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The Water Management Crisis in Soviet Central Asia

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TABLE OF CONTENTS

APPENDIX A - Figures

APPENDIX B - Tables

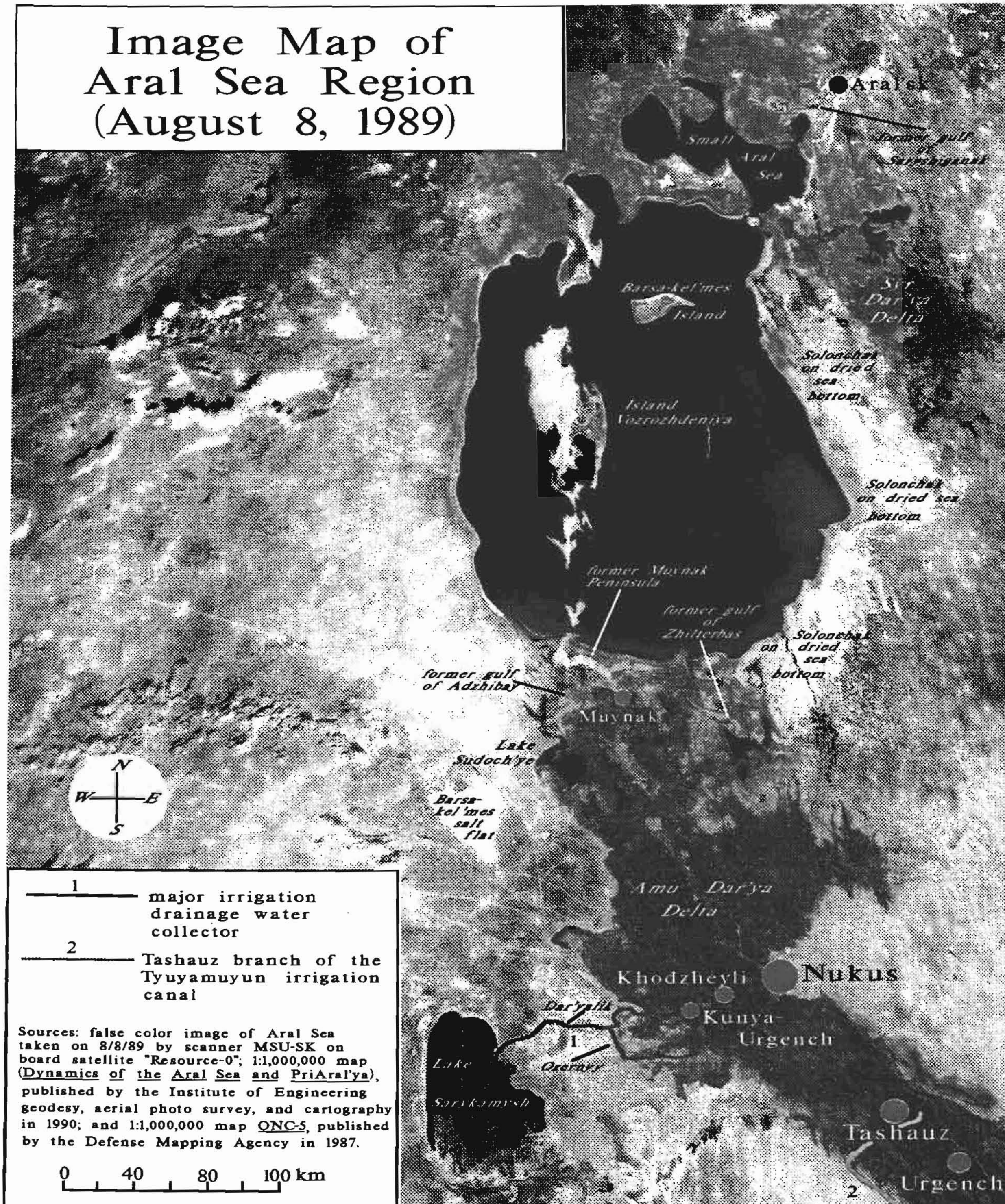
Image Map of
Aral Sea Region
(August 8, 1989)
Aral'sk
Small Aral Sea
Barsa-kel'mes Island
Syr Dar'ya Delta
Solonchak on dried sea bottom
Island Vozrozhdeniya
Solonchak on dried sea bottom
former Muynak Peninsula
former gulf of Zhilterbas
Solonchak on dried sea bottom
former gulf of Adzhibay
Muynak
Lake Sudoch'ye
N
W
E
S
Barsa-kel'mes salt flat
Amu Dar'ya Delta
Khodzheyli
Nukus
Dar'yalik
Kunya-Urgench
1
Ozerniy
Lake Sarykamysh
Tashauz
Urgench
2
1 major irrigation drainage water collector
2 Tashauz branch of the Tyuyamuyun irrigation canal
Sources: false color image of Aral Sea taken on 8/8/89 by scanner MSU-SK on board satellite "Resource-0"; 1:1,000,000 map (Dynamics of the Aral Sea and PriAral'ya), published by the Institute of Engineering geodesy, aerial photo survey, and cartography in 1990; and 1:1,000,000 map ONC-5, published by the Defense Mapping Agency in 1987.
0 40 80 100 km

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 However, since irrigation is a major consumptive user of water (i.e., a large proportion of water withdrawn is not returned directly to the supply source), rivers and ground water suffer significant depletion with attendant ecological, economic, and social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 daunting task. Many people are aware of what has happened in the American southwest. There, 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 over drafting, irrigation is in decline because of rising costs and competition for water from cities, and conflicts between water users are growing more bitter. (Ref. 1)

Problems in the Colorado River basin pale beside the management situation 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 negative consequences.

The Soviet government until the mid 1980s 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 pending a complete reevaluation. Local means of resolving water management problems are being pursued. However they may fall well short of expectations. If so, Soviet Central Asia will continue to suffer severe ecological, economic, and social consequences which likely will have profound political consequences as well.

1. Central Asia

1.1. Location

Soviet Central Asia lies in the southern Soviet Union, with the Caspian Sea on the West and mountain ranges (Kopet-Dag, Pamir, and Tyan' Shan) on the south and east (Figs. 1 and 2; figures are in Appendix A). 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; the former designation will be used in the rest of this study. For purposes of this study, Central Asia is defined to include the Uzbek, Tadzhik, Kirgiz, and Turkmen Soviet Socialist Republics (SSRs), constituting administrative Central Asia, as well as two of the southern *oblasts* of the Kazakh SSR (Kzyl-Orda and Chimkent). In terms of water management, it is logical to include the two *oblasts* as 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 square kilometers - 7.3% of the USSR's territory (Table 1; tables are in Appendix B). The region is mainly lowland desert but has mountains on the extreme south and in the southeast (with peaks over 7000 meters) which are characterized by foothill-steppe, mountain-steppe, and high mountain desert climates (Ref. 2; 6, 87, 206-213, 243-254 and folded end maps). Annual average precipitation in the lowland desert is from less than 100 millimeters (mm) to the south and east of the Aral Sea to near 200 mm approaching the foothills of the southeastern mountains. Potential Evapo-Transpiration (PET), a measure of water loss from the soil and plants assuming no moisture deficiency, ranges from 1000 mm in the north to over 2250 mm in the extreme south of the desert zone, 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 more humid with precipitation varying 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 Pamir and Tyan-Shan ranges are moist with average annual precipitation from 800 to 1600 mm and PET 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 Dar'ya, 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 $3{,}000^0$ C (degrees centigrade) in the north to over $5{,}000^0$ C in the south of the desert zone (Ref. 3; 100). In the foothills and valleys of the mountains, temperature totals range from 2000 to over 4000^0 C. Hence, conditions are favorable for raising crops needing heat 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 (Ref. 4).

A variety of soils are found here: serozem (desert), gray-brown desert, meadow, alluvial, sand, takyr (clay) and heavily salinized (*solonets* and *solonchak*) (Ref. 3; 104). These soils, with the exception of the heavily salinized, can be made agriculturally productive with irrigation. The area that could benefit from irrigation in the Aral Sea basin has been estimated in excess of 50 million hectares (ha) (Ref. 5), but this is likely a considerable exaggeration.

1.3. Water Resources and Water Use

Although most of Central Asia is desert, it has substantial water resources. Mountains on its southern and southeastern periphery capture the plentiful precipitation, storing most of it in snow fields and glaciers. Runoff from these, 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 cubic kilometers/year (km^3/yr) (Fig. 2; Table 2). The Aral Sea drainage basin accounts for 90% (110 km^3) of this. It, in turn, encompasses the drainage basins of the Amu Dar'ya [*dar'ya* in Turkic means river] (73 km^3/yr) and Syr Dar'ya (37 km^3/yr), and Kara-Kum Canal (0.25 km^3/yr). Eighty six percent of the flow in the Amu Dar'ya basin is accounted for by that river, but there are two terminal rivers (Zeravhan, 5.27 km^3/yr, and Kashkadar'ya, 1.34 km^3/yr) whose flow disappears in the desert before reaching the Amu's channel. 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 transpiration) and, consequently, heavy surface runoff. The desert zone, on the other hand, has opposite conditions, contributing essentially nothing to river flow while inducing substantial water loss owing to high evaporation rates, transpiration from phreatophytes (plants with deep root systems and high water requirements that grow along the banks and in the deltas of rivers), and bed losses to filtration. The Amu Dar'ya and Syr Dar'ya (until the 1960s) lost about half their flow before reaching the Aral Sea (Ref. 6; 235). According to Table 2, usable supplies of ground water (i.e., that are not hydraulically connected with river flow) are estimated at 18 km^3/yr. Thus, aggregate average annual water resources for Central Asia are around 140 km^3, with 90% (126 km^3) in the Aral Sea drainage basin.

River flow varies from year-to-year because of the natural interannual variation of precipitation, temperature, evaporation and other climatic variables. For the Syr Dar'ya and Amu Dar'ya basins, hydrological statistical analysis indicates that whereas their combined average annual flow is around 110 km^3 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 km^3 and a 5% chance that it will be less (Ref. 6; 227). Put another way, over the long term we could expect 19 of 20 years to have river discharge above 84 km^3 and 1 in 20 years below. On the other hand, there is a 5% probability the discharge of these basins will be more than 141 km^3 in any given year and a 95% chance it will be less. Thus, over many years we could expect more than 141 km^3, on average, 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 in an arid region such as Central Asia where the probability of having a certain quantity of water in a given year is a more essential consideration for decision making than average annual flow over a period of years. It also points up the fallacy of using average annual flows as the main indicator of a region's surface flow resources. Low flow conditions (90 or 95% exceedance probability) are more critical for proper water management planning in arid zones.

