion and improved water use efficiency were calculated. The first stage is characteristic of the 1990-95 period but the time frames for the remaining three are not specified. Only partial information is given for the first variant for the Amu Dar'ya. At the 3rd stage, irrigation would grow from 3.6 million ha in 1985 to 6.7 million in conjunction with renovation of old irrigation systems on 2 million ha. This scenario is characterized by an accelerated pace of irrigation expansion and a somewhat lagging tempo of reconstruction. More details are provided for variants II to IV. Each allows a growth of the irrigated area owing to water gained by reconstruction of old irrigation

systems over an area of 2.2 million ha (with delivery system efficiencies to be raised from an average of 55% to 78%), by greater use of ground water not associated with river flow (2.2 km^3), and by further reservoir regulation of river flow (raising the average annual controlled discharge to 66.4 km^3). Variant I has the irrigated area rising to 4 million hectares in the 1st stage and to 4.9 million in the 4th, similar figures for variant II are 4 and 5 million, and variant III maintains the irrigated area at a constant 4.1 million ha (the 1990 level).

Only one scenario, with four stages of development, is given for the Syr Dar'ya basin since irrigation expansion here is more constrained by lack of water. The irrigated area (3.1 million ha in 1985) grows to 3.3 million ha in stage 1 and to 3.6 million ha in stage 4. Regulated flow is $35.2 \text{ km}^3/\text{yr}$.

Irrigation and water use data for the entire Aral Sea basin (i.e. Amu Dar'ya + the Syr Dar'ya basins) are also given or derivable. The first variant would expand irrigation to 10.2 million ha at the third stage of development - a 42% increase over the current level. Water withdrawals only for irrigation could rise to 87 km^3 in the Amu Dar'ya basin and 42 km^3 in the Syr Dar'ya basin for a total of 129 km^3 in the 4th stage. This amount of water could not be supplied from local resources and, it is stated, this variant would necessitate large-scale, long-distance importation from outside the basin to meet irrigation and other water needs.

The differences between scenarios II and III are minor and they can be discussed together. Stages 1 to 4 show irrigation development ranging from 7.3 to 8.6 million ha. and overall water withdrawals

(irrigation+industrial+municipal+agricultural+fishery+pasture watering) rising from 120.8 to 137.8 km³. Withdrawals for irrigation would vary from 97 in stage 1 to 111 km³ in stage 4 whereas withdrawal rates would decline from 13,600 to 12,700 m³/ha. Aggregate water withdrawals for stages 2-4 in variant II and for stages 3-4 in variant III are 1-10 km³ above average annual basin water supply of 128 km³ but return flows for the different stages are 46-51 km³, an unspecified part of which is reused or replenishes the rivers. On the other hand, a portion of river flow (around 13 km³) is lost to evaporation or reserved for maintenance of instream sanitary conditions and increased use of water in Afghanistan. Also a portion of irrigation return flows (12-16 km³) would be composed of highly saline water (4-6 grams/liter) which cannot be repetitively used for irrigation nor should be discharged to rivers. The plan is to direct this flow directly to the Aral Sea. No figures are given for the most critical indicator of exhaustion of available water resources - aggregate consumptive use. Nevertheless, the authors conclude that for variants II and III, irrigation expansion beyond the 2nd stage (7.7 million ha) would result in a "deficit" water management balance ranging from 1 to 8 km³. Unfortunately, they do not explain this term nor show how values for it were calculated. (It should be noted that there are other errors, inconsistencies, and discrepancies in the data and information presented in the study.)

Variant IV shows little increase in irrigation from stage 1 to 4 (7.4 to 7.7 million ha). Consequently, there is a slight downward trend in both aggregate withdrawals (124 to 121 km³) and irrigation withdrawals (99 to 95 km³) as water use efficiency improves with time (from 13,400 to 12,300 m³/ha). In all stages aggregate withdrawals remain

below basin water supplies by about 4 km³. Return flows range from 41 to 45 km³ of which the highly mineralized portion is 11-13 km³. Around 13 km³ are lost to evaporation or reserved for other purposes. All stages have a positive water management balance, ranging from 4-7 km³. On the other hand, aggregate withdrawals for this scenario considerably exceed basin water resources of 110 km³ available during a low flow (90% exceedance probability) year.

In spite of the problems associated with estimating the limits of irrigation in Central Asia (more precisely, the Aral Sea basin), the possibility seems reasonably high that even with a "successful" water usage improvement program expansion, based on local water resources, beyond 8 to 8.5 million hectares will prove very difficult. This is only 11 to 18% above the current area of around 7.2 million ha and will likely, if obtainable, be reached by the mid-1990s or 2000. This raises fundamental social and economic questions for the Soviet government which will have to be resolved in a relatively short period. How will employment be provided for the many new entrants to the labor force? Will greater emphasis be placed on industrialization, what will be its nature, and where will water for this be obtained (shifted from irrigation, as is happening in the American southwest), which, in turn, could not only prevent expansion but even lead to contraction of the irrigated area? What will be the consequences for local food production, will it decrease and, given the inevitability of a much larger population, will large-scale food imports from other parts of the USSR be necessary? Finally, will the government be forced to take more rigorous measures to encourage emigration to areas with more plentiful water supplies in order to bring population size in Central Asia into

balance with local water availability?

If these difficulties were not enough, there is the additional problem of the drying of the Aral Sea with its attendant adverse ecological, economic, and social consequences. This extremely serious situation is discussed in the next part.

3. THE ARAL SEA PROBLEM

3.1. Introduction

The Aral Sea is a huge, shallow, saline waterbody located among the deserts of Central Asia (Figs. 4,5). A terminal lake (having no outflow), its secular level is determined by the balance between river and ground water inflow and precipitation on its surface on the one hand and evaporation from the sea on the other.

The Aral depression has repeatedly been flooded and desiccated since the Pliocene (89;90, pp. 277-297). The most recent filling began in the late Pleistocene, around 140,000 years ago, when the Syr Dar'ya flowed into the lowest part of the hollow. The lake did not attain great size until the beginning of the Holocene (Recent) Epoch when inflow was increased some threefold by capture of the Amu Dar'ya. Marine fossils, relict shore terraces, archaeological sites, and historical records point to repeated major recessions and advances of the sea during the past 10,000 years. Until the present century, fluctuations in its surface level were at least 20 m and possibly more than 40 m (89;91). Significant variations of sea level during this period resulted from major changes in river discharge into it caused by climatic alteration, by natural diversions of the Amu Dar'ya away from the Aral, and during the past 3000 years by man. Human impacts included sizable withdrawals for irrigation from the Amu Dar'ya and periodic diversions of this river westward into lower lying channels and hollows because of the destruction of dikes, dams, and irrigation systems in its lower reaches during wars (89;19).

From the middle 18th Century until 1960, sea level varied 4 to 4.5 m (89;92). For the period from 1910, when accurate and regular level

FIGURE 5. ARAL SEA

FIGURE 6. THE CHANGING PROFILE OF THE ARAL SEA

Adapted from 94; 175; 176;., p. 56.

TABLE 6. AVERAGE ANNUAL WATER BALANCES FOR THE
ARAL SEA, 1926 TO 1985 (1)

	1926-60(2)		1960-70(3)		1970-85(4)	
Avg. area (sq. km)	65,780		63,470		53,660	
	cubic		cubic		cubic	
	km	mm	km	mm	km	mm
Gain(5)	63.4	963.5	51.2	806.7	22.9	426.8
river discharge	55.2	838.6	42.8	674.0	16.3	304.3
precipitation	8.2	124.9	8.4	131.7	6.6	122.6
Loss: evaporation	64.1	973.5	63.3	997.7	56.2	1046.6
Average net volume change	0.7	10.0	-12.2	-191.9	-33.3	-619.7

Calculated from 94.

(1) Some figures do not correspond exactly to others because of cumulative rounding errors.

(2) period of stable level

(3) period of moderately rapid decline

(4) period of rapid decline

(5) there is a small net groundwater gain which is usually ignored

ANNUAL WATER BALANCE EQUATION FOR THE ARAL SEA

$$Q_r + Q_u + (P \cdot F) / 10^6 = (E \cdot F) / 10^6 + (dh \cdot F) / 10^6, \text{ where}$$

Q_r = annual river inflow in km^3 ;

Q_u = annual net groundwater inflow in km^3 ;

P = annual precipitation on the sea in millimeters;

E = annual evaporation from the sea in millimeters;

F = average annual area in km^2 ;

dh = net annual sea level change in millimeters.

10^6 = proportionality constant in mm/km

observations began, to 1960, the lake was in a "high" phase with level changes of less than one meter (93). However, during the past 28 years the sea's surface has dropped precipitously. In 1960, sea level was 53.4 m, area 68,000 km², volume 1090 km³, average depth 16 m, and average salinity near 10 g/l (94;95, pp. 42-43). The Aral was the world's fourth largest lake in area, behind the Caspian Sea, Lake Superior, and Lake Victoria. By the beginning of 1987, sea level had fallen 12.9 m, area decreased by 40%, volume diminished by 66%, average depth dropped to 9 meters, and average salinity risen to 27 g/l (Fig. 6). The sea had dropped to 6th place in area among the world's lakes (Michigan and Huron are now considerably larger).

The recent recession has been the most rapid and pronounced in 1300 years (89). Human actions have been the primary cause. Desiccation continues at a rapid pace and if unchecked will shrink the sea to several briny remnants in the next century. Severe and widespread ecological, economic, and social consequences which are progressively worsening have resulted from the Aral's recession. The scale and magnitude of impacts on such a large waterbody over so short a period is unprecedented. Soviet commentators in recent years have referred to the Aral situation as "one of the very greatest ecological problems of our century (96)," an "impending disaster (97)," and as "a dangerous experiment with nature (98)."