Water use in Central Asia is large. 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 (Ref. 7; 202-219). These data have been used to construct a water usage profile for Central Asia for 1980 (Table 3). Water withdrawals, including reservoir evaporation, are estimated at 145 km^3 with consumptive use (water directly lost to evaporation and transpiration or incorporated into plants, animals, or other products) of 80 km^3 (59% of withdrawals). The balance of 75 km^3 (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. Reservoir evaporation, in essence a consumptive use, was 11 km^3. Central Asia accounted for 39% of withdrawals and 49% of consumptive use nationally in 1980 (Ref. 7; 111).

Withdrawals in 1980 were 154% of low flow (95% exceedance probability), 118% 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). The corresponding figures are even higher for the Aral Sea basin: 170%, 130%, and 113%. 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. A better gauge 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 returned as precipitation).

Consumptive use and reservoir evaporation (together totalling 91 km^3) 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, where consumptive use plus reservoir evaporation was 89 km^3, the percentages were 106%, 81%, and 71%. However, even this measure understates the actual losses of water since a significant portion of return flow is lost to evaporation and transpiration and does not recharge ground water or reach the major rivers in Central Asia. An authoritative estimate is that of the 34 km^3 of irrigation drainage water generated annually in the drainage basins of the Amu Dar'ya and Syr Dar'ya in the early 1980s, only 21 km^3 (62%) returned to these rivers or their tributaries (Ref. 8). Adding the balance (13 km^3) to consumptive use plus reservoir evaporation gives a total of 102 km^3 and brings the percentages for the Aral Sea basin to 121%, 93%, and 81% of low flow, average annual flow, and average annual basin water resources. The combination of anthropogenic and natural losses had diminished the flow of the Amu Dar'ya and Syr Dar'ya in their lower reaches (and into the Aral Sea) to practically nothing by 1980 (Ref. 9).

Irrigation is by far the dominant use of water in Central Asia (Table 3). In 1980 at 121 km^3, it accounted for 84% of aggregate withdrawals, including reservoir evaporation, and 85% of consumptive use (including the 13 km^3 of return flows that are lost to evaporation) plus reservoir evaporation. It predominates in all drainage basins except the Caspian Sea's east coast where thermoelectric uses are primary. Thus, the water management crisis in Central Asia is caused by 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. Even relatively small savings in this sector could provide enough water to meet future needs of other economic branches, excluding those associated with the Aral Sea.

1.4. Population

According to the Soviet census of January 12, 1989, the population of Central Asia, as defined for this study, was 35 million, 12% of the USSR total (Table 1). The rate of natural increase (births minus deaths) averaged 2.54% from 1979-89, compared to a national figure of 0.87%. This is the most rapid growth of any region in the USSR, exceeding rates in many developing countries (Ref. 10). The growth rate of ethnic Central Asians was higher than this figure indicates since it was diluted by the substantial but much slower growing Slavic population living in this region. Fertility among the indigenous Muslim peoples, although falling since the mid 1970s, 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 (Ref. 11). These compared with rates of 2.4 for the USSR as a whole and 2.1 for the Russians and Ukrainians - the two largest Soviet 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 (Refs. 12 and 13). A recent study has detected increasing out-migration from the Central Asian republics during the 1980s (Ref. 14). However, it is still small (-0.2% in 1983) compared to rates of natural growth here and is almost entirely Russian and other Slavic groups in ethnic composition. 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. Optimistically assuming the slowing of the average growth rate (births minus deaths plus or minus net migration) in Central Asia to 2.0% for the period 1989-2000 and to 1.5% for 2001-2010, would still mean a population rising to 44 million, a 24% increase, by 2000 and to 50 million, a 42% increase, a decade later.

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 third place in the world in irrigated area, after China and India, and slightly ahead of 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. Since Gorbachev's rise to leadership in March 1985 and the introduction of his program of *peristroika* 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 shelter belt planting are receiving particular promotion as cheaper, more effective, and less environmentally harmful means of increasing agricultural production (Ref. 15).

Nevertheless, the final guidelines for the 12th Five Year Plan (1986-1990) scheduled the irrigated zone to grow by 3.3 million hectares from its 1985 level of 20 million ha - an increase of 14% (Refs. 16; 245 and 17; 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 (Ref. 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 much diminished pace in the 1990s.

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 (Ref. 19). Archaeological excavations have unearthed ancient irrigation systems along and between the Syr Dar'ya and Amu Dar'ya that provided water to several million ha beginning some 3500 years ago (Ref. 20). Since the consolidation of Soviet power in Central Asia in the early 1920s, irrigation has steadily expanded. By 1984 the irrigated area of state enterprises encompassed 7.2 million ha, around 40% of the national total

(Refs.: 21; 272-275 and 22; 97-100). By 1989, the irrigated zone was near 7.8 million ha (author's estimate).

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. 3. 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 sown to crops with the residual used for gardens, orchards, and vineyards; hay fields and pastures; and private plots. Technical crops (almost entirely cotton) were planted on the largest area, followed by fodder crops (grasses, alfalfa, corn for silage), grains (corn, rice, winter wheat, barley), and potatoes, vegetables, and melons. However, there was considerable diversity within the region in terms of relative crop importance according to area planted: cotton was dominant in the Uzbek, Kirgiz, and Tadzhik republics as well as in Chimkent oblast, whereas fodder crops and grains were 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 is third in the world in cotton production (after Egypt and the U.S.), with over 90% of output from Central Asia (Ref. 23). All the Soviet Union's cotton is irrigated. This is far and away the region's most important crop. In 1986 the total harvest of raw cotton in the USSR was 8.2 million metric tons with the Uzbek Republic accounting for 61%, the Turkmen for 14%, the Tadzhik for 11%, Chimkent Oblast of the Kazakh SSR for 4%, and Kirgizia for 1% (the remaining 9% was grown in Azerbaijan) (Ref. 16; 228). Nearly all the raw cotton is ginned here and a portion of this goes to the local textile and clothing industry. But the dominant share of the cleaned and pressed fiber (around 88% in the late 1980s) is shipped to other parts of the USSR, particularly the Central Region around Moscow, for processing and manufacture (Ref. 24). Central Asian cotton varies considerably in quality with the best grades (long and fine fibers) produced in the southern part of the region. A portion of the processed fiber (713,000 tons or 27% in 1986) is exported from the USSR (Ref. 16; 641).

Thus, cotton production in Central Asia earns foreign exchange for the USSR as well as meeting a national need for this commodity. Indeed, Central Asians trace the heavy emphasis on cotton production for their region directly 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" (Ref. 25). Cotton raising 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), and also bringing in considerable money from outside the region since it functions largely as a "basic industry". Cotton is frequently referred to as "white gold" in terms of its economic importance to Central Asia (Ref. 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 vegetables and melons are grown on irrigated lands here (Ref. 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 hectarage (Ref. 16; 227, 233, 248). The Uzbek SSR, with the largest irrigated area of the Central Asian republics, received 69% of grain, 56% of vegetable, 69% of potato, 60% of melon, and all rice production from irrigated lands in 1987 (Ref. 27; 100, 101, 123). Reportedly over 90% of aggregate crop production in the region depends on irrigation (Ref. 28).

Yields from irrigated lands are also much above those on unirrigated lands. For example, grain yields from irrigated compared to unirrigated fields in the four Central Asian republics (Uzbek, Kirgiz, Tadzhik, and

Turkmen) were 30.7 against 9.8 centners/ha in 1985, a ratio of over 3:1 (Ref. 21; 208-209, 230-231). From 1960 to the mid 1980s, irrigation expansion in Central Asia allowed agricultural production to increase by 8.6 billion rubles (in constant 1973 prices) or more than two fold (Ref. 29). With inclusion of related branches of industry and construction, the joint contribution to the growth of the social product was 21.5 billion rubles and led to an increase in employment of 3 million.

Given the certainty of continued substantial 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. Inadequate food supplies are already a problem for the region. Per capita consumption is significantly below the national norm for a number of basic foodstuffs (Ref. 30). Per capita consumption of meat, milk, and eggs in Uzbekistan dropped during the 1980s to less than 50% of national levels (Ref. 31). Problems have become especially serious in rural areas of the republic where consumption of meat and meat products by collective farmers is only 14%, and of milk and milk products 45%, of the level considered necessary for optimum health (Ref. 32).

Although not the only means to meet employment and food needs, irrigation has several advantages. It is labor intensive and many operations do not require highly skilled workers. This 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 (Ref. 12; 8-13). Irrigation's importance to food production in this arid region is obvious. Crops can be grown without irrigation on the humid slopes of the region's foothills and in mountain valleys; animals can be raised on natural pastures. But crop yields and meat production are much lower and more variable than on land with irrigation. To satisfy rapidly growing food needs mainly by stressing non-irrigation production modes would be difficult to say the least.

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Until the mid 1980s, 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 Uzbek, Tadzhik, Kirgiz, and Turkmen SSRs (Ref. 17; 77-84). The long-range reclamation plan to 2000 stipulated that irrigation in the four Central Asian republics should expand to 8.2-9.0 million ha by the turn of the century - 23-27% above 1985 (Ref. 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 was drastically reduced (Ref. 28) The projected annual increase in the irrigated area for Central Asia and southern Kazakhstan was lowered from 160,000 to 50,000 for the remaining years of the 12th Five Year Plan (1988-90) (Ref. 33).

2.4. Water Use in Irrigation and Its Efficiency

Irrigation is the major user of water in Central Asia. Withdrawals for it were 121 km^3 in 1980, or 84% of all withdrawals, including reservoir evaporation (Table 3). Irrigation is a heavily consumptive use of water and significantly depletes river flow. In 1980, an estimated 62% of the water withdrawn for irrigation was consumed and 38% constituted return flows. Consumption is actually a larger share of withdrawals since a significant 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 by the early 1980s the water resources of the two primary rivers of Central Asia, the Amu Dar'ya and Syr Dar'ya, were fully utilized. A 1988 estimate put total withdrawals for irrigation around 100 km^3 in these two river basins, with 35 km^3 lost to filtration (in main, inter-, and intrafarm distribution networks and at the fields where the water is applied) (Ref. 25). Of total filtration losses, 14 km^3 was ultimately consumptively used, suggesting 21

km^3 (35 minus 14), or 21% of withdrawals, constituted water returned to rivers and 79 km^3 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 (Ref. 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.

Water management in Central Asia and its improvement has become a controversial issue since the mid 1980s. Critics of irrigation, most of whom have no professional training in the water management field, contend that water wastage associated with this activity is enormous and that large amounts of water can be freed that will be sufficient to meet regional needs far into the future (Refs. 35 and 36) Water management specialists, on the other hand, are much more cautious, alleging the amount of water that can saved is much less than the optimists believe, and will somewhat alleviate but by no means "solve" regional water problems, furthermore, they conclude 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 poleznogo 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[field]/W[withdrawn]) and is simply the product of the efficiencies of the main, interfarm, and intrafarm canals which bring the water to field side. Thus, if the respective efficiencies for each are 0.9, 0.8, and 0.7, the aggregate KPD would be 0.5 or 50% (Ref. 37; 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 (Ref. 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% (Refs. 23 and 38). These figures, characteristic of the early 1980s, indicate that at least 40% of the water withdrawn was lost before it reached the fields, primarily due to filtration from earthen canals. Based on the 1980 estimate of 121 km^3 withdrawn for irrigation (Table 3), this equals 50 km^3.