3.2. Water Balance Changes

As in the past, the cause of the modern recession of the Aral is a marked diminution of inflow from the Syr and Amu Dar'ya, the sea's sole sources of surface water discharge, that has increasingly shifted the water balance toward the negative side (Table 6). Excepting the un-

usually heavy flow year of 1969, the river discharge trend has been steadily downward since 1960 (Fig. 7). Consequently, the gap between the gain and loss sides of the water balance has steadily increased and, accordingly, the sea's level and area have diminished at an increasing rate.

A shrinking waterbody is dominantly a negative feedback mechanism, i.e., one that resists change and promotes stability. Evaporative losses significantly diminish as area decreases, forcing the water balance system toward equilibrium. Hence, in the future, assuming some level of surface- and ground water inflow, the Aral should stabilize. However, this is not likely to occur for decades. The primary determinant of level change, the difference between inflow and net evaporation, is currently large and negative. It will only decrease slowly as the sea shrinks to a much smaller size.

The causes of reduced inflow since 1960 are both climatic and anthropogenic. A series of dry years occurred in the 1970s, particularly 1974-75, that lowered discharge from the zones of flow formation of the Amu Dar'ya and Syr Dar'ya around 30 km³/yr (27%) compared to the average over the preceding 45 years (95, pp. 42-43; 7, p. 227). Naturally low flows also occurred in 1982 and 1986 (8;46;99). Nevertheless, the most important factor reducing river flow has been large consumptive withdrawals, overwhelmingly for irrigation.

Irrigation has been practiced in the lower reaches of the Amu and Syr Dar'ya for several millenia (19). In antiquity and again during the middle ages, the irrigated area in the Aral Sea basin may have reached 5 million ha (89). By 1900 more than 3 million ha were irrigated in the Aral Sea basin, growing to 5 million ha by 1960 when consumptive water

FIGURE 7. WATER BALANCE PARAMETERS OF THE ARAL SEA, 1926 TO 1985

loss from it reached an estimated 40-44 km³ (39;89;100, pp. 312-322). However, irrigation withdrawals prior to the 1960s did not measurably reduce inflow to the Aral. These artificial losses were compensated by correspondingly large reductions of natural evaporation, transpiration, and filtration, particularly in the deltas of the Syr Dar'ya and Amu Dar'ya where truncated spring floods diminished floodplain inundation, the area of deltaic lakes, and the expanse of phreatophytes (7, pp. 225-240;100, pp. 312-322;101). Also, the installation of drainage networks increased irrigation return flows to these rivers.

By 1980, the irrigated area in the Aral Sea basin had grown to nearly 6.0 million ha (Table 2). Withdrawals from the Amu Dar'ya and Syr Dar'ya for all purposes were 132 km³ with consumptive use, including evaporation from reservoirs, given as 90 km³ (Table 3). Consumptive use was actually higher than this since a substantial portion of water included in the irrigation return flows category was lost to evaporation and transpiration before reaching rivers. Irrigation withdrew 120 km³ (91% of the total) and consumed 74 km³ (83% of the total for this category). As discussed in section 2.4, irrigation efficiency was substantially improved after 1980, so that even though the irrigated area grew to around 7.2 million ha by 1988, a 20% rise, water withdrawals for irrigation may have dropped here as much as 14 km³ (30;44, p. 22). Consumptive use in irrigation, however, probably remained steady and perhaps increased somewhat since a larger portion of withdrawals were lost to evaporation and transpiration.

Factors that compensated the earlier growth of consumptive withdrawals reached their limits in the 1960s (89;7, pp. 225-240;100, pp. 312-322;101) Hence, as irrigation expanded over the past three decades,

the increase in water usage has not been balanced by commensurate reductions in natural losses. Furthermore, the irrigation of huge new areas such as the Golodnaya (Hungry) steppe along the Syr Dar'ya consumed huge volumes of water to fill soil pore spaces, newly created, giant reservoirs required filling and heightened evaporative losses, increased flushing of soils to counteract secondary salinization raised water usage, and new irrigation systems discharged their drainage water into the desert or natural depressions where it evaporated rather than returning to rivers (102).

The Kara-Kum Canal has been the single most important factor contributing to the diminution of inflow to the Aral in recent decades. The largest and longest irrigation canal in the USSR, it stretches 1300 km westward along the southern margins of the Kara-Kum desert from where the Amu Dar'ya emerges from the mountains (Fig. 4). Between 1956 and 1987, 225 km³ were diverted into it as annual withdrawals rose from less than one to more than 14 km³ (103;104;105). All of the water sent along the Kara-Kum Canal is lost to the Aral.

3.3. Environmental and Economic Impacts of Recession

When plans for a major expansion of irrigation in the Aral Sea basin were developed in the 1950s and 1960s, it was anticipated that this would reduce inflow to the sea, substantially reducing its size. At the time, a number of water management and desert development experts believed this a worthwhile tradeoff: a cubic meter of river water used for irrigation would bring far more value than the same volume delivered to the Aral Sea (93;106, pp. 5-25;107, pp. 85-96;108;109). They based this calculation on a simple comparison of economic gains from irrigated agriculture against tangible economic benefits from the sea. Indeed,

the shrinkage of the Aral to a residual brine lake as all its inflow was devoted to agriculture and other economic needs was viewed as both desirable and inevitable.

These experts largely dismissed the possibility of significant adverse environmental consequences accompanying recession. For example, they claimed that the sea had little or no impact on the climate of adjacent territory; therefore, its shrinkage would not perceptibly alter meteorological conditions in the littoral zone (93). The threat of large quantities of salt blowing from the dried bottom and damaging agriculture in adjacent areas was considered minimal (106, pp. 5-25). This theory, firstly, assumed that during the initial phases of the Aral's drying only calcium carbonate and calcium sulfate would be deposited on the former bottom. Although friable and subject to deflation, these salts have low plant toxicity. Secondly, it was predicted that the more harmful compounds, chiefly sodium sulfate and sodium chloride, deposited as the sea continued to shrink and salinize, would not be blown around because of the formation of a durable crust of sodium chloride. Some optimists even suggested the dried bottom would be suitable for farming (106, pp. 5-25).

Although a small group of scientists warned of serious negative effects from the sea's desiccation, they were not heeded (99;108). Time has proven the more cautious scientists not only correct but conservative in their predictions.

3.31. Bottom exposure and salt-dust storms. The Aral contained an estimated 10 billion mt of salt in 1960, with sodium chloride (56%), magnesium sulfate (26%), and calcium sulfate (15%) the dominant compounds (106, pp. 5-25). As the sea has shrunk, enormous quantities of

salts have accumulated on its former bottom. This results from capillary uplift and subsequent evaporation of heavily mineralized ground water along the shore, to seasonal level variations which promote evaporative deposition, and to winter storms which throw precipitated sulfates on the beaches (70;109;110).

Much of the 27,000 km² of bottom exposed between 1960 and 1987 is salt covered. Contrary to earlier predictions that were founded on a faulty understanding of the geochemistry of a shrinking, salinizing Aral, not only have calcium sulfate and calcium carbonate deposited but sodium chloride, sodium sulfate, and magnesium chloride as well (108). Because of the concentration of toxic salts in the upper soil layer, a friable and mobile surface, and lack of nutrients and fresh water, the former bottom is proving stubbornly resistant to natural and artificial revegetation (110;111;112;113).

However, the most serious problem is the blowing of salt and dust from the dried bottom. By the late 1970s, there was no evidence of the formation of the predicted sodium chloride crust which was expected to retard or prevent deflation (108). The largest plumes arise from the up to 100 km wide dried strip along the sea's northeastern and eastern coast and extend for 500 km (Fig. 5)(98;109). Recent reports in the popular media claim traces of Aral salt have been found a 1000 km to the southeast of the sea in the fertile Fergana Valley, in Georgia on the Black Sea coast, and even along the arctic shore of the Soviet Union (114;115). However, Dukhovnyy and Razakov assert traces of dust and salt from the Aral are not detectable more than 400 km from the sea (30).

Major storms were first spotted by cosmonaut in 1975 (26). Between

1975 and 1981, 29 large storms were confirmed by Soviet scientists from analysis of high-resolution Meteor imagery (98). (Meteor is a Soviet weather satellite with capabilities similar to the NOAA series of polar-orbiting satellites of the U.S.). As many as 10 major storms were noted in one year. Sixty percent of the storms moved in a southwest direction which carried them over the ecologically and agriculturally important delta of the Amu Dar'ya. Twenty-five percent of storms travelled westward and passed over the Ust-Yurt plateau which is used for livestock pasturing. More recent observations by Soviet cosmonauts indicate the frequency and magnitude of the storms is growing as the Aral shrinks (116).

An estimated 43 million metric tons of salt are carried annually from the sea's dried bottom into adjacent areas and deposited as aerosols by rain and dew over 150,000-200,000 km² (8;98;117). The dominant compound in the plumes is calcium sulfate but they also contain significant amounts of sodium chloride, sodium sulfate, magnesium sulfate, and calcium bicarbonate (118). Sodium chloride and sodium sulfate are especially toxic to plants, particularly during blossoming. In spite of the expected increase in the area of former bottom, the export of salt is predicted to slightly diminish to 39 million metric tons/yr by 2000 as a result of the exhaustion of deflatable material, the leaching of salt into deeper layers, and through the process of diagenesis (consolidation) of the older surface salts (117).

3.32. Loss of aquatic productivity. As the sea has shallowed, shrunk, and salinized, aquatic productivity has rapidly declined. By the early 1980s, 20 of 24 native fish species had disappeared, 12 of which had commercial importance, as the fishery harvest (48,000 mt in

1957) fell to zero (90, pp. 507-524;8;110). Major fish canneries at the former ports of Aral'sk and Muynak - now-tens-of-kilometers from the shoreline - have slashed their workforce and barely survive on the processing of fish brought at high cost from as far away as the Atlantic, Pacific, and Arctic oceans (114;115;119;120). The Muynak facility produced 20 million cans per year at one time but was working at only 30% capacity by 1988 (121). Both plants were to be switched to economic accounting principles of management in 1988 and because of their high operating expenses may be forced to close (115). Commercial fishing continues in lakes such as Sudochn'ye in the Amu Dar'ya delta and in the two largest irrigation drainage water lakes that have formed (Sarykamysh and Aydarkul'). But the catch is of poorer quality and much smaller than was formerly taken from the Aral. Levels of pesticides and herbicides, from cotton field runoff, in fish taken from Sarykamysh and Aydarkul' are dangerously high, prompting a halt to commercial fishing in the former in 1987 (99;114).

Employment directly and indirectly related to the Aral fishery, reportedly 60,000 in the 1950s, has disappeared (122). The demise of commercial fishing and other adverse consequences of the sea's drying have led to an exodus from Aral'sk and Muynak whereas many former fishing villages have been abandoned (115;119). The population of Muynak, formerly between 10 and 30 thousand, has dropped 80% (121) and more than 40,000 have left the districts of Kzyl-Orda Oblast which abut the Aral on the east and northeast (115).

3.33. Degradation of deltaic ecosystems. The Aral's shrinkage along with the greatly diminished flow of the Syr and Amu Dar'ya has had particularly devastating effects on these rivers' deltas (8;98;99;-

110;123;123a). Prior to the 1960s, these oases surrounded by desert not only possessed great ecological value because of the richness of their flora and fauna but provided a natural feed base for livestock, spawning grounds for commercial fish, raw materials (reeds) for the paper industry, and opportunities for commercial hunting and trapping. Deltaic environments deteriorated as river flow diminished and sea level fell, leading to the drying or entrenchment of distributary and even main channels, the cessation of spring floods, and the shrinkage or disappearance of lakes. Between 1960 and 1974, the area of natural lakes in the Syr Dar'ya delta decreased from 500 km² to several tens of square kilometers whereas in the Amu Dar'ya delta from the 1960s until 1980, 11 of the 25 largest lakes disappeared and all but four of the remainder significantly receded (124;125).

Native plant communities have degraded and disappeared. The area of Tugay forests, composed of dense stands of phreatophytes (popular, willow, tamarisk, ash and buckthorn) mixed with shrubs and tall grasses fringing delta arms and channels to a depth of several kilometers, which was estimated at 13,000 km² for the Amu Dar'ya delta in the 1950s, had been halved by 1980 (123). Thirty years ago hydromorphic ecosystems (marshy lakes and reed communities) covered nearly 800,000 ha in the Amu Dar'ya delta. This has been reduced to no more than 100,000 ha which are supported by residual river flow and irrigation drainage (123a). The major cause of deltaic vegetation impoverishment has been the 3-8 m drop of ground water along with the end of floodplain inundation.

Disappearance and degradation of vegetational complexes and water table drops have been accompanied by desertification in both deltas. This is characterized by desiccation of the surface layer and its

salinization to a depth of 2 meters forming Solonchak soils (with high salt concentrations in the soil and accumulations on the surface) and the creation of mobile sand dunes (123a). Prior to 1960, annual floods provided natural flushing of salts from delta soils. With their demise, salinization has dominated the soil-forming process. In the Amu Dar'ya delta, Solonchak soils occupied 135,000 ha in 1960 but have spread to 311,000. Owing to soil and vegetation deterioration, pastures for livestock have decreased in area and lost productivity as halophytic (salt tolerant) and xerophytic (drought tolerant) vegetation has supplanted more nutritious species (123a). Where this has occurred in the Amu Dar'ya delta, productivity has declined from 1 to 1.6 metric tons/ha in 1960 to 0.06 to 0.3 tons/ha today. The area of hayfields and pastures in this delta shrank 81% between 1960 and 1980 (110). Satellite imagery and photography from manned spacecraft indicate desertification is spreading rapidly (98).

Habitat deterioration has harmed delta fauna, which earlier included muskrat, wild boar, deer, jackal, many kinds of birds, and even a few tigers. At one time, 173 animal species lived around the Aral, mainly in the deltas; 38 survive (110;115). Commercial hunting and trapping have largely disappeared. The harvest of muskrat skins in the Amu Dar'ya Delta has fallen to 2,500/yr from 650,000 in 1960 (99).

3.34. Climatic changes. Earlier claims to the contrary notwithstanding, research over the past two decades has established that the Aral affects temperature and moisture conditions in an adjacent strip estimated to be 50-80 km wide on its north, east and west shores and 200-300 km wide to the south and southwest (8;110;126). With contraction, the sea's climatic influence has substantially diminished. Sum-

mers have become warmer, winters cooler, spring frosts later and fall frosts earlier, the growing season has shortened, humidity has lowered, and there has been an overall trend toward greater continentality. The most noticeable changes have occurred in the Amu Dar'ya delta. At Kungrad, now located about 100 km south of the Aral, comparison of the period 1935-60 with 1960-81, indicates that relative humidity diminished 28%, the average May temperature rose 3-3.2 and the average October temperature decreased 0.7-1.5 Celsius-degrees (8). The growing season in the northern Amu Dar'ya delta has been reduced an average of 10 days, forcing cotton plantations to switch to rice growing (99;110).

3.35. Ground water depression. The drop in the level of the Aral has been accompanied by a reduction of the pressure and flow of artesian wells and a decline of the water tables all around the sea (8). Soviet scientists have estimated that a 15 m sea level drop, likely by the early 1990s, could reduce ground water levels by 7-12 m in the coastal zone and affect the water table 80-170 km inland (127). The sinking water table has had significant adverse impacts outside the Amu and Syr Dar'ya deltas, drying wells and springs and degrading natural plant communities, pastures and hayfields.

3.36. Water supply and health concerns. The reduction of river flow, salinization and pollution by contaminated irrigation return flows and industrial and municipal effluent of what is left, and lowering of ground water levels has caused drinking water supply problems for communities around the sea. Conditions are most severe in the more heavily populated deltas (8;26;110). To provide a reliable, safe water supply to Nukus (1987 population of 152,000) in the Amu Dar'ya Delta, a 200 km pipeline costing 200 million rubles is under construction from

the upstream Tyuyamuyun Reservoir. The declining quality of drinking water is believed the main factor increasing intestinal illnesses, kidney failure and liver ailments, and throat cancer among the population in the lower reaches of the Amu Dar'ya and Syr Dar'ya (26;119;120). The infant mortality rate in some places here is reported to be 100 per 1000 live births - 4 times the national rate in 1988 (10;26). There is fear of epidemic because of the deterioration of water supply quality and the increasing rodent population (95, pp. 42-43;120). Desert animals who use the Aral Sea as a drinking source are dying because of its greatly increased mineralization, including the endangered Kulan (Asiatic wild ass) and Saiga (Steppe antelope) that live in the zapovednik (nature reserve) on Barsakel'mes Island (26;110).

3.37. Estimates of monetary losses. There are no accurate figures on damages associated with the Aral's recession. Soviet scientists and economists have attempted to estimate the costs of the more tangible consequences. A 1979 study concluded that aggregate damages within the Uzbek Republic, which has suffered the greatest harm, totalled 5.4 to 5.7 billion rubles (128). A 1983 evaluation concluded that annual damages in the the Amu Dar'ya delta were 92.6 million rubles with the following distribution: agriculture - 42%, fisheries - 31%, hunting and trapping - 13%, river and sea transport - 8%, and living and working conditions - 6% (110). Dukhovnyy and Razakov have recently cited a figure of 100 million rubles per year as the "social product" losses from degraded pastures, reduced livestock productivity, lowered ground water levels, fishery damage, etc. in the Amu Dar'ya delta (30). A popular article published in late 1986 listed, without elaborating, a figure of 1.5 to 2 billion rubles as the annual losses for the entire

Aral Sea region (99).

3.4. Local Schemes to Preserve the Aral.

What is the future for the Aral Sea? If surface inflow remains low (averaging only 5 km³/yr from 1981-85 and near zero in 1986), shrinkage will continue rapidly into the next century (46;94;99;129). By 2000, the sea could consist of a main body in the south with a salinity well above the ocean and several small brine lakes in the north (Fig. 6). Subsequently, assuming a residual inflow of irrigation drainage water and ground water totalling around 10 km³, the southern sea will separate into two parts with an aggregate area around 12,000 km² - 8% of the Aral's size in 1960 (130). Salinity would rise to 140 grams/liter. This scenario is not inevitable. The sea's recession could be arrested quickly if considerably more water reached it. Indeed, it could be restored to its pre 1960 state with an average annual inflow around 55 km³ (probably a few cubic kilometers less would suffice owing to a small positive ground water contribution) (Table 6). Dukhovnyy and Razakov estimate this would require a 60% reduction of the irrigated area in the Aral drainage basin and lead to losses of 18-20 billion rubles/yr (30).