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. This method has the advantage of taking into account unproductive water losses during the irrigation process (e.g., percolation of applied water downward into the ground water zone and surface runoff from the field into adjoining lands). However, the latter is considerably more difficult to calculate than the former. Nevertheless, this approach has been employed to calculate irrigation efficiencies for the main irrigation zones of the Amu Dar'ya and Syr Dar'ya basins for 5 year periods from 1960 to 1980 (Ref. 39).

The authors of one study wrote the irrigation water use equation thusly: W[withdr] = W[prod] + W[ret] + W[unprod] + W[drain], where W[withdr] is water withdrawn at the head works for irrigation; W[prod] is the amount of withdrawn water used productively by crops; W[ret] is the volume of return flow from irrigated areas that re-enters the river network by surface and ground water flow; W[unprod] is the quantity of withdrawn water that is lost to unproductive evaporation in unirrigated lands within irrigated areas 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[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 (Ref. 39).

According to this research, withdrawals for irrigation rose from 30.8 to 55.5 km^3/yr between 1960-65 and 1976-80 in the Amu Dar'ya basin and from 30.7 to 37.6 km^3/yr in the Syr Dar'ya basin between 1960-65 and 1976-78. Total withdrawals for the two basins thus rose from 61.5 km^3 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 km^3/yr between 1960 and 1980, are not included (Ref. 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 m^3 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 m^3/ha between 1960-65 and 1976-78. Combining data for the two basins, withdrawals rose from 17,088 to 19,283 m^3/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 m^3/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 m^3/ha and somewhat raises the aggregate rate for the Amu Dar'ya and Syr Dar'ya basins to 19,682 m^3/ha. There is great regional variation in withdrawal rates with the lowest in the Amu Dar'ya basin found in Samarkand Oblast (Zeravshan River drainage) (12,600 m^3/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 m^3/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 annual irrigation withdrawals (52 out of 93 km^3) 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 km^3 or 25% of withdrawals in the Amu Dar'ya basin and 12.9 km^3 or 34% of withdrawals in the Syr Dar'ya basin, was estimated to be return flows (W[ret]) which re-entered the river network by surface or ground water routes. Hence, water actually lost from further use in both basins taken together was not 52, but about 25 km^3 (52 minus 26.8 km^3).

The above analysis suggests that as of the late 1970s there were major opportunities for water savings in Central Asia through improving irrigation efficiency. Ideally, one would like to raise the KPD of an irrigation system to 1, meaning no water loss in transportation from source to field. This is technically impossible and even to come close is economically unjustifiable. Soviet water managers have set a goal of raising the efficiency of irrigation systems in Central Asia, on average, to 80% (Ref. 42). This refers to the simpler measure of system efficiency as the ratio of water arriving at field side to withdrawals. Accepting the average efficiency here in 1980 as 60% and withdrawals for irrigation around 120 km^3 (Table 3), raising the average KPD to 80% (a 25% improvement in efficiency) would have allowed irrigating the same area with withdrawals of only 90 km^3, 30 km^3 (25%) less than was actually withdrawn. Net savings, again, would be less since part of water lost in the delivery network ends up as return flows to rivers.

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 (Ref. 43). He estimates that average withdrawals for irrigation (including water used for flushing excess salt from fields during the winter) in Central Asia averaged 16,700 m^3/ha in 1980 with 39% of the withdrawal productively used. Modern irrigation systems here withdrew 11,000 m^3/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 m^3/ha and raise the productive efficiency to 65%. These water use improvements would be brought about by reducing losses in (1) the water delivery and distribution network (the main, interfarm, and intrafarm canals), giving 34% of savings; (2) at the fields (21% of savings); (3) through reductions in water used for flushing salt from the fields (30% of savings); and (4) by diminishing evaporation and transpiration (15% of savings).

The improvement of irrigation efficiency in Central Asia has been a priority since 1982 when tight water supplies forced imposition of strict limits on water consumption (Ref. 44; 22). It has received additional emphasis under the Gorbachev regime as part of the general program for agricultural intensification and was given the highest priority for the 12th Five Year Plan (Refs. 28 and 46).

The irrigation efficiency improvement program has produced some 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 (Ref. 42). As a result, the KPD of irrigation systems (ratio of water arriving at field side to water withdrawn) 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 m^3/ha (30). He also indicates that average withdrawals in the Central Asian region dropped from 18,700 m^3/ha in 1980 to 13,700 m^3/ha in 1986 (Ref. 44; 22). However, 1986 was a very low flow year which necessitated especially strict limits on water use in irrigation and, thus, the figure for this year may exaggerate the improvement trend (Ref. 34). Withdrawal rates in 1985 were around 16,000 m^3/ha (Ref. 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 km^3 (Table 3). The improvements in efficiency since then have allowed around a 25% increase in the irrigated area (from 6.2 million to around 7.8 million ha by 1989) with a decrease in water withdrawals from 116 to 107 km^3, based on Dukhovnyy's figures for average withdrawals per hectare in 1980 and 1986. Using Dukhovnyy's 1980 number and the figure of 16,000 m^3/ha characteristic of 1985, implies a slight increase in withdrawals, from 116 to 125 km^3.

Irrigation efficiency in Central Asia can be improved further (Ref. 47). Employing Dukhovnyy's figures for 1986 of 13,700 m^3/hectare as typical of average withdrawal rates for the late 1980s, and 8,000 m^3/ha as a target, suggests it might be possible to irrigate 7.8 million ha with withdrawals of 62 km^3 - a reduction of 45 km^3. Other experts believe the minimum obtainable average withdrawal for irrigation in the Aral Sea basin, which is estimated to have had 96% of the irrigated area in Central Asia, as defined for this study, in 1989, is higher. The Deputy Minister of the former Ministry of Reclamation and Water Management, P. Zade, considers that evaporation and transpiration from irrigated fields and flushing consumptive losses, taking into account partial reuse of the latter, can be reduced to an average of 7000 and 1500 m^3/ha, respectively (Ref. 48). Thus, total minimum average field side losses would be 8500 m^3/ha. Assuming the average efficiency of the irrigation water delivery network can be raised to 80%, implies around 10,600 m^3/ha would need to be withdrawn at the source to supply 8,500 m^3/ha at the field. This figure is close to the 11,000 m^3/ha for minimum obtainable average irrigation withdrawals calculated for Uzbekistan, the republic which has by far the largest irrigated area in Central Asia (Ref. 49). Using the 10,600 m^3/ha figure means that at least 83 km^3 would need to be withdrawn to irrigate 7.8 million ha, resulting in withdrawals 24 km^3 lower than with a withdrawal rate of 13,700 m^3/ha. Net water savings from improved efficiency would be much less than 45 km^3 or 24 km^3 because of reduced return flows to rivers (i.e., net savings = withdrawal reduction - return flow reduction).

Soviet studies support the conclusion that water savings in Central Asia are considerably smaller than they appear at first glance. 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 km^3 withdrawn for this purpose (Ref. 44; 7). N.R. Khamrayev of the Uzbek Council for the Study of Productive Forces, estimated that 60 km^3 are "lost" in the Aral Sea basin: 40 km^3 to evaporation from irrigated lands, 15 to 20 km^3 to evaporation from river flood plains and hollows flooded by drainage from irrigated zones and in collector-drainage systems and other discharges, and 2 km^3 from reservoir evaporation (Ref. 41). However, he considered only 9 out of the 40 km^3 to be unproductive evaporation and felt that it is feasible to reuse about 10 km^3 of collector-drainage water. Thus, maximum potential water savings would be around 20 km^3. In reality, they would be somewhat less since some of the 10 km^3 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 to improve the water use situation in Central Asia. Rebuilding of older irrigation systems to reduce water losses has received and continues to receive the greatest attention. Given the region's long history of irrigation development, 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 (Ref. 30). These systems were built with earthen canals and crude water withdrawal facilities and had infrequent drainage channels of an open (surface) type. Consequently, they have suffered from low water use efficiencies.

To provide funds for reconstruction of old systems, the development of new irrigated lands has been slowed in Central Asia and the freed capital devoted to the renovation effort. Reconstruction of irrigation systems nationally was to receive 45% of all investment in reclamation during the 12th Five Year Plan (1986-90), compared to 18% in the 11th Five Year Plan, whereas the figure rises to 70% in Central Asia (Refs. 25, 28 and 30). In the Uzbek SSR a minimum of 100,000 ha/yr were to be renovated (Ref. 38). This program, by the early 1990s, is supposed to bring all old irrigation systems in Central Asia up to modern standards (Ref. 28).

Reconstruction involves implementation of a complex of measures. Fundamentally important is the reduction of filtration and evaporation from main and distributary canals. A late 1980s estimate was that 35 km^3 are lost to the former from irrigation canals in the basins of the Amu Dar'ya and Syr Dar'ya (Ref. 25). 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 filtration and evaporation 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% (Ref. 50; 68).

However, lining and other anti-filtration measures are expensive. Concreting medium size canals in Central Asia costs 250,000-400,000 rubles/km (Ref. 51). Considering that there are 165,000 km of interfarm irrigation canals in only the Uzbek SSR, long stretches of which are still unlined, one obtains some idea of the magnitude of the task (Ref. 47). Anti-filtration measures, in general, are reported to run 800-2000 rubles/ha (Ref. 43). Because of the high cost as well as a shortage of concrete, a universal policy of lining earthen canals is not justified in Central Asia (Ref. 51). Small and medium capacity canals with efficiencies of 60-70%, in most cases, should be lined. But medium and large capacity canals with efficiencies 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 (Ref. 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 ground water at an optimal level (this depends on site specific conditions but, usually, is around 3 meters below the surface), thereby minimizing water logging and soil salinization caused by the deposition of salts as saline ground water rises to the surface by capillary action and evaporates (Ref. 52; 114-127). Most of the older irrigation systems in Central Asia either lack engineered drainage networks entirely, or have crude, ineffective open channels, frequently choked with weeds. Modern systems are of a horizontal or vertical character. The former consist of perforated metal or plastic pipes placed at shallow depths beneath the field surface. The latter are wells spaced at even intervals over the field. Excess soil and ground water collects in the pipes or 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 water logging 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 late winter-early spring period is greater than that expended over the subsequent growing season (Ref. 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. A major campaign has been mounted to correct the problem. In the Uzbek SSR alone, 26,000 km of surface drainage pipe were to be laid over 390,000 ha of irrigated lands in the 12th Five Year Plan (1986-1990) (Ref. 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 (Ref. 52; 16-27). Application of water into furrows is the most widely used surface technique in Central Asia; other methods are the 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. 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 water (Refs. 33 and 43). Dukhovnyy estimates that field-side efficiency 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 (Ref. 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 (Ref. 52; 19). Soviet reclamationists consider it possible to cut unproductive losses at the field associated with surface methods of irrigation from their late 1980s level of 30% to 16% (i.e., to raise the field- side efficiency from 70% to 84%) by 2010 (Ref. 33).