To maintain the sea's 1987 area (41,000 km²) would require much less surface inflow. Water balance calculations indicate around 30 km³/yr would suffice (based on data in 70, Table 2). This is 24 km³ more than average annual discharge to the Aral for 1980-1985 (94). Dukhovnyy cites the average deficit for 1980-87 as 22 km³/yr (30). To supply even this much additional water would still require a major lowering of consumptive withdrawals, primarily for irrigation. As discussed in sections 2.4 through 2.6, in spite of on-going efforts to

improve irrigation efficiency and develop supplementary sources of irrigation water supply, it is extremely doubtful that consumptive diminution of river flow can feasibly be reduced substantially.

Is the Aral, therefore, inevitably doomed? Not necessarily or completely. Means are available to preserve the sea, albeit in a much shrunken form, or at least to improve environmental conditions in the Amu and Syr Dar'ya deltas. The simplest and quickest approach would be to supplement the sea's water balance by channeling irrigation drainage water to it that is now lost to evaporation or accumulated in lakes. In the early 1980s, this may have totalled $13 \text{ km}^3/\text{yr}$ (8). It has been suggested that perhaps $10\text{--}12 \text{ km}^3$ of drainage water annually could be sent to the Aral by collectors paralleling the Amu and Syr Dar'ya (96). However, drainage is saline, commonly above 4 grams/liter, as well as pesticide and herbicide laden; it should be purified and demineralized before discharge to the sea (70;114;131). Indeed, the need to keep this contaminated, poisonous flow out of the two rivers stimulates interest in such a scheme as much as the need to provide more water to the Aral. Work on an enormous project to collect drainage water along 1500 km of the right bank of the Amu Dar'ya for delivery to the Aral has started (132). The program to improve irrigation efficiency will significantly reduce the amount of drainage water available for delivery to the Aral.

Diverting irrigation drainage water to the sea will dry the two largest lakes supported from this source, Aydarkul' (also called Arna-say) and Sarykamys. The former has an area of $2,300 \text{ km}^2$ and contains 20 km^3 whereas the latter is near $3,000 \text{ km}^2$ with a volume of around 30 km^3 (133-136). Since their origins in the 1960s, each has developed considerable fishery and wildlife importance; the latter owes mainly to

their role as havens for migratory water birds, some of which are rare. The catch of fish from Aydarkul' runs near 10,000 metric tons whereas about 3000 metric tons are taken from Sarykamysh (137;138). It has been proposed to create zapovedniks (nature reserves) encompassing parts of both lakes (135;139). A zakaznik (protected area) has recently been established for Lake Sarykamysh (133).

The fishery and ecological value of both lakes, however, is threatened by rising salinities and contamination from herbicides, pesticides, and fertilizer contained in irrigation drainage (133;134). The 1987 average salinity of 12 grams/liter for Sarykamysh could rise to 15-17 grams/liter by 2000, adversely affecting the fish. Reportedly commercial fishing was halted in Sarykamysh in 1987 because of pesticide contamination (114). The full cut-off of irrigation drainage water now sent to the lake along the Dar'yalik and Ozerney collectors (so that it could be delivered to the lower reaches of the Amu Dar'ya river and the Aral Sea) would drop Sarykamysh's level 15-17 meters and raise average salinity to 40-50 grams/liter (133). This would destroy all the lakes important fish species.

Delivery of 12 km³ of irrigation drainage water plus 4 km³ of net ground water inflow would support a sea of only 20,000 km² whose salinity would be so high (well above 50 grams/liter) that its ecological and economic value would be null. Hence, additional measures will be necessary if the Aral is to be preserved as a greatly shrunken but viable waterbody and to reduce the adverse impacts of its recession. One approach, first suggested in the 1970s, is to partition the sea with dikes to preserve low salinity conditions in a portion of it while allowing the remainder to dry or become a residual brine lake receiving

outflow from the freshened part (92;127;130). Several ^{schemes} for this are shown on Figure 8. Discharge to the Aral has dropped so rapidly, however, that schemes A through C are obsolete in that it is unlikely there would be sufficient inflow (24-30 km³/yr) to sustain them. Design D, on the other hand, would be viable since it requires only 8 km³ of inflow. As part of this plan, the shoreline of the "active" portion of the sea would be steepened by dredges to minimize seasonal area fluctuations that contribute to salt deposition (44).

Dukhovnyy and his colleagues at the Central Asian Research Institute for Irrigation have put forward an interesting proposal for restoring the Amu Dar'ya delta (8;30). They assume meager future availability of water for the Aral and contend the best strategy is to use this limited resource to restore and preserve the delta because of its great ecological and economic value. The scheme would involve constructing a 200 km dike on the dried bottom in front of the delta to create a shallow reservoir of 300-400 thousand ha with a surface elevation 8 m above current sea level but 5 m below that of 1960. This would raise ground and surface water levels in the delta and, it is claimed, allow restoration of its former vegetation and soil character as well as its fishery and muskrat production. Low earth dams and regulating reservoirs would be built in the delta proper to provide further water control. Liman (shallow flood) irrigation would be developed over 300-350 thousand ha south of the reservoir for the growing of reeds and fodder crops to aid in the re-establishment of cattle raising.

A total of 12.2 km³/yr, 3.5 of fresh river water and 8.7 of saline irrigation drainage water, would be delivered to the main reservoir. The drainage water would be gathered by collectors along both sides of

FIGURE 8. SCHEMES TO SAVE THE ARAL

1-active (freshened and circulating) part of sea; 2-isolated (salt accumulating) part of sea; 3-dried part of sea; 4-earthen dam; 5-spillway; 6-location and direction of inflow and outflow for active part of sea

- A. Separation of northern "small sea" in 1980 and deeper western part of sea in 1985. Average annual physical characteristics of active sea: area-20,000 km²; volume-293 km³; level-53 m (small sea) and 46.5 m (large sea); salinity-5 to 6 g/l by 2050; surface inflow-30 km³; outflow-15 km³.
- B. Isolation of northern part of sea in 1980 and western part in 2000. Average annual physical characteristics of active sea: area-30,000 km²; volume-285 km³; level-46.6 m; salinity-13 to 15 g/l by 2050; surface inflow-30 km³; outflow-15 km³.
- C. Separation of eastern part of sea from western with canal connecting small northern sea. Average annual physical characteristics of active sea: area-20,000 km²; level-38 m; salinity-12 g/l; surface inflow-24.4 km³; precipitation on sea surface-2.5 km³; groundwater inflow-2 km³; outflow-10.3 km³; evaporation from sea surface-18.6 km³.
- D. Separation of central and southern part of eastern sea. Average annual physical characteristics of active sea: area-12,000 km²; level-38 m; salinity-12 g/l; minimum surface inflow-8.05 km³; precipitation on sea surface-1.51 km³; groundwater inflow-1.6 km³; outflow-dependent on inflow above minimum; evaporation from sea surface-11.6 km³.

the Amu Dar'ya. A large part of the flow to Lake Sarykamysh would be diverted into this system. The dried sea bed in front of the main reservoir would be stabilized by planting halophytes and xerophytes to prevent the encroachment of sand dunes and the blowing of salt and dust. The reservoir also would present a 50 km wide water surface in the direction of the prevailing winds (from the northeast), promoting the settling of salt-bearing aerosols before they reached the delta. Mineralization of the main reservoir would be prevented by an outflow to the Aral of 3.2 km³. The residual Aral Sea would stabilize near 30 meters (10 meters lower than in 1987) and have a salinity of 60 grams/liter. Estimated project cost is 406 million rubles. A similar plan could be implemented for the Syr Dar'ya delta, requiring some 7 km³/yr (8).

Regardless of what, if any, scheme is implemented to preserve a residual Aral Sea or improve conditions in the Amu and Syr Dar'ya deltas, it is essential to stabilize the salt-covered exposed bottom to reduce the blowing of salt and dust. There has been some success in establishing salt tolerant xerophytic shrubs (e.g. black saksaul - Haloxylon aphyllum). But this program is so far limited to relatively small areas with the most favorable conditions and the survival rate is low (131;140;141). Scientists are also investigating the feasibility of using mechanical and chemical means of binding the loose surface (8;111-113).

3.5. The Siberian River Diversion Project

The Aral's water balance could also be improved by importing water from more humid regions to the north. Although average annual surface flow across the USSR is estimated at 4700 km³, second after Brazil,

distribution is highly uneven (Fig. 9). Rivers carrying 84% of discharge flow north and east through sparsely inhabited and economically underdeveloped territory to the Arctic and Pacific oceans. The remaining 16% of river flow crosses the southern and western zones of the Soviet Union where lives 75% of the population, which generates 80% of economic activity, and which contains over 80% of cropland, including all of the most fertile (142). The Aral Sea basin with 6% of the nation's land area, 39% of aggregate water withdrawals, and 41% of consumptive use, including reservoir evaporation, has only 2.3% of its surface flow (Table 3;7a, p. 111). Furthermore, the headwaters of major northern and southern flowing rivers in European Russia are proximate (separated by a water divide nowhere more than 160 m) whereas a structural trough (the Turgay Gate) with a maximum elevation of 120 m links the arctic and Aral Sea drainage basins. Favorable natural conditions not only simplify the engineering but improve the economic feasibility of water transfers.

Hence, it is not surprising that there has been long-standing interest among Soviet hydraulic engineers and water planners in diverting a portion of river discharge from the arctic drainage basin to the arid south. The possibility and value of diverting water from the rivers of Western Siberia into Central Asia was recognized even in Tsarist times. In 1871, the engineer Ya. Demchenko proposed channeling water from the Ob' into the Aral basin and further to the Caspian Sea to make the desert live (142;143, pp. 20-46). Such a scheme was well beyond construction technology of the time. New interest in north-south water diversions arose in the 1920s and 1930s as part of plans for the general development of the country's water resources. In the late 1940s

FIGURE 9. MEAN FLOW USSR RIVERS (km^3/year)

A. Percentage of USSR's territory covered by drainage basins

B. Percentage of total flow accruing to drainage basins.

Arctic Ocean Basin
Pacific Ocean Basin
Black Sea Basin

Baltic Sea Basin
Caspian/Aral Sea Basins

in line with the general promotion by Stalin of various schemes for the radical "transformation of nature", a Leningrad engineer (M. Davydov) proposed the most grandiose Siberian project. It would take 315 km^3 annually from the Ob' and Yenisey rivers, 27% of the estimated average annual flow (1150 km^3) at the mouth of their estuaries, for delivery into the Aral Sea basin and the Caspian Sea (144). The Davydov plan would have flooded $250,000 \text{ km}^2$ of the West Siberian plains, greatly worsening the already serious problem of excessive moisture here, as well as inundating valuable forests, farmland, and major transportation routes. Worst of all, it would flood the most important oil and gas production region in the USSR. Construction costs of the scheme would run into the hundreds-of-billions of rubles.

The Davydov plan was never seriously considered. Planning work on diversions continued after Stalin's death in 1953. In the early 1960s, a project to transfer around $40 \text{ km}^3/\text{yr}$ from the European north into the Caspian Sea drainage basin (the Volga-Kama river system) was seriously contemplated (145). Opposition from water management and resource analysis experts on the grounds of potentially severe ecological and economic damage to regions of water export led to the reappraisal and abandonment of this scheme. However, research and design work on north-south water transfers continued since the water resource problems they were intended to alleviate (growing water use and declining levels and environmental degradation of seas in the south) were growing worse.

The 1970s was a period of intensive development of water redistribution plans but with a greater focus on minimizing their potential environmental impacts (145). By the end of the decade, detailed designs had been formulated for both the European and Siberian parts of the

country. The lead design agency, Soyuzgiprovodkhoz (All-union institute for water management planning and design for diversion and redistribution of the waters of northern and Siberian rivers), part of the Ministry of Reclamation and Water Management, and the Institute of Water Problems of the Soviet Academy of Sciences which headed environmental impact assessment work contended that the schemes would not cause unacceptable environmental harm. This claim was based on the results of impact assessment studies conducted between 1976-80 by more than 120 scientific research and planning agencies. The schemes underwent scrutiny by a Government commission during the early 1980s, resulting in several minor revisions. The final versions of the projects are shown on Figure 10 and in Table 7. By the end of 1984, construction on the 1st stage of 1st phase European diversions ($5.8 \text{ km}^3/\text{yr}$) received governmental approval and work began on infrastructure facilities (access roads, concrete plants, workers' housing, etc.).

The first phase of Siberian transfers ($27.2 \text{ km}^3/\text{yr}$) was undergoing detailed engineering design in 1985 and was scheduled for implementation by the late 1980s or early 1990s (145). It would take 27.2 km^3 annually from the arctic flowing Ob' and Irtysh rivers in Western Siberia. Water would be sent 2500 km southward through the Turgay Gate into the Aral Sea basin and as far as the Amu Dar'ya by a system of low dams, pumping stations, and a huge earth-lined canal (popularly named "Sibaral" - Siberian to the Aral Sea Canal) (Fig. 4). Soyuzgiprovodkhoz set the cost of building first phase facilities at 14 billion rubles with another 18 billion rubles needed for the construction of water distribution facilities along the route, for a total of 32 billion rubles.

Table 8 shows selected economic and environmental information on

FIGURE 10. USSR RIVER DIVERSION PROJECTS

TABLE 7. CHARACTERISTICS OF SOVIET RIVER DIVERSION PROJECTS

Stage/phase (numbers refer to Figure 2)	Water source	Average annual diversion (cubic-km.)	Notes
EUROPEAN SCHEMES			
1st stage, 1st phase (1)	a. lakes Lacha & Vozhe	1.8	1. Construction begun on 1st phase in 1985 with completion by 2005. Project halted in 1986. Further design and construc- tion postponed indef- initely. Ecological and economic re-evalu- ation ordered. Project and proponents bit- terly denounced in popular media.
	b. Lake Kubena & upper Sukhona	4.0	
1st stage total		5.8	
2nd stage, 1st phase (2)	Lake Onega	3.5	
3rd stage, 1st phase (3)	upper Pechora R.	9.8	
2nd and 3rd stage total		13.3	
First phase total		19.1	
1st stage, 2nd phase (4)	Lower Sukhona & Malaya Northern Dvina rivers	10.2	2. Construction orig- inally set for early 21st century. Post- poned (note 1).
2nd stage, 2nd phase (5)	Onega Gulf reservoir	37.7	3. Construction poss- ible in 21st century (note 1).
Second phase total		47.9	
European diversions total		67.0	
SIBERIAN SCHEMES			
1st phase (6)	a. Irtysh River at Tobol'sk	17.0	4. Design work on 1st phase nearly com- pleted by 1986. Con- struction seemed im- minent. Project halted in 1986 for re-evalu- ation (note 1). Owing to severe water prob- lems in Central Asia, local people are plea- ing for its restor- ation. 2nd phase per- haps for next century
	b. Ob' River at Belogor'ye	10.2	
First phase total		27.2	
2nd phase (7)	Ob' River at Belogor'ye (with possible compensation from Yenisey River)	32.8	
Siberian diversions total		60.0	

the project. Around 2/3 of the diverted water was planned to be used in the Aral Sea basin; the balance would be lost to evaporation and filtration enroute or be diverted for irrigation, municipal, and industrial purposes in southern Western Siberia and the Ural mountains as well as in northern Kazakhstan. Providing more water for irrigation was the schemes main purpose (90% was intended for this sector) but it would have helped the Aral as well, for example, by increasing irrigation return flows to the Amu and Syr Dar'ya rivers (143, pp. 20-46;145). A second phase of Siberian transfers was contemplated which would raise the total to 60 km³. To prevent substantial ecological damage to the Ob' downstream from the point of transfer, this would require supplementing its flow from the Yenisey River lying to the east. Second phase implementation would require careful evaluation and would not be seriously contemplated until well into the next century.

Following Gorbachev's ascension to Soviet leadership in March 1985, the fortunes of the European and Siberian schemes waned. The diversion schemes had been periodically attacked during the 1970s and early 1980s by some scientists and a group of Russian national writers who foresaw severe ecological, economic, and cultural damage occurring in northern regions of water export (38;142;145). But expressions of public doubt had been discouraged for several years as the projects moved closer to implementation. By summer 1985, public criticism was again permissible and probably officially encouraged.

Subsequently, the schemes were bitterly attacked in the Soviet popular media by the same Russian national writers and a number of prominent scientists, including several academicians (36;38;142;145). The final guidelines for the 12th Five Year Plan, released following the

27th Party Congress in February 1986, made no references to further design and construction work on European and Siberian water transfers, only stating it was necessary "To deepen the study of problems connected with the regional redistribution of water resources(17, p. 47)." In August 1986, a decree of the Communist Party and Soviet Government formally ordered a cessation of planning and construction on the European project and a halt to further design refinement for the Siberian undertaking (146). However, research on the scientific problems associated with interbasin water redistribution, stressing ecological and economic concerns, the employment of contemporary economic-mathematical methods, and the analysis of both domestic and foreign experience in the water transfer field, was directed to continue.

Why the sudden reversal of policy? Excessive costs compared to expected benefits was the dominant factor (142). Gorbachev and his advisors (e.g. A. Aganbegyan) with their strong orientation to efficiency, see the projects as a poor investment of scarce capital. In their view, there are cheaper, simpler, and shorter term local measures to increase available water supplies and improve agricultural production in southern regions such as enhanced water use efficiency in irrigation and dry farming techniques (e.g. fertility enhancement, erosion control, snow retention, crop rotation, and shelterbelt planting) (15).

Another argument made against the projects is that Soyuzgipro-vodkhoz and the Institute of Water Problems were thoroughly biased toward implementation and even engaged in collusion and falsification of data to promote the projects (35;148). Allegedly, costs were underestimated and benefits exaggerated, criticism from outside experts ignored, and efforts made to prevent outside review and to stifle public

debate. For instance, the estimate of 32 billion rubles for the first phase of the Siberian transfer may be far too low. One critic claims it would be at least 45 and likely closer to 100 billion rubles (86). The agricultural benefits of this project, its main justification, also appear to be exaggerated (Table 8). To take one example, after deducting for losses in transport (2.6 km^3) and industrial and municipal uses (around 5 km^3), leaves 19.6 km^3 for irrigation (145). To be able to irrigate 4.5 million ha from this, as claimed, implies a withdrawal rate of $4355 \text{ m}^3/\text{ha}$ - far below current or expected norms in the Aral Sea basin.

The Gorbachev reformation has stimulated a new and sincere public interest in environmental protection and preservation, particularly among intellectuals. Consequently, it is hardly surprising that inadequate study of the potential negative environmental, economic, and socio-cultural consequences of the projects have been cited as a major reason for stopping their implementation (35;142;146). However, as indicated above, a major research effort was made between 1976-80 to forecast potential significant environmental impacts. Apparently serious and credible studies revealed that there would be perceptible negative consequences from first phase European and Siberian diversions, mainly confined to northern regions of water export (145). Table 8 lists the most important of these as well as the claimed benefits for the Siberian project. The contention was that adverse effects, overwhelmingly, would be of a local or regional nature and that national or international consequences would be nonexistent or trivial.