There are more modern, efficient irrigation technologies than surface application such as sprinklers, drip, and intersoil whose use could be expanded in Central Asia. The use of sprinkler irrigation has increased rapidly in the USSR and was employed on 43% of irrigated lands in 1986 (Ref. 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 terrain, eliminating the cost of levelling (Ref. 52; 9-15, 47-92). On the other hand, sprinkler systems are usually more expensive and energy consumptive than surface mechanisms 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 southeastern European Russia (Ref. 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 field-side efficiency to 65-70%. Innovative sprinkling methods adapted for desert regions hold promise such as 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% (Ref. 52; 88-93).

Drip irrigation applies water at the base of the plant whereas intersoil delivers it to the root zone (Ref. 52; 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). 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 (Ref. 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 (Refs. 33 and 43).

Besides saving water, the various irrigation improvements discussed above also contribute to better soil and crop growth conditions, raising yields and reducing losses 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 precise water application methods and effective drainage aid in combatting the widespread, serious problems of erosion, water logging, leaching and secondary salinization typical of the older irrigated zones in Central Asia (Refs. 53 and 54). From 40 to 50% of irrigated land in Central Asia suffers from salinization causing yields in Uzbekistan to be reduced 20-25%. (Refs. 36, 37, and 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 (Ref. 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 (Ref. 51). Such information is still woefully inadequate; rectification of this deficiency is considered fundamental to improved water management planning (Ref. 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 via centralized management (Refs. 38; 56, 57, 58 and 59). In Kirgizia, 21 irrigation systems with 400 km of main and distributary canals were automated by the mid 1980s. It was planned 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 were in use by the mid 1980s. The largest irrigation facilities in the republic, which distribute a total of 20 km^3 of water, were automated. However, they accounted for only 40% of the 50 km^3 used for irrigation in the republic. The process of combining separate, partially automated systems into fully integrated basin-wide systems of water management (ASUB = *avtomatizurovanniye sistemy upravleniya vodnymi resursami basseynov rek*) is underway in Uzbekistan and, when completed, will allow the automated distribution of water over an area of more than 1 million ha, equal to one fourth of the irrigated area in 1988. 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 the establishment of basin-wide water management directorates for the Syr Dar'ya and Amu Dar'ya (Refs. 33 and 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 allocation, taking into account the interests of all water users. Soviet water management experts reported at the Sixth World Water Congress in June 1988 (Ottawa, Canada) 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 in 1988, subordinated to *Minvodkhoz,* USSR (Ref. 33). The management system for the Syr Dar'ya was operational by the end of the 1980s, but the status of the Amu Dar'ya system is unclear.

The title of the Ministry of Reclamation and Water Management (*Minvodkhoz*) was changed to the Ministry of Water Construction (*Minvodstroy*) in 1988. This was accompanied by a diminution of its ability to control water use and allocation in Central Asia. Authority to enforce the limits on water withdrawals established annually by Gosplan was removed (Ref. 60). If these are exceeded, the matter must now be referred back to

Gosplan in Moscow and in complicated cases even to the Council of Ministers (now the Cabinet of Ministers) of the USSR. Republics are also asserting the right to control water usage within their territory through the Soviets of Peoples' Deputies. According to water management experts, the lack of an independent state organization with power to regulate water use in Central Asia is contributing to excessive withdrawals and wasteful use as each republic attempts to manage its own water resources without taking account of the interests of its downstream neighbors. This has also led to water disputes between republics (Ref. 60). *Minvodstroy* was abolished in June 1990 which will likely make the situation even worse.

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) (Refs. 57 and 61). 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 (Ref. 62). 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 (Ref. 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 rice (for which withdrawals along the lower course of the Syr Dar'ya can reach 40,000 m^3/ha) to lower water consuming crops such as small grains, vegetables, melons, and fodder plantings (perennial grasses, alfalfa, corn) which would not only lower per hectare withdrawals, but contribute to the direly needed improvement of regional food crop and milk and meat supplies (Ref. 51). An added advantage is higher profits: corn and other fodder crops give 130 rubles/ha, calculated in terms of milk and meat production, versus 30-50 for rice (Ref. 64). The beginnings of such a shift is underway in Central Asia (Refs. 31 and 65).

Cotton growing, in particular, has been severely criticized (Refs. 66, 67 and 68). It has moderately high water requirements (although one suggested substitute, alfalfa, can use twice as much) and contributes to soil deterioration by removing large amounts of key nutrients and promoting erosion. Cotton has also been implicated in water pollution and health problems associated with the very heavy use of pesticides, defoliants, and fertilizers. Finally, 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 have caused a negative reaction to this crop.

Nevertheless, cotton will continue to be the dominant irrigated crop in Central Asia for the foreseeable future because of its existing infrastructural support and great economic importance to the region, particularly to Uzbekistan (Ref. 31). An optimum production model formulated for Uzbekistan by the SANIIRI suggests the area planted with cotton should decrease from 62% of the irrigated sown area in 1986 to 37% in the (unspecified) future (Ref. 64). Efforts are also underway to lower unproductive water losses from cotton fields by optimizing the plant density and to raise yields of cotton, mainly by instituting and enforcing more frequent rotations with alfalfa to maintain soil fertility. The latter measure 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 (Refs. 31 and 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 (Ref. 43). Established norms, which are frequently and significantly exceeded in Central Asia, are believed above what is optimal for crop growth. A related suggestion is switching to night irrigation, thereby lowering evaporative losses (Ref. 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 sufficiently mineralized that it cannot be employed for irrigation without desalination. 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 without pretreatment may be only 18 km^3/yr (Table 2).

A larger share of irrigation drainage water could be reused. Its volume in the early 1980s was estimated at about 34 km^3/year in the Aral Sea basin (Ref. 8). Approximately 21 km^3 (60%) returned to rivers from which withdrawn and was reused. The remaining 13 km^3 ran onto fallow lands (*perelog*) 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 *perelog*, by planting crops on the *perelog*, and by installing interception networks around irrigated areas to collect the drainage water for reuse for irrigation or discharge to rivers (Ref. 41). However, a substantial portion of the drainage water has such high salinities from leached salts that without dilution it would severely damage most crops (Ref. 70). Drainage water with salinities up to 3 grams/liter could be used for irrigating rice, a salt-tolerant crop (Ref. 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 periods for use in low flow seasons and years and increases usable water resources. Reservoirs completed or under construction in the basins of the Amu Dar'ya and Syr Dar'ya have a usable storage capacity of 55 km^3 (Ref. 71; 118). When finished (scheduled around 1995), these will allow the available (regulated) water resources of these rivers to be raised to 107 km^3 during a 90% flow exceedance year (occurring, on average, one in ten years), compared to a flow in the absence of storage of 84 km^3 (an increase of 23 km^3 or 27%) (Ref. 72). However, 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 phreatophytes growing on their banks, and filtration; raise ground water levels of adjacent territory, leading to water logging and soil salinization; and markedly reduce the downstream flow of water, sediments, and nutrients with harmful environmental consequences, particularly for the deltas of the Amu Dar'ya and Syr Dar'ya (Ref. 73). One means of reducing evaporative, transpirative, and filtrative losses from reservoirs in

Central Asia is to store 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 (Ref. 41).

Two other means of increasing usable water resources in Central Asia deserve mention. Central Asia has many small, ephemeral streams as well as *takyr* (clay) 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. Evaporation and transpiration from flood plains 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, which, however, cause a variety of ecological problems (Ref. 41).

2.56. Institutional and Economic Measures.

Economic and institutional changes could contribute to the improvement of irrigation 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* and *uskoreniya* (acceleration) as stimuli to improving the performance of all economic sectors. The main components of the program (*khozraschyet,* economic or balance sheet accounting, *samookupaemost',* or self-capital financing, *samofinansirovaniye,* or 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 (Refs. 28, 45, 74 and 75).

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. (Refs. 28, 47, and 76). Such 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 be or are not utilized. Central Asia has been singled out as being especially seriously afflicted by these difficulties.

A serious problem 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 (Ref. 77). This situation could be improved in Uzbekistan by consolidating multiple operational and repair organizations in each district (*rayon*) into one service - the district repair-operational association for reclamation and water management (Ref. 78). Such an 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 lakes and rivers since 1982 and from ground water since 1984, water used for domestic and agricultural purposes is provided at no charge (Refs. 79-81). Since 1985, critics of irrigation have argued that the best way to encourage efficient water use in this sector is to establish a meaningful charge for water use (Refs. 79, 82, and 83). The now disbanded Ministry of Reclamation and Water Management and its former Minister, N.F. Vasil'yev, were originally opposed or lukewarm at best to this idea, although other water management experts familiar with Central Asian problems, such as Victor Dukhovnyy, favored it (Refs. 43, 80, and 82).

However, by the late 1980s, the water management apparatus had accepted the inevitability of some kind of charge for irrigation water.

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 (Refs. 84 and 85). These payments were abolished when collectivisation was implemented 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/m^3 was levied on water used directly for irrigation and 0.035 kopecks/m^3 for water employed in flushing soil salts. The payments were dropped in 1957 because of deleterious effects on economically weak farms.

The most recent experiment with water pricing for irrigation began in the Kirgiz SSR in 1977 (Refs. 84 and 85). The system has promoted more efficient water use and lowered waste, improved water accounting, 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 few stimuli 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 these would be covered by outside funds.

The system for pricing irrigation water is now under discussion and debate is more comprehensive and far-reaching than past efforts (Ref. 85). 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 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 some problems (Ref. 84). Water prices levied on weak farms could worsen their economic situation and, in turn, adversely affect management organizations working under full *khozraschyot*, which would be 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, are not equipped for this. To outfit both interfarm and intrafarm irrigation nets with adequate facilities could easily cost 250 million rubles. Also, much more comprehensive record keeping of water usage than has been practiced in the past would be needed along with a 6,000 to 7,000 increase in personnel. Finally, sucess of an irrigation water fee system is dependent on the government (or, in a less regulated economy, market forces) increasing prices of agricultural products from irrigated lands to include water costs. This could substantially raise food prices, promoting further social unrest and instability. Some have 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-financed and not dependent on state subsidies, to raise the state purchase prices for agricultural products from irrigated farms.

Recognition of the above problems 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 (Ukraine) (Ref. 84). Based on this experience, it is planned to implement water charges for irrigation nation-wide in 1991 (Ref. 86). However, for a time after their introduction, there will likely be provisions such as bonuses, tied to performance, for economically weak farms and a gradual increase of water prices toward a full recovery cost level to alleviate some of the harsher consequences for water management organizations and irrigated farms (Ref. 85).

2.6. The Future of Irrigation

Irrigation in Central Asia faces an uncertain future. The ultimate success of programs to save water and generally improve irrigated agriculture is open to question. Past campaigns to solve basic 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 (Refs. 31, 47, 65 and 76). 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 water logging 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 (Ref. 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 whether 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 (Ref. 86). Several experts have placed the cost of saving one cubic kilometer of irrigation water at 2-3.5 billion rubles (Ref. 87). Thus, the "low" estimate of future water savings here (10 km^3) could run 20-35 billion rubles. This does not include the costs associated with loss of agricultural production from irrigated lands undergoing 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 certain. A Central Asian water management official 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 (Ref. 88).

Forecasting the limit of expansion of irrigation in Central Asia based on local water resources and in conjunction with the 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.

Some estimates by Soviet water management experts are available. Dukhovnyy and Razakov of SANIIRI state 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 (Ref. 30). This would represent about a 12% growth over the estimated 1989 irrigated area of 7.5 million ha while freeing a net 10 km^3. The water saved 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 (Ref. 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 km^3 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. 2 and Table 2) can be increased to 127.6 km^3, of which 119.4 and 8.2 km^3 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 third 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 lst 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 there is more constrained by lack of water. The irrigated area (3.1 million ha in 1985) grows to 3.3 million ha in stage one and to 3.6 million ha in stage four. Regulated flow is 35.2 km^3/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 fourth 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 one to four 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 km^3. Withdrawals for irrigation would vary from 97 in stage one to 111 km^3 in stage four whereas withdrawal rates would decline from 13,600 to 12,700 m^3/ha. Aggregate water withdrawals for stages two to four in variant II and for stages three and four in variant III are 1-10 km^3 above average annual basin water supply of 128 km^3 but return flows for the different stages are 46-51 km^3, an unspecified part of which is reused or replenishes the rivers. On the other hand, a portion of river flow (around 13 km^3) 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 km^3) 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 second stage (7.7 million ha) would result in a "deficit" water management balance ranging from 1 to 8 km^3. 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 one to four (7.4 to 7.7 million ha). Consequently, there is a slight downward trend in both aggregate withdrawals (124 to 121 km^3) and irrigation withdrawals (99 to 95 km^3) as water use efficiency improves with time (from 13,400 to 12,300 m^3/ha). In all stages aggregate withdrawals remain below basin water supplies by about 4 km^3. Return flows range from 41 to 45 km^3 of which the highly mineralized portion is 11-13 km^3. Around 13 km^3 are lost to evaporation or reserved for other purposes. All stages have a positive water management balance, ranging from 4-7 km^3. On the other hand, aggregate withdrawals for this scenario considerably exceed basin water resources of 110 km^3 available during a low flow (90% exceedance probability) year.

In spite of the problems associated with estimating the limits of irrigation in the Aral Sea basin, which contained 96% of Central Asia's irrigated area in 1989, 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 6 to 13% above the 1989 area of around 7.5 million ha and will likely, if obtainable, be reached by the mid-1990s or 2000.

This raises fundamental social and economic questions. How will employment be provided for the many new entrants to the labor force? Will greater emphasis be placed on urbanization and industrialization, what will be its nature, and where will water for this be obtained? If it is gained by transfers from irrigation, as is happening in the American southwest, it could not only prevent expansion but require contraction of the irrigated area. What will be the consequences of freezing or contracting irrigation for local food production? Will food supplies 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 large-scale emigration to areas with more plentiful water supplies become a necessity for Central Asia in order to bring population size 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.

3. The Aral Sea Problem

3.1. Introduction

The Aral Sea is a huge, shallow, saline waterbody located among the deserts of Central Asia (Fig. 4). A terminal lake (having no outflow), its 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 (Refs. 89 and 90; 277-297). The most recent filling began in the late Pleistocene, around 140,000 years ago, when the Syr Dar'ya, entering from the east, filled 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 from the south. 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, level fluctuations were at least 20 m and possibly more than 40 m (Ref. 89 and 91). Significant variations of sea level were caused by major fluctuations of river discharge into the Aral related to climate change; by natural diversions of the Amu Dar'ya's course westward away from the Aral caused by the buildup of alluvial deposits in its bed; and during the past 3000 years by man. Human impacts included sizable irrigation withdrawals and periodic diversions westward into lower lying channels and hollows because of the destruction of dikes, dams, and irrigation systems in the river's lower reaches during wars (Refs. 89 and 19).

From the middle 18th Century until 1960, sea level changes were within a 4 to 4.5 m range (Refs. 89 and 92). For the period from 1910, when accurate and regular level observations began, to 1960, the lake was in a "high" phase with level variations of less than one meter (Ref. 93). However, during the past 30 years the sea's surface has dropped rapidly. In 1960, sea level was 53.4 m, area 68,000 km^2, volume 1090 km^3, average depth 16 m, and average salinity near 10 g/l (Refs. 94 and 95; 42-43). The Aral was the world's fourth largest lake in area, behind the Caspian Sea, Lake Superior, and Lake Victoria. By 1989, sea level had fallen more than 14 m, area decreased by 40%, volume diminished by two- thirds, and average salinity risen to 30 g/l (Fig. 5). 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 several thousand years (Ref. 89). Desiccation continues at a rapid pace and if unchecked will shrink the sea to several briny remnants in the next century. The result has been severe and widespread ecological, economic, and social harm which is worsening as the Aral dries. The scale and magnitude of impacts on such a large waterbody over so short a period is unprecedented. Soviet commentators have characterized the Aral situation as "one of the very greatest ecological problems of our century (Ref.

96)," an "impending disaster (Ref. 97)," and as "a dangerous experiment with nature (Ref. 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 Dar'ya and Amu Dar'ya, the sea's sole sources of surface water input, that has increasingly shifted the water balance toward the negative side (Table 6). Excepting the heavy flow year of 1969, river discharge has trended steadily downward since 1960 (Fig. 6). Consequently, the gap between water gain and loss has steadily increased and, accordingly, the sea's level and area have diminished at an accelerating pace.

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 residual level of surface- and ground-water inflow, the Aral should stabilize. In the absence of human intervention, this is not likely to occur for decades. The primary determinant of level change, the difference between inflow and net evaporation (evaporation from the sea surface minus precipitation on it), 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 km^3/yr (27%) compared to the average over the preceding 45 years (Refs. 95; 42-43, and 6; 227). Naturally low flows also occurred in 1982 and 1986 (Refs. 8, 46 and 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 Dar'ya and Syr Dar'ya for several millennia (Ref. 19). In antiquity and again during the middle ages, the irrigated area in the Aral Sea basin may have reached 5 million ha (Ref. 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 loss from it reached an estimated 40-44 km^3 (Refs. 39, 89 and 100; 312-322). Irrigation withdrawals prior to the 1960s did not excessively reduce inflow to the Aral. These artificial losses were largely compensated by 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 flood plain inundation, the area of deltaic lakes, and the expanse of phreatophytes (Refs. 6; 225-240, 100; 312-322, and 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 million ha (Table 2). Withdrawals from the Amu Dar'ya and Syr Dar'ya drainage basins were 143 km^3, with consumptive use and evaporation from reservoirs estimated at 89 km^3 (Table 3). As explained in section 1.3, actual consumptive use was probably at least 13 km^3 higher than this, for a total of 102 km^3 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 km^3 (84% of the total) and consumed 87 km^3 (83% of the total for this category). For 1980, withdrawals in the Aral Sea basin were 130% of average annual surface flow of 110 km^3 and 113% of average annual water resources (surface flow + usable ground water) which equaled 126 km^3 (withdrawals can be more than 100% of the resource because return flows are repetitively used downstream). Consumptive use plus reservoir evaporation, a more accurate measure of the strain on the regional water balance, at 102 km^3 was 94% of average annual flow and 81% of average annual water resources. Irrigation in the Aral Sea basin grew to around 7.5 million hectares by 1989, a 25% increase over 1980. Because of improvements in irrigation efficiency since 1980, this resulted in little or no increase in aggregate water withdrawals, although consumptive use necessarily rose.

Factors that compensated the earlier growth of consumptive withdrawals reached their limits in the 1960s (Refs. 89, 7; 225-240, 100; 312-322, and 101) Hence, as irrigation in the Aral Sea basin grew from around 5 to 7.5 million ha, a 50% increase over the past three decades, consumptive water usage associated with this activity more than doubled from 40 to over 90 km^3. But the rise in consumptive withdrawals was not offset 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 (Ref. 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 capacity and longest irrigation canal in the USSR, it stretches 1300 km westward along the southern margins of the Kara-Kum desert from the Amu Dar'ya where it emerges from the mountains (Fig. 3). Between 1956 and 1987, 236 km^3 were diverted into it as annual withdrawals rose from less than one to 12 km^3 (Refs. 103, 104 and 105). All of the water sent along the Kara-Kum is lost to the Aral. Nevertheless, diversions into it from 1956 through 1986 were only 15% of the inflow necessary to maintain sea level at the 1960 mark (53 m) and in recent years it has probably accounted for not more than 10-12% of aggregate consumptive water use in the Aral Sea basin. Water management experts from the Turkmen Republic have rightly claimed that it is simplistic and unfair to lay the basic blame for the Aral's recession on the Kara-Kum Canal (Ref. 103).

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 trade off: a cubic meter of river water used for irrigation would bring far more value than the same volume delivered to the Aral Sea (Refs. 93, 106; 5-25, 107; 85-96, 108 and 109). They based this calculation on a simple comparison of economic gains from irrigated agriculture against tangible economic benefits from the sea. 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 (Ref. 93). The threat of large-scale wind transport of salt and dust from the dried bottom damaging agriculture in adjacent areas was considered minimal (Ref. 106; 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 (Ref. 106; 5-25).

Although a small group of scientists warned of serious negative effects from the sea's desiccation, they were not heeded (Refs. 99 and 108). Time has proven the more cautious scientists not only correct but conservative in their negative 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 (Ref. 106; 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 dried shore, to seasonal level variations which promote evaporative deposition, and to winter storms which throw sulfates, precipitated by colder water temperatures, on the beaches (Refs. 70, 109 and 110).

Much of the 28,000 km^2 of bottom exposed between 1960 and 1989 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 (Ref. 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 resistant to natural and artificial revegetation (Refs. 110, 111, 112 and 113).

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 (Ref. 108). The largest plumes arise from the up to 100 km wide dried strip along the sea's northeastern and eastern coast, although storms occur all around the sea whereever there are large expanses of dried bottom (Fig. 4) (Refs. 98 and 109). The lighter aerosols entrained in the plume are lifted to 4 km and deposited as far as 400 km downwind (Ref. 114; 26-28). Major storms were first spotted by Soviet cosmonauts in 1975 (Ref. 26). From 1975 to 1981, 29 large storms were confirmed by Soviet scientists from analysis of their satellite imagery (Ref. 98). Between 1966 and 1985, 60% of the time during storms the wind was from the northwest, which carried dust and salt over the ecologically and agriculturally important delta of the Amu Dar'ya, 27% of the time from the east, and 12% from the south (Ref. 114; 26-28). The greatest number of days with dust/salt storms (1299) was recorded in Aral'sk at the northern end of the sea, followed by Muynak at the southern end (965).