The position of the Soviet government until the policy reversal was that potential positive impacts outweighed the negative and that the

TABLE 8. SELECTED ECONOMIC AND ENVIRONMENTAL CHARACTERISTICS
OF THE FIRST PHASE SIBERIAN WATER TRANSFER PROJECT

<u>Annual average diversion</u> (cubic kilometers)(1).....	27.2
<u>Capital cost of Main Diversion Canal</u> (millions of rubles)(1)	
total	13,000
per cubic kilometer	478
<u>Capital cost of Water distribution and irrigation facilities</u> (1)	
(millions of rubles)	18,000
<u>Amortization (payoff) period</u> (years)(1).....	10
<u>Irrigated area</u> (millions of hectares)	
1984 irrigated area in affected zone (2).....	8.7
area to be irrigated from diversions(1).....	4.5
percentage increase over 1984 irrigated area	50
feasible irrigation area in affected zone by 2010(1).....	16-17
<u>Benefits of first phase Siberian diversion</u> (1)	
increased food production: grain (17.1 mill. tons), including 13.1	
of corn; vegetables, potatoes and melons (6.7 mill. tons);	
fodder crops (45.1 mill. tons); meat (2.9 mill. tons); milk	
(10.9 mill. tons); eggs (9.2 bill.); vegetable oil (130,000	
tons)	
creation of a navigable waterway from the Amu Dar'ya to the Ob'	
River improved industrial and municipal water supplies	
creation of employment opportunities for the rapidly growing	
population of Central Asia	
improved water quality along the Amu and Syr Dar'ya	
some reduction of flooding and waterlogging below points of	
diversion along the Ob' and Irtysh rivers in Western Siberian	
<u>Potential harmful consequences of diversion project to northern regions</u>	
<u>of water export</u> (Western Siberia) (examples)	
flooding of land including agricultural (amounts unknown)	
inundation of commercial timber (amount unknown)	
resettlement of people (numbers unknown)	
fishery deterioration of the Ob', Irtysh, and Ob' Gulf	
thicker and longer ice cover on Ob' Gulf leading to cooler springs	
and summers along its coast	
degradation of water quality downstream from points of diversion	
deterioration of flood plain meadows with agricultural value	
downstream from points of withdrawal owing to reduced spring	
flooding	
worsened low-flow navigation conditions below points of diversion	

Adapted from 152, p. 72.

(1) According to the project design agency (Soyuzgiprovdokhoz) and the Institute of Water Problems.

(2) Kazakhstan and the republics of Central Asia; some water would be used for irrigation in the RSFSR (southern Western Siberian).

latter in themselves were not of sufficient magnitude to forego implementation of the projects. Indeed, specters of Siberian diversions causing global weather changes invoked by Western writers were rejected by Soviet experts as absurd; careful studies in the West supported this view (142;146). Since the projects have been under fire, the very same contention has been made by commentators in the popular Soviet media (149). Certainly, the potential adverse consequences are not inconsequential and deserve careful attention. A case can be made that the seriousness of environmental concerns was earlier understated whereas some key economic and socio-cultural problems were largely ignored. However, it appears that over the past few years these have been exaggerated, probably to lend further credence to the fundamentally investment based decision to halt the projects.

The campaign against river diversion schemes did not end with their official suspension in August 1986. Indeed, attacks in the press and other popular media intensified during 1987 (35;36;148). The Institute of Water Problems, its director G.V. Voropayev, and staff scientists directly and indirectly connected with the proposed diversions were particularly singled-out for criticism. The attacks have had considerable success: research on the environmental aspects of water transfers, even though not only permitted but required by the August 1986 decree, is virtually nil and the much maligned Voropayev was forced to resign as director in September 1988 (36;88;150). Clearly, opponents of the schemes fear they could be revived and are intent on ousting diversion supporters from positions of authority and putting an end to even basic ecological and economic investigation. Their views, interpretations, and opinions related to the water transfer controversy,

although frequently factually inaccurate, gross misrepresentations, and inflammatory, are presented as the Gospel truth in the Soviet popular media. Voropayev and others have attempted to set the record straight on the most obvious distortions but have had no success in obtaining corrections or retractions and little impact on the general public's perception of the situation (36;150).

The Siberian water transfer project may very well be revived. Central Asian water management agencies and personnel and government officials have long been ardent supporters of importing water from Siberia as has much of the general public (142;145). The halting of the project was a great shock and disappointment. There is compelling evidence that regional water resources are insufficient to meet future economic and social needs and preserve the Aral Sea in any viable form, no matter how carefully used.

Hence Central Asian water management experts and politicians, silent for several years after the suspension of diversions, are likely to push strenuously again for water transfers from the north as the only means to save the region from a water management catastrophe. The campaign has already begun. In March 1988, a joint article in the Uzbek party and government paper Pravda vostoka signed by the president of the Uzbek Academy of Sciences, P. Khabibullayev, and V. Dukhovnyy stated that the ecological and social-economic difficulties of the Aral region could not be solved without diversion of water from Siberian rivers (29). This call has been repeated by Dukhovnyy and Razakov in the reclamation and water management journal Mellioratsiya i vodnoye khoz-yaystvo (30). In October 1988 a water management expert from Soyuz-giprovodkhoz stated that water resources in the Aral Sea basin would be

exhausted no later than 2005, in spite of comprehensive and successful efforts to improve water usage (88). He contended diversions would be needed by this data and, considering that 15 years are required for their implementation, stated that it was criminal that even research work on their ecological and economic aspects had come to a standstill.

Thus, the Soviet central government may be forced to resurrect the scheme in the 1990s not only for water management but political reasons. One possibility could be a downsized version of the Siberian plan in which the diverted water would be intended specifically for the Aral and not for irrigation expansion. Water could be delivered to the northern part of the sea or into the Syr Dar'ya delta by a system of concrete lined canals and siphons (huge pipelines), somewhat shortening the route and considerably reducing filtration and evaporation losses. This would not only be cheaper and more rapidly implementable than the original scheme, but would reduce impacts downstream from points of diversion on the Ob' and Irtysh. Furthermore, it would be clearly defensible on the environmental grounds of saving the Aral - arguably a result outweighing the environmental harm caused in Western Siberia. Ten to fifteen cubic kilometers of fresh water from Siberia per year along with implementation of one or a combination of local measures could probably preserve the Aral near its present size (40,000 km²) and lower salinity to ecologically tolerable levels.

On the other hand, the Aral could be allowed to dry to a briny remnant and Central Asians told to survive on their own water resources or emigrate to other regions of the country. But given the economic, ecological, and social costs of such a strategy and its demographic, strategic, and political implications, is the Soviet government willing

to take this rather considerable risk? The Moscow correspondent of the Manchester Guardian reported that Gorbachev during his April 1988 visit to Tashkent, capital of the Uzbek Republic, after pleas from local officials, agreed to a new feasibility study of the project (151).

3.6. A New Concern for the Aral

Although the Aral has been steadily receding for nearly three decades, the problem until recently was not a high national priority. In the 1960s, the dominant (but not universal) wisdom was that the sea's shrinkage was a justifiable trade-off for economic benefits derived from withdrawing water from its influent rivers for irrigation and that accompanying environmental damage would be minimal (93;106, pp. 5-25). This attitude slowly changed in the 1970s as the drying of the Aral continued and its seriousness began to be appreciated. Study of the so-called "Aral Problem" and its amelioration was elevated to national status in 1976 under the direction of the State Committee on Science and Technology (109;131). The Institute of Geography in Moscow was given major responsibility for the research effort. Articles in scientific journals and conferences on the Aral issue became common after 1976 (20;89;92;108;152, pp. 21-23). These revealed many of the adverse consequences of what was occurring and stated that action needed to be taken. Nevertheless, until the Gorbachev regime with its policy of glasnost', the magnitude and gravity of the situation was not fully emphasized and the Aral Problem received relatively little attention in the popular media (standard procedure for all bad news). This led to complacency and inaction in the face of a growing disaster.

There has been a complete reversal since 1986. Numerous articles on the Aral and its desperate plight have appeared in popular journals

and the press and even on television. Pravda vostoka has been filled with items (29;96;153-161). The literary journal of the Uzbek writers' union, Zvezda vostoka, has also dealt with the subject (99;162;163). At the national level, the newspapers Pravda (23) and Literaturnaya gazeta (97), as well as the journal Ogonyok (26;119) among others, have carried major pieces on the issue. The dimensions of the Aral problem have been laid out in stark terms and calls have been made to take immediate action to save the sea.

Widespread anger has been expressed as to why things were allowed to become so bad and who is responsible. Much of the blame has been placed on the USSR Ministry of Water Management and its Central Asian branches for promoting so extensive development of irrigation in the Aral Sea basin, for wasteful use of water, and for their cavalier disregard for the fate of the Aral. These attacks have come from a broad spectrum of soviet society including journalists, writers, artists, social and natural scientists, and the general public. Critics claim that relatively simple and inexpensive local measures can save enough water to provide 30-35 km³/yr to the sea - enough to stabilize it around its current level (159;160). For this reason, they also see little justification for Siberian water transfers.