There is considerable disagreement as to the quantity of dust/salt transport. Estimates range from 13 to 231 million tons annually, with the most probable range from 40 to 150 million tons (Ref. 115; 21-22). Field work suggests the actual transport may be toward the lower end of the estimates. Measurements from 1977 to 1985 indicated that about 43 million metric tons of salt and dust are carried annually from the sea's dried bottom into adjacent areas whereas deposition, based on 1981-86 data from a network of recording stations in the Amu Dar'ya Delta, was 9.5 tons/ha, or less than half of earlier estimates (Refs. 116 and 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 (Ref. 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/dust 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 diagensis (consolidation) of the older surface salts (Ref. 116).

3.32. Loss of Aquatic Productivity.

As the sea has shallowed, shrunk, and salinized, aquatic productivity has rapidly declined. By the early 1980s, all 24 native fish species had disappeared, although a few introduced salt tolerant types (e.g., *Kambala* or Black Sea flounder) survived (Refs. 90; 507- 524, and 119). The catch of fish which reached 44,000 metric tons in the 1950s, fell to zero. Major fish canneries at the former ports of Aral'sk and Muynak - now-tens-of-kilometers from the shoreline - have slashed their work force and barely survive on the processing of frozen fish brought, at high cost, from the Baltic and Caspian seas and Atlantic (Ref. 120). Commercial fishing continues in lakes such as Sudoch'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. Also, levels of pesticides and herbicides, from cotton field runoff, in fish taken from Sarykamysh and Aydarkul' are dangerously high (Ref. 99).

Employment directly and indirectly related to the Aral fishery, reportedly 60,000 in the 1950s, has disappeared (Ref. 121). The demise of commercial fishing and other adverse consequences of the sea's drying have led to an exodus from Aral'sk and Muynak and the abandonment of former fishing villages all around the sea (Ref. 122).

3.33. Degradation of Deltaic Ecosystems.

The Aral's shrinkage and the greatly reduced flow of the Syr Dar'ya and Amu Dar'ya has devastated these rivers' deltas (Refs. 8, 98, 99, 110, 123 and 124). Prior to the 1960s, they 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, reeds used for paper-making and for home construction by local inhabitants, 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 km^2 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 (Refs. 125 and 126).

Native plant communities have suffered. The area of *tugay*, a forest association 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 (estimated at 13,000 km^2 for the Amu Dar'ya delta in the 1950s) had been halved by 1980 (Ref. 123). The *tugay* is floristically rich with 576 identified higher plants (Ref. 115; 30-31). By the early 1980s, 54 of these were on the verge of extinction, including a number of relict and endemic types. Prior to the 1960s, 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 (Ref. 124). The major cause of deltaic vegetation impoverishment has been the 3-8 m drop of ground water along with the end of flood plain 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 formation of shifting sand dunes (Ref. 124). 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 spread to 311,000 by the 1980s. 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. Where this has occurred in the Amu Dar'ya delta, productivity declined from 1 to 1.6 metric tons/ha in 1960 to 0.06 to 0.3 tons/ha by the late 1980s. The area of hay fields and pastures in this delta shrank 81% between 1960 and 1980 (Ref. 110). Satellite imagery and photography from manned spacecraft indicate desertification is spreading rapidly (Ref. 98).

Habitat deterioration has severely damaged the previously rich natural fauna of the deltas (Ref. 115; 30-31). Deltaic environments are critical to a variety of birds, some considered endangered, particularly waterfowl such as geese, ducks, pelicans, herons, swans, and cormorants, who are permanent residents or winter, breed, or rest during migration here. Degradation of vegetation and diminution of wetlands has greatly reduced the diversity of bird species. For example, the number of nesting species of birds in the Syr Dar'ya delta has fallen from 173 to 38. Mammals have also suffered. Muskrat, boar, deer, and jackal were found in abundance in the deltas prior to the 1960s, but their numbers have dwindled. Commercial hunting and trapping have largely disappeared. The harvest of muskrat skins in the Amu Dar'ya delta fell from 650,000 to only 2,500/yr between 1960 and the mid 1980s (Ref. 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 (Refs. 8, 110 and 127). With the sea's contraction, its climatic influence has substantially diminished. Summers have become warmer, winters cooler, spring frosts later and fall frosts earlier, the growing season has shortened, and humidity has lowered (i.e., there has been an overall trend toward greater continentality). The most noticeable changes have occurred adjacent to the former shoreline of the Aral. Thus, at Muynak (Fig. 4), formerly along the southern coast, comparing the period 1951-60 with 1981-85, the average July temperature rose from 25.7 to 28.3 ^{o}C (Ref. 114; 12-28). At Aral'sk, formerly on the northern shore, average July temperature for the same periods increased from 25.6 to 28.6 ^{o}C whereas relative humidity fell from 44 to 32%. According to data from a number of meteorological stations around the sea, the onset of spring (defined as the rising of the average daily temperature above $0^{o}C$) has been delayed 7-10 days. At Muynak, the first fall frost now arrives 10 to 12 days earlier than before the sea's recession (Ref. 115; 20). Reportedly, 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 (Refs. 99 and 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 (Ref. 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 (Ref. 128). The sinking water table has had significant adverse impacts outside the Amu Dar'ya and Syr Dar'ya deltas, drying wells and springs and degrading natural plant communities, pastures and hay fields.

3.36. Water Supply and Health Concerns.

The reduction of river flow, salinization and pollution by toxic 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. Drinking water contamination is believed the main cause of high rates of intestinal illnesses, hepatitis, esophageal cancer, kidney failure and liver ailments, typhoid and cholera, and even birth defects (Refs. 26, 122 and 129). Conditions are most severe in the more heavily populated deltas (Refs. 8, 26 and 110). Muynak has an esophageal cancer rate 15 times the national average for the USSR (Ref. 129). 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 infant mortality rate for the Karakalpak ASSR was 60/1000 in 1988 and is said to be near 100/1000 some places in this republic - 4 times the national rate (Refs. 10 and 26 and 129). There is fear of epidemic because of the deterioration of water supply quality and the increasing rodent population (Ref. 95; 42-43). Desert animals who use the Aral Sea as a drinking source are dying because of its raised salinity, including the endangered *kulan* (Asiatic wild ass) and *saiga* (Steppe antelope) that live in the *zapovednik* (nature reserve) on Barsakel'mes Island (Refs. 26 and 110).

3.37. Estimates of Monetary Losses.

There is no accurate means to determine comprehensive damages associated with the Aral's recession but Soviet scientists and economists have attempted to estimate the costs of the more tangible consequences. A 1983 evaluation concluded that annual damages in 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% (Ref. 110). In the late 1980s, Dukhovnyy and Razakov 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 (Ref. 30). A popular article published in 1986 listed, without elaborating, a figure of 1.5 to 2 billion rubles as the annual losses for the entire Aral Sea region (Ref. 99). A book published in 1990, contended losses are equal to the cost of corrective measures, which were cited as 37 billion rubles (Ref. 115; 46).

3.4. Local Schemes to Preserve the Aral.

What is the future for the Aral Sea? If surface inflow remains low (it averaged near 7.0 km^3/yr from 1981 through 1989), shrinkage will continue rapidly into the next century (Ref. 130). By 2000, the sea could fall an additional 6 m compared to its 1989 level and consist of a main body in the south with a salinity around 70 grams/liter, nearly double that of the ocean, and several small brine lakes in the north (Fig. 5). Subsequently, assuming a continuing surface inflow averaging 7.0 km^3/yr, a net ground water input of 3-4 km^3 (estimates of this water balance component for the sea in its pre-1960 dimensions range from near zero to over 5 km^3/yr, but as sea level drops, ground water inflow should grow), precipitation on the sea surface of 124 mm/yr, and evaporation from the surface of 1000 mm/yr, the southern portion of the waterbody will separate into two parts with an aggregate area between 11.4 and 12.6 thousand km^2, or 17 to 19% of the Aral's size in 1960 (Refs. 114; 36, 115; 113). Salinity would rise to more than 170 grams/liter.

This scenario is not inevitable. The sea's recession could be arrested quickly if considerably more water reached it. It could be restored to its average size from 1911 to 1960 (level, area, and volume around 53 m, 66,000 km^2, and 1060 km^3, respectively) with an average annual inflow of 55 km^3, although the process would require decades. 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 per year (Ref. 30).

To maintain the sea's 1989 area (40,394 km^2) would require much less surface inflow (Ref. 130). Water balance calculations, using the same assumptions about evaporation and precipitation as cited above, indicate around 32 km^3/yr would suffice, assuming a supplemental net ground water inflow of 3 km^3/yr. If net ground water inflow is essentially zero, as some believe, it would require 35 km^3/yr. This is 25-28 km^3 more than average annual discharge to the Aral for 1981-1989. To supply even this much additional water would require a major improvement of irrigation efficiency to substantially lower consumptive withdrawals. 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 will be very difficult to guarantee an inflow of 32-35 km^3 annually to the Aral in the near term (next 5-10 years) in order to stabilize its level near the current mark.

The situation has been complicated by the 1988 separation of the Small Aral Sea in the north from the large sea to the south. In 1989, the Small Sea had a level of 40.6 m, 1.53 m above the large sea, an area of 2984 km^2, a volume of 20 km^3, and a salinity, depending on where measured, of 30-34 grams/liter. The large sea had a level of 39.07 m, an area of 37,410 km^3, a volume of 350 km^3, and an average salinity of 30.38 grams/liter (Ref. 130). Stabilization of these water bodies is now separate tasks. The Syr Dar'ya flows into the northern sea, although it could be easily diverted into the south, and the Amu Dar'ya into the southern water body. Stabilization of the Small Aral Sea would require surface inflow from the Syr Dar'ya averaging around 2.4 km^3/yr; with a reasonable effort this could be ensured in the near term. On the other hand, the southern sea would require inflow from the Amu Dar'ya averaging 30 km^3. Considering that the flow of the Amu Dar'ya at the last measuring post before the sea (Kyzylzhar - 120 km from the shoreline) averaged only 5.7 km^3 for 1985-89, stabilization of the southern sea would be a much more difficult task (Ref. 130).

Is the Aral, therefore, doomed to become several, shrunken, salinized remnants with little ecological or economic value? Not necessarily. There are possibilities to preserve the sea as an ecologically viable entity, albeit in a smaller form, and to improve environmental conditions in the Amu Dar'ya 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 evaporated in the deserts or accumulated in lakes. In the early 1980s, this may have totalled 13 km^3/yr (Ref. 8). It has been suggested that perhaps 10-12 km^3 of drainage water annually could be sent to the Aral by collectors paralleling the Amu Dar'ya and Syr Dar'ya (Ref. 96). However, drainage is saline as well as pesticide, herbicide, and cotton defoliant laden (Refs. 70 and 131). 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. Preliminary 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, reportedly, started (Ref. 132). The program to improve irrigation efficiency will significantly reduce the amount of drainage and, furthermore, some that would be delivered now reaches the sea as part of river flow. Hence, the net potential contribution of drainage water to the Aral's water balance is less than it might appear.