Central Asian water management specialists have responded to these attacks. They admit deficiencies in irrigation development and water use in Central Asia that must be corrected but defend irrigation development (29;30;163;158;159). And while recognizing the tragedy of the Aral, they are much less sanguine than their attackers that large amounts of water can be saved easily and cheaply in order to preserve the sea near its present size. Furthermore, in their view Siberian

water diversions remain a necessity to the future health of Central Asia. They have warned the public to be wary of simple and easy solutions to the Aral problem put forward by unqualified people (88;158).

In contrast to the past, people are not waiting for the Soviet government to take action. Taking a lesson from the Russian national writers who led the battle against north-south diversion projects, the Uzbek Writers' Union has formed a "Public Committee for the Saving of the Aral" (157;160;164). The committee is composed of some 80 writers, scientists and others. It has been in the forefront of attacks on water management and managers in Central Asia and is among those claiming there are quick and easy local means to deliver sufficient water to the Aral to arrest its recession if the irrigation establishment will only implement them. A fund has been established in the committee's name to collect money for their campaign. Reportedly, the well-known Uzbek writer Chingkhiz Aitmov and world famous poet Yevgeniy Yevtushenko were early contributors (164). An exposition of paintings of the Aral has also been held in Nukus, capital of the Karakalpak ASSR, the entrance fees of which were donated to the Aral fund (165).

Another "grass roots" effort was mounted by the literary journals Novyy Mir and Pamir (166). At the end of August 1988, they organized a joint fact-finding expedition with the Soviet peace committee, the State Committee for Education, and the new State Committee for Nature Protection (Goskompriroda) to investigate the Aral situation and report their findings to the government. Work finished in early October 1988. The expedition's main findings and conclusions: (1) there is a split in opinion between Central Asian water managers and social representatives

- the former believe the sea is doomed whereas the latter are demanding it be restored to its former grandeur; (2) the sea as a biological entity has perished and it is an illusion to think it can be returned to its former condition; (3) therefore, the main task is to preserve its present size and to ameliorate the adverse impacts on the region from the sea's recession; (4) information upon which to base a rational rescue program is lacking and major efforts need to be made to correct this; (5) nevertheless, it is clear the situation is very serious and quick action must be taken; and (6), thus, efforts to improve drinking water supplies and improve health care in the Karakalpak ASSR, to reduce the sowing of rice and cotton and switch to less water intensive crops, and to encourage the development here of low water use, ecologically sound, processing and auxiliary enterprises should be diligently pursued. The expedition found that a program to reduce cotton sowing, they recommended by 30-40%, not only to save water but reduce pesticide and herbicide pollution, was not being implemented. It should be noted that the journal Novyy Mir and its editor, S. Zaligin, led the fight against north-south water transfers and hence the expedition's views about the Aral situation and, particularly, strategies to rectify matters may be biased.

The Soviet government, perhaps pushed by events, has also shown much greater interest in the Aral Problem. The August 1986 decree ordering the cessation of work on diversion projects directed that scientific and planning agencies devise a comprehensive program for the development of Central Asia to 2010, considering the demographic, water management, and agricultural situation (146). This report was supposed to be ready by early 1987 but has either not been completed or, if

finished, released. A special government commission was appointed in December 1986 to study ecological problems around the Aral (29). Its 1987 report recommended several measures to improve drinking water supplies and health conditions for people living near the sea. The commission also supported the plan to preserve the delta of the Amu Dar'ya discussed above.

The most detailed and prestigious study of the Aral situation, so far, was conducted by the State Commission on the Aral Problem. The Commission was headed by Yu. Izrael', director of the State Committee for Hydrometeorology (Goskomgidromet) and had such luminaries as A. Yanshin, Vice-President of the USSR Academy of Sciences, A. Aganbegyan, the well-known economist, and other prominent scientists and high governmental officials from the Central Asian republics, as members. Appointed in April 1987, the Commission purposely avoided publicity, no doubt because of the high emotions surrounding the issue. Its findings and recommendations were delivered to the Presidium of the USSR Council of Ministers and to the Party Politburo and then released by Izrael' to the public in an interview with Pravda in early September 1988 (168).

The Commission found the Aral situation very grave but concluded that the sea could not be allowed to shrink to a group of bitter-salt lakes (with a total area around 10,000 km²), which it would across 15 to 20 years in the absence of decisive action. Recognizing that there is no feasible immediate means of greatly increasing inflow, they recommended a strategy for gradually increasing discharge: 8.7 km³ by 1990, 11 km³ by 1995, 15-17 km³ by 2000, and 20-21 km³ by 2010. The water would come from a 15-25% raising of irrigation system efficiencies (KPDs), providing 15 km³ in 2010, all of which would be delivered to the

Aral, and from the channeling of of 6 km³ of polluted and saline irrigation drainage water directly to the sea. These are to be guaranteed minimum inflows and actual discharge could be somewhat larger. According to Izrael, this would allow preservation of the sea at a shrunken, but unspecified by him, size. Another expert from Soyuzgipro-vodkhoz who served on the Commission stated the sea would be stabilized 5-6 meters below the current level (in 1988 sea level was likely around 39 or 40 meters) (88). Izrael' did not exclude Siberian diversions as a means of aiding the Aral but said they would only be justified after all local water improvement measures had been exhausted.

The recommendations of the Izrael' Commission received quick action from the Council of Ministers and Party Central Committee. The 30 September issue of Pravda published their decree: "Concerning measures for the radical improvement of the ecological and sanitary situation in the Aral sea region and for raising the effectiveness of use and strengthening the protection of water and land resources in its basin (169)." The resolution directed that all efforts be made by appropriate national and regional Party and governmental organs to implement between 1988 and 2000 measures to improve the natural environment and drinking water supplies as well as medical and health services in the lower reaches and delta of the Amu Dar'ya river and to strictly observe water efficiency measures in the Aral Sea basin. Efforts are also to be made to improve the sea's hydrologic regime and the ecological condition of it and surrounding territory including the restoration of plant and animal life.

The decree contained the same schedule of minimum guaranteed water deliveries to the Aral as the Izrael' Commission recommended with the

exception that the 20-21 km³ level was to be obtained by 2005 rather than 2010. However, no mention was made of Siberian water transfers. Specific directives were issued to water management, agricultural, scientific-research, and planning organizations as well as the governments of the Central Asian republics and Kazakhstan. Among the most crucial were (1) the rebuilding of irrigation systems and collector-drainage networks on 3.3 million and 1.8 million ha, respectively, in the republics of Central Asia and in southern Kazakhstan by 2000; (2) reconstruction of main irrigation canals in the Karakalpak ASSR in 1989-95; (3) reducing per hectare withdrawals for irrigation 15% by 1990 and 25% by 2000; (4) decreasing planned expansion of irrigation in the Aral sea basin in 1988-89 by 160-170 thousand ha and ceasing in 1991 the development of new large irrigation systems in the Aral Sea basin which would take water from the Amu or Syr Dar'ya; (5) development of a plan for stabilizing the dried bottom of the Aral and preventing deflation of salt and dust from it in 1988-90 and its implementation in 1991-2000; and (6) completion by 1989 of a feasibility study for restoring the Amu and Syr Dar'ya deltas (similar to what was discussed in section 3.4).

A variety of other important measures were also specified to improve drinking water supplies, health and medical conditions, scientific research activities on problems related to the Aral's desiccation, and employment opportunities. Provisions have also been made to guarantee the financing of the decree's requirements, but specifics were not reported. The Committee of Peoples' Control for the USSR will watch dog governmental bodies and agencies to ensure they fulfill their responsibilities. The Committee has already stated it intends to monitor compliance very closely and take measures up to firing to punish those

not doing their duty (170).

The decree was warmly greeted in Central Asia. Meetings were quickly held to discuss it and Party and government officials emphatically stated their intention to ensure implementation (171;172;173). It surely must be comforting to see the problem taken seriously at the highest levels of government and the party after a long period of neglect and cancellation of the Siberian water diversion project.

Nevertheless, the Aral problem is far from solved. The program to preserve the Aral and deal with problems created by its recession will be hugely expensive. If figures on the cost of water savings through reconstruction cited in section 2.6 of this report are reasonable (2.5 to 3.5 billion rubles/km³), then the part of the plan to free 15 km³ by this approach, alone, would cost 40 to 53 billion rubles. Furthermore, this assumes a 25% reduction in per hectare withdrawals which may be difficult to reach in light of already substantial improvements in irrigation efficiency in Central Asia. Expenditures to implement other parts of the resolution will cost billions if not tens-of-billions more. This may be fully justified but can the Soviet government afford it given their lack of capital and competing demands for it?

Even if the program is fully implemented results may be disappointing. If the past is any guide, reconstruction of irrigation facilities and other engineering work will take longer than anticipated and not be up to design standards. The stepped increase of "guaranteed" inflow to the Aral to reach 20-21 km³/yr by 2005 will result in the sea's continued shrinkage, albeit at a decreasing rate, into the next century. Stabilizing the Aral 5 or 6 meters below the current mark means the sea will be around 34 or 35 meters and have an area around

28,000 km². Unless measures are taken to desalinize and detoxify irrigation drainage water delivered to the sea, it will not only have a salinity above the ocean's but be seriously polluted. Perhaps some especially tolerant ocean species could endure (flounder from the Black Sea were introduced in the late 1970s and some have survived) but the economic and ecological value of the sea would be practically nil. Saving the deltas of the Amu and Syr Dar'ya is a wise choice but is it enough if you lose the rest of the sea? Stopping major irrigation development in 1991 which would require further withdrawals from the Amu and Syr Dar'ya may be necessary to save water for the Aral but could present serious problems for the economy and food supply of Central Asia given its rapidly growing population. There are other local sources of water such as ephemeral streams and ground water but they are limited.