Diverting irrigation drainage water to the sea will dry the two largest lakes supported from this source, Aydarkul' (also called Arnasay) and Sarykamysh. The former has an area of 2,300 km^2 and contains 20 km^3 whereas the latter is near 3,000 km^2 with a volume of around 30 km^3 (Refs. 133, 134, 135 and 136). Since their origins in the 1960s, each has developed considerable fishery and wildlife importance. Sarykamysh is a noted haven for migratory waterfowl, some of which are rare. The catch of fish from Aydarkul' runs near 10,000 metric tons whereas about 3000 metric tons were taken from Sarykamysh (Refs. 137 and 138). A *zapovednik* (nature reserve) has been proposed to protect parts of Aydarkul' and a *zakaznik* (protected area) established for Lake Sarykamysh (Refs. 134 and 135).

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 (Ref. 133). 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 (Ref. 139). The full cut-off of irrigation drainage water now sent to the lake along the Dar'yalik and Ozernyy 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, wiping out all fish species (Ref. 134).

Delivery of irrigation drainage water could make a substantial contribution to supplying the 32-35 km^3 of surface inflow necessary to stabilize the sea near its 1989 level. However, unless drainage flows were treated to remove toxic contaminants and diluted with reasonably fresh water, a polluted sea with salinities too high for fish, even ocean species, to survive would result. The cost and complexity of purifying a large volume of drainage water would be daunting.

Another approach, first suggested in the 1970s, is to partition the sea with dikes and allow sufficient outflow from the preserved part to maintain low salinity while allowing the remainder to dry or become a residual brine lake receiving outflow from the freshened part (Refs. 92, 128 and 140). Several schemes for this are shown on Figure 7. Schemes A through C would require 24-30 km^3/yr of surface inflow. Design D, on the other hand, needs only 8 km^3, and, for this reason, may be the most viable of this group of alternatives. As part of this plan, the shoreline of the "active" portion of the sea would be steepened by dredging to minimize seasonal area fluctuations that contribute to salt deposition (Ref. 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 (Refs. 8 and 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 km^3/yr, 3.5 of fresh river water and 8.7 of saline irrigation drainage water, would be delivered to the main reservoir. 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 km^3. The residual Aral Sea, it is claimed, would stabilize near 30 meters (9 meters lower than in 1989) 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 km^3/yr (Ref. 8). Objections to the plan have been made on grounds that its ecological and health consequences (e.g., that the large, shallow reservoir could be a source of disease vectors) have not been sufficiently investigated nor clearly delineated and its costs underestimated (Ref. 115; 101-102).

Regardless of what, if any, scheme is implemented to preserve a residual Aral Sea or improve conditions in the Amu Dar'ya 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 aphullum*). But this program is so far limited to relatively small areas with the most favorable conditions and the survival rate is low (Refs. 131 and 141). Scientists are also investigating the feasibility of using mechanical and chemical means of binding the loose surface (Refs. 8, 111, 112 and 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 km^3, second only to Brazil, distribution is highly uneven (Fig. 8). Rivers carrying 84% of this discharge flow to the north and east through sparsely inhabited and economically underdeveloped territory into 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 crop land, including all of the most fertile (Ref. 142). The Aral Sea basin with 6% of the nation's land area and nearly 40% of water withdrawals in 1980, has only 2.3% of its surface flow (Table 3; Ref. 7; 111). Furthermore, the headwaters of major northern and southern flowing rivers in European Russia are not only proximate but separated by a water divide with a maximum elevation of 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 bloom (Refs. 142, 143; 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, 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 (Ref. 144). The Davydov plan would have flooded 250,000 km^2 of the West Siberian plains, greatly worsening the already serious problem of excessive moisture, 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 (in todays currency) would be at least several hundred billion rubles.

The Davydov plan was never seriously considered but planning work on diversions continued after Stalin's death in 1953. In the early 1960s, a project to transfer around 40 km^3/yr from the European north into the Caspian Sea drainage basin (the Volga-Kama river system) was seriously contemplated (Ref. 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 abandoning 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 becoming more severe.

The 1970s was a period of intensive development of water redistribution plans but with a greater focus on minimizing their potential environmental impacts (Ref. 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* (The 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 and 1980 by more than 120 scientific research and planning agencies. The schemes underwent scrutiny by a governmental commission during the early 1980s, resulting in several minor revisions. The final versions of the projects are shown on Figure 9 and in Table 7. By the end of 1984, construction on the 1st stage of 1st phase European diversions (5.8 km^3/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 km^3/yr) was undergoing detailed engineering design in 1985 and was scheduled for implementation by the late 1980s or early 1990s (Ref. 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) (Figs. 3 and 9). *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 the project. Around two-thirds 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 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 Dar'ya and Syr Dar'ya rivers (Refs. 143; 20-46, and 145). A second phase of Siberian transfers was contemplated which would raise the total to 60 km^3. 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 projects had been periodically attacked during the 1970s and early 1980s by some scientists and a group of nationalistic Russian writers who foresaw severe ecological, economic, and cultural damage occurring in northern regions of water export (Refs. 35, 142 and 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 nationalistic writers and a number of prominent scientists, including several academicians (Refs. 35, 36, 142 and 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." (Ref. 17; 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 (Ref. 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 (Ref. 142). Gorbachev and his advisors at the time (e.g., A. Aganbegyan), with their strong orientation to efficiency, saw the projects as a poor investment of scarce capital. In their view, there were 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 shelter belt planting) (Ref. 15).

Another argument made against the projects is that *Soyuzgiprovodkhoz* and the Institute of Water Problems were thoroughly biased toward implementation and even engaged in collusion and falsification of data to promote the projects (Refs. 35 and 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 (Ref. 87). The agricultural benefits of this project, its main justification, also appear to be exaggerated (Table 8). To take one example, 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 (Ref. 145). To irrigate 4.5 million ha from this, as claimed, implies a consumptive withdrawal rate of 4355 m^3/ha, which is 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 was cited as a major reason for stopping their implementation (Refs. 35, 142 and 146). However, as indicated above, a major research effort was made between 1976 and 1980 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 (Ref. 145; Table 8). Adverse effects would be of a local or regional nature and national or international consequences would be nonexistent or trivial.

The position of the Soviet government until the policy was reversed was that potential positive impacts outweighed the negative and that the latter, in themselves, were not of sufficient magnitude to forego implementation of the projects. Indeed, specters of initial phase Siberian diversions (27 km^3/yr) causing global weather changes invoked by Western writers were rejected by Soviet experts as absurd; careful studies in the West supported this view (Refs. 142 and 146). Since the projects have been under fire, the potential of global change from them has been made by commentators in the popular Soviet media (Ref. 149). 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 and some key economic and socio-cultural problems were largely ignored. However, it appears that following the policy reversal in 1985-86, these were exaggerated, probably to lend further credence to the fundamentally investment-based decision to halt the projects.

The campaign against river diversion schemes did not cease with their official suspension in August 1986 (Refs. 35, 36 and 148). Savage criticism of the Ministry of Water Management and Reclamation *(Minvodkhoz),* its subagency *Soyuzgiprovodkhoz,* and the Institute of Water Problems continued. As a result basic research on water transfers, even though not only permitted but required by the August 1986 decree, virtually stopped and the much maligned Voropayev was forced to resign as director of the Institute of Water Problems in September 1988 (Refs. 36 and 88). Clearly, opponents of the schemes fear they could be revived and are intent on ousting diversion supporters from positions of authority and stopping any further research.

The Siberian water transfer project is, however, not yet dead. In January 1988 a joint decree of the Central Committee of the Communist Party and the Council of Ministers devoted to the improvement of water use, directed that scientific study of north-south water transfers continue (Ref. 150). After a two year silence following the August 1986 decree, Central Asian water management officials, scientists and party and government officials began, again, to push for water transfers as the only means to save the region from a catastrophe. Having counted on importation of water from Siberia, the halting of the project was a great shock and disappointment for them (Refs. 142, 143, 144 and 145). 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 (director of the Central Asian Irrigation Research Institute) stated that the ecological and social-economic difficulties of the Aral region could not be solved without diversion of water from Siberian rivers (Ref. 29). In October 1988, a water management expert from *Soyuzgiprovodkhoz* 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 (Ref. 88). He contended diversions would be needed by this date 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.

By 1989, Central Asian political leaders such as I.A. Karimov, President of the Uzbek Republic and First Secretary of the Uzbek Communist Party, were stressing the dire nature of the water management situation in Central Asia, raising the question if the region could survive without water from outside, and calling on Moscow for help (Ref. 151). With the weakening of central (Moscow) authority and the declarations of sovereignty by the Union Republics, Central Asian politicians have become more adamant on this issue. On June 23, 1990, the presidents of the four Central Asian republics and Kazakhstan signed a joint declaration on mutual problems and approaches to their solution (Ref. 152). The ecological catastrophe of the Aral Sea and adjacent area 0was cited as being so acute that it could not be solved by regional efforts alone. The leaders called on the national government to declare the Aral region one of national calamity and to provide real help. They also stated that it was necessary to return to the idea of water diversions from Siberia as one of the principal routes of saving the Aral and ensuring an adequate food supply for the region. In their view, diversions will decide the region's future.

A Siberian diversion "compromise" might be the implementation of a considerably down sized version of the original plan. Ten to 15 km^3 annually could be sent directly into the northern part of the Aral sea or into the Syr Dar'ya delta by a concrete lined canal and huge pipelines, somewhat shortening the route and considerably reducing filtration and evaporation losses, compared to the original conception. 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. Along with implementation of local measures, such action could preserve the sea near its current level and area while lowering salinity to ecologically tolerable levels, all without any significant cutback in irrigation. It could be argued that saving the Aral outweighs the harm to Western Siberia (although inhabitants of the latter region, no doubt, would take exception). The Soviet government and Russian Republic could also insist that no Siberian water be used for irrigation, encouraging Central Asian water interests to be more efficient, since expansion of irrigation and other water uses would be possible only from water freed by this means.

The Central Asian republics might also be able to use their exports of food and cotton to the Russian Republic as a bargaining chip (i.e., a "food and cotton for water trade"). On the other hand, there is no indication whatsoever that the Russian Republic is willing, under any circumstances, to consider water transfers to Central Asia. And given the present balance of power between Moscow and the republics and the likelihood it will move more in favor of the latter, diversions without the approval of

Russia (even though the national government may give their go-ahead) appear improbable if not impossible.

3.6. A New Concern for the Aral

Although the Aral has been steadily receding for nearly three decades, until recently the problem was not a high national priority. In the 1960s, the dominant attitude 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 (Refs. 93, and 106; 5-25). This perception slowly changed in the 1970s as the drying of the Aral continued and the magnitude of the calamity 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 (Refs. 109 and 131). The Institute of Geography of the Academy of Sciences in Moscow was given major responsibility for the research effort. Articles in scientific journals and conferences on the Aral issue became common after 1976 (Refs. 20, 89, 92 and 108). 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 extent 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, the press and on television. *Pravda Vostoka*, the Uzbek government and Communist Party paper, has been filled with items (Refs. 29, 96, 153 through 160). The literary journal of the Uzbek writers' union, *Zvezda Vostoka*, has also dealt with the subject (Refs. 99 and 162). At the national level, the newspapers *Pravda* (Ref. 23) and *Literaturnay gazeta* (Ref. 97), as well as the journal *Ogonyok* (Refs. 26 and 122) among others, have carried major pieces on the issue. *Soviet Life,* the popular English language journal published by the Soviet government for U.S. domestic consumption, carried a story on the Aral in its September 1989 issue (Ref. 161) as did *National Geographic* for its international audience of more than 30 million in February 1990 (Ref. 163).

Widespread anger has been expressed as to why things were allowed to become so bad and who was responsible. Much of the blame has been placed on the now defunct USSR Ministry of Water Management and its Central Asian branches for promoting excessive 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 various local measures, implementable in the short term (next 5-10 years), can save enough water to provide 30-35 km^3/yr to the sea; enough to stabilize it at the 1989 level of 39 m (Refs. 155 and 156). Some claim it is possible over the intermediate term (next 10-15 years) to deliver up to 50 km^3, which would even allow raising sea level to around 51 meters and restoring the area to 90% of pre-1960 conditions (Ref. 115; 124-126). Based on such assumptions, adherents of these views 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 (Refs. 23, 29, 30, 117, 156, 157 and 164). And while recognizing the tragedy of the Aral, they are much less sanguine than their critics that large amounts of water can be saved in the near future 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 (Refs. 88 and 156).

In contrast to the past, the concerned public did not wait for the Soviet government to take action to remediate the Aral situation. Borrowing a lesson from the Russian national writers who led the battle against north-south diversion projects, the Uzbek Writers' Union formed a "Public Committee for the Saving of the Aral and Priaral" in 1987 (Refs. 155, 158 and 165). The committee is composed of some 80 writers, scientists and others. Pirmat Shermukhamedov, a writer and Peoples Deputy of the Karalkalpak ASSR, is committee chair. A fund has been established by the committee to collect money for the campaign to save the Aral. The well-known Kirgiz writer Chingiz Aytmatov and world famous Russian poet Yevgeniy Yevtushenko were early contributors (Ref. 165). Various public events have been held to raise money for the fund, including a telemarathon (Ref. 166).

Another "grass roots" effort was mounted by the literary journals *Novyy Mir* and *Pamir* (Ref. 167). During September and October 1988, they, with the help of the Soviet Peace Committee, the State Committee for Education, the public group "Ecology and Peace" and the State Committee for Nature Protection (*Goskompriroda*) sponsored a fact-finding expedition of writers, journalists, scientists and others to the Aral Sea region. The purpose of the "Aral-88" expedition was not only to gather first-hand information but to use it to influence the Soviet government's soon to be announced decree on the Aral situation (discussed below).

The expedition's main findings and conclusions based on 13,000 km of travel and numerous meetings with local people and officials: (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) neverthe-

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less, 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 of low water use, ecologically sound processing and auxiliary enterprises should be diligently pursued (Ref. 168). The expedition found that a government ordered program to reduce cotton sowing, intended not only to save water but reduce pesticide and herbicide pollution, was not being implemented.

The Soviet government, pushed by events and public pressure, has shown a much heightened concern for the Aral problem in recent years. 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 (Ref. 146). This report was supposed to be ready by early 1987. Then completion was delayed until the end of 1989, but by early 1991 the report still had not been released (Ref. 169). A special government commission was appointed in December 1986 to study ecological problems concerning the Aral (Ref. 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 (Ref. 170). 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.

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, which it would across 15 to 20 years in the absence of decisive action. Recognizing that there is no feasible and immediate means of greatly increasing inflow, they recommended a strategy for gradually increasing annual discharge: 8.7 km^3 by 1990, 11 km^3 by 1995, 15-17 km^3 by 2000, and 20-21 km^3 by 2010. The water would come from a 15-25% increase in irrigation system efficiencies, providing 15 km^3 by 2010, all of which would be delivered to the Aral, and from the channeling of 6 km^3 of irrigation drainage water directly to the sea. These figures establish guaranteed minimum inflows; actual discharge could be somewhat larger. 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 1988 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 (Ref. 171)." 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 km^3 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 Dar'ya 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 Dar'ya 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 were made to guarantee the financing of the decree's requirements, but specifics were not reported. The Committee of Peoples' Control for the USSR was assigned responsibility for ensuring that governmental bodies and agencies fulfill their responsibilities.

The decree was warmly greeted in Central Asia. Meetings were held to discuss it and party and government officials emphatically stated their intention to ensure implementation (Refs. 172, 173 and 174). The decree is being taken seriously. Work on some elements of the plan (e.g., delivering more drainage water to the sea, hydrotechnical construction to improve water management in the Amu Dar'ya delta, and measures to provide higher quality drinking water and better medical services for the population) is underway, and oversight agencies to ensure compliance of responsible organizations have been established (Refs. 175 and 176). In spite of these commendable efforts, vehement complaints are being heard from Central Asians that the program is going slowly and poorly. Tulepbergen Kaipbergenov, the well-known Karakalpak writer, scathingly criticized efforts in his speech to the Congress of Peoples' Deputies in June 1989 and stated that during the first five months of 1989, not one drop of river water had reached the Aral (inflow for all of 1989 was estimated from 4 to 6 km^3) (Ref. 177). Similar complaints were heard from Central Asians during the visit of the UNEP working group (see below) to the Aral Sea region in fall 1990 (Ref. 176).

Thus, the Aral problem is far from solved. In the first place, the program to preserve the Aral and deal with problems created by its recession will be enormously 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/km^3), then the part of the plan to free 15 km^3 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. Can such large funds be found given all the other competing demands for investment?

Secondly, even if the program is fully funded and 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 km^3/yr by 2005 will result in the sea's continued shrinkage, albeit at a decreasing rate, into the next century. Assuming all the 21 km^3 was delivered to the large Aral Sea in the south, it would stabilize at around 34 m, 5 m below the 1989 level and have an area around 27,500 km^2, 10,000 km^2 less than in 1989. Salinity would grow to more than 60 g/l. Unless measures are taken to desalinize and detoxify irrigation drainage water delivered to the sea, it would pollute the waterbody. The economic and ecological value of the sea would be minimal. The now separated Small Aral Sea in the north would dry to several highly saline remnants unless some of the 21 km^3 were delivered to it. Attempting to save the deltas of the Amu Dar'ya and Syr Dar'ya, particularly the former, seems wise because of their high ecological, economic, and human value. But guaranteeing the water needed for this project may necessitate "writing off" the main Aral Sea. Halting major irrigation development in 1991 which depends on new withdrawals from the Amu Dar'ya 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.

In spite of the 1988 decree on the Aral and near Aral region, doubts and concern remain as to how best to deal with the situation. These have been expressed at two international conferences. In July 1990, more than 30 Soviet scientists, publicists and writers, representatives of environmental organizations, and water management experts met with their American counterparts in Bloomington, Indiana, to give presentations and discuss environmental issues in Central Asia (Ref. 178). There was substantial and, at times, acrimonious debate among the Soviets about the causes, fundamental nature, and appropriate strategies for improving ecological, economic, and human conditions in the Aral region. The Central Asian representatives expressed frustration and bitterness at the slow pace of improvement efforts and the central government's seeming lack of concern for their plight.

Nukus, Karakalpak ASSR served as host for a second international gathering on the Aral problem in October 1990 (Refs. 179 and 176). It was sponsored by the new "Special Research and Coordination Center 'Aral,'" which is housed in the Institute of Geography of the Academy of Sciences in Moscow. Besides a large contingent of Soviets, about 40 invited foreigners participated. Among other things, the conference resolution called for the Supreme Soviets of the Central Asian republics (including Kazakhstan) and the national Supreme Soviet to declare the region around the Aral as an ecological disaster zone. Although participants from the Central Asian republics and Russian Republic agreed on much, there was a clear split on the matter of Siberian water transfers. A substantial number of the former thought the diversions questions should at least be reevaluated, whereas the latter were unalterably opposed to this.

The United Nations has also become involved in efforts to ameliorate the Aral problem. The Soviet government and UNEP (United Nations Environmental Programme) signed an agreement in January 1990 that established a two year joint program (with the cooperation of the International Lake Environment Committee, ILEC, of Japan) to develop an action plan for rehabilitation of the Aral Sea and near Aral Region (Refs. 176 and 180). A working group of "Foreign Experts" and "National Experts" is to provide recommendations to the Soviet government for improving conditions in and around the sea, based on field visits to the Aral Sea region and a "diagnostic study" carried out by the Institute of Geography and Aral Research Center under the supervision of the State Committee for Nature Protection (*Goskompriroda*). These recommendations are to be submitted in January 1992. The first field visit to the Aral regions was held in September 1990 and a working meeting in Moscow during February 1991 (Refs. 176, 180 and 181).

Working group members (the author is one of the foreign experts) agree that first priority should be given to improving health and medical conditions, including the availability and quality of drinking water, for the population living in the most severely affected zone around the sea. They also are in accord on such matters as the need for an integrated, ecological approach to the complex of issues that constitute the "Aral Problem" and development of a basin wide water management strategy and authority for the Aral Sea watershed. However, there is lack of agreement among Soviet experts and between Soviet participants and foreign experts over, for example, such vital matters as the desirable nature, extent, and timing of changes in the economy, particularly agriculture, of Central Asia (e.g., how much and how rapidly should the area of irrigated cotton be reduced and what sorts of economic activities should replace it) in order to lower water use; whether primary efforts should be devoted to preserving the Aral Sea proper (and in what form it might be "saved") or the deltas of the Amu Dar'ya and Syr Dar'ya; and, perhaps, most importantly, what is the potential for reducing consumptive water use in the Aral Sea basin in order to provide more inflow to the sea. The foreign experts were particularly concerned about the adequacy of the data base upon which recommendations for a rationale rehabilitation program for the Aral region must be founded. The diagnostic study, to be completed and distributed to members of the working group in Spring 1991, should help answer these questions and concerns.

The most recent major action on the "Aral Problem" has been taken by the USSR Supreme Soviet. On March 4, 1991, it issued a lengthy, detailed decree titled "Concerning the implementation of the resolution of the Supreme Soviet of the USSR concerning urgent measures for improving the ecological condition of the country related to the problem of the Aral Sea (Ref. 182)." This was follow-up and oversight legislation to the earlier resolution of November 27, 1989 which had led to the establishment of a government commission on the "Aral Problem," a union-republic consortium ("Aral") for implementing specific improvement measures, and a scientific-research coordinating center ("