One does not want to be overly pessimistic: the program for the Aral is certainly a step in the right direction. Furthermore, 1987 and 1988 were heavier than normal flow years (i.e. above average basin runoff). Reportedly, 10 km³ reached the sea in 1987 and by November 1988, 14 km³ had already entered the Aral (30;174). Water from the Syr Dar'ya nourished the sea for the first time in 9 years. All this has raised hopes for saving the waterbody. However, above average flow conditions will not continue over the longer term and even in 1987 its level still fell more than 0.7 of a meter (159). Hence, local water saving measures and other efforts may not be sufficient to adequately resolve the Aral problem, particularly in light of the other crucial water management issues in Central Asia. Thus, somekind of Siberian water transfer, as many Soviet water management experts have claimed, may be necessary to ensure an acceptable future for the Aral region.

SUMMARY AND CONCLUSIONS

There is a grave water management crisis in Soviet Central Asia. Although the region has an arid climate, water resources here are substantial owing to two rivers, the Amu and Syr Dar'ya, that flow from surrounding well-watered mountains across the deserts and into the Aral Sea. However, the flow of these has been almost completely depleted by heavy withdrawals for irrigated agriculture. This is the most important region for irrigation in the Soviet Union, accounting for nearly 40% of all lands under this use in the country. Irrigation in Central Asia is very important. It not only produces 95% of the nation's cotton but is the basis of food production and the prime contributor to employment in the region.

Until recently, the assumption has been that irrigation would continue to grow and remain the economic foundation of Central Asia. This strategy is in grave doubt because of the regions severely strained water situation. The problem is compounded by a large (34 million in 1987) and rapidly growing population whose size could easily reach 63 million by 2020. Means must be found to ensure an adequate water and food supply as well as employment opportunities for future generations. If water supplies are exhausted, precluding any significant expansion of irrigation, how will this be done? To be sure, large-scale emigration to Central European Russia, Siberia, or the Far East where water shortages are not a problem and new workers are needed is one, albeit a drastic, solution. But most ethnic Central Asians have no desire to move to these regions with a climate, language, and culture so different from their native lands. Hence, this does not appear a viable option.

In the absence of large-scale migration what can be done locally?

Using water more carefully in order to make it go farther is an obvious approach. Water usage in irrigation accounts for around 90% of withdrawals and over 80% of consumptive use and, hence, is where major water savings are possible. Irrigation in Central Asia has historically been an inefficient user of water. Earthen canal conveyance systems lost large amounts of water to filtration. What did arrive at field-side was frequently applied in excessive amounts, resulting in uplift of ground water, waterlogging, soil salinization, runoff into the desert and hollows surrounding irrigated areas, and depressed crop yields. In the late 1970s, 56% of water withdrawn for irrigation in the Amu and Syr Dar'ya basins may have been lost to noncrop (i.e. nonproductive) uses. However, part of the "lost" water was returned to rivers by ground water or surface flow and, hence, was available for reuse.

Major efforts have been made since 1982 in Central Asia to improve the efficiency of irrigation. Although the evidence is not entirely clear, it appears substantial gains have already been made. One expert (V. Dukhovnyy) claims average per hectare withdrawals in 1986 were 27% below those of 1980. Since the advent of the Gorbachev regime in 1985, renewed efforts are being made to improve water use in the region. Reconstruction of old irrigation systems, improvements in water application technologies, automation, computerization, and telemechanization, shifts from higher to lower water consuming crops, and a number of other technical measures are being stressed. There is also great interest in introducing a price for water in irrigation to promote its careful use. This is easier said than done given the nonsensical Soviet price system, but does appear to have great promise. Water prices for irrigation are to be introduced nationally in 1991.

How much additional water can be saved in Central Asia by these programs is disputed. Critics of irrigation, most of whom have little or no training or experience in the water management field, contend the potential savings are enormous - more than enough to meet regional needs far into the future. Water management specialists, on the other hand, see only modest quantities of water being freed, perhaps a net gain as small as 10 km³/yr (less than 10% of present withdrawals for irrigation) and at enormous cost, certainly tens-of-billions and perhaps approaching a hundred billion rubles. Consequently they project only modest increases in the irrigated area (11-18%) are possible based on water savings through these measures. Both sides of the argument no doubt exaggerate their case, but available evidence seems to come down more on the side of the water management experts than their opponents.

There are additional local means to deal with the water supply problem here. Available water supplies could be increased by greater use of ground water, reuse of irrigation drainage, more regulation of river flow, reduction of floodplain water losses, and the use of water collected in small natural basins and ephemeral streams. These possibilities need to be pursued but most have drawbacks and probably could not supply as much water as appears to be the case at first glance. Another suggestion is to fundamentally alter the economic structure of Central Asia away from water intensive irrigation and toward low water use industries (e.g. electronics). This should not be dismissed but would require massive increases in capital investment, the rate of which, although still positive, has been decreasing in the 1980s, and retraining of the populace and would not solve the problems of increasing local food production.

Additionally, there is the problem of the Aral Sea. This huge lake has been steadily shrinking since 1960. By 1987, its level had fallen 13 meters, area decreased 40%, volume diminished 66% and salinity risen from 10 to around 27 grams/liter. The sea's recession owes to greatly reduced inflow from the Amu and Syr Dar'ya caused overwhelmingly by irrigation. If preventive measures are not taken, the Aral will shrink to several residual brine lakes in the next century.

The sea's desiccation has had severe adverse impacts. Salt and dust have been blown from the dried bottom hundreds of kilometers inland with harmful effects on prime agricultural and ecological areas such as the Amu Dar'ya delta. Rising salinity has destroyed the sea's biological productivity and decimated the its fishery. Ecosystems of the deltas of the Amu Dar'ya and Syr Dar'ya have been severely degraded and lost much of their former economic importance. The climate around the sea has grown more extreme as the moderating influence of the waterbody diminished. Living conditions around the Aral have generally become much more difficult as water supplies have disappeared or become polluted, medical and health conditions deteriorated, and employment opportunities vanished. Owing to this, districts adjacent to the Aral Sea are experiencing large net emigration. There are no accurate estimates of aggregate losses from the Aral's desiccation but they must already have accumulated into the tens-of-billions of rubles.

Although the Aral problem was neglected for many years, its resolution has become a national priority in recent years. The Soviet public in general and Central Asians in particular are alarmed. A committee to save the Aral has been formed by the Uzbek Writers' Union which has pushed hard for specific actions to be taken. A special

commission to study the Aral, headed by Academician Izrael', reported their findings to the Council of Ministers and Politburo in September 1988. The report confirmed the situation was critical but that the sea must be saved. A action plan was recommended. The Council of Ministers and Central Committee issued a decree on the Aral in October 1988 based on the Israel' Commission study. It entails a comprehensive program based on local water resources to stabilize sea level at around 35 m, 5 m below its current standing, by 2005 and to ameliorate the problems induced in the surrounding region. Although the decree is a step in the right direction, it will not only be difficult to implement and enormously costly, but would result in a polluted waterbody with a salinity higher than the ocean and only 40% of its size in 1960.

Other plans, founded on local water resources, had been suggested earlier. Some of these would dike-off and preserve parts of the Aral at a low salinity while letting the rest dry and salinize. Most of these would require more water than will likely be available. A recent plan focuses on saving the deltas of the Amu Dar'ya and Syr Dar'ya. It has been incorporated as part of the decree.

Until recently, hopes to resolve Central Asia's water problems rested on future massive water transfers from the Ob' and Irtysh rivers to the north. It was proposed to lift 27 km³/yr initially, possibly rising to 60 km³ in the next century, across the water divide between the Aral Sea basin and Western Siberia. The scheme was intended mainly to provide water for irrigation but would have helped the Aral Sea situation as well. The project was in the final engineering design phase and was scheduled for construction by the late 1980s or early 1990s. However, after Gorbachev's rise to leadership in 1985, the plan,

along with a similar scheme for the European USSR, was halted pending further study. Central Asia was told it would have to survive on its own water resources for the foreseeable future. The decision was based mainly on economic considerations although fears of potential adverse environmental effects played some role.

The Siberian scheme is likely to be resurrected in some form. There would be a reasonably good chance to resolve water problems associated with irrigation in the absence of the Aral sea's difficulties or vice versa. To adequately deal with both these issues simultaneously without water importation seems extremely difficult if not impossible. Critics of the diversion project and of water management in Central Asia may claim otherwise but the facts simply do not support their arguments.

Hard choices are ahead for the Soviet government; there are no simple, cheap, or easy answers. Dependent on only local water resources, irrigation expansion, in spite of efficiency measures, will have to stop in the 1990s. To provide the amount of water the Aral needs to remain viable, irrigation would have to be substantially reduced. The first may cause severe social and economic disruption and necessitate large-scale emigration and the last certainly would. This, in turn, would provoke long-lasting enmity toward the Central Government and Communist Party that could have unpredictable consequences. It would seem a rational Soviet power structure would be unwilling to take this risk. On the other hand, diversion of 10 to 15 km³ annually from Siberian rivers into the Aral sea along with implementation of some local measures could preserve the sea near its current level and area while lowering salinity to ecologically tolerable levels without any cut-back in irrigation. Furthermore, this could be defended on the

ecological grounds of saving the Aral - arguably outweighing the environmental harm caused in Western Siberia. The Soviet government could, as a condition of the "deal", stipulate that no Siberian water be used in irrigation, encouraging Central Asian water managers to make every effort to use the resource carefully, since expansion of irrigation and other water uses would be possible only from water freed by this means.

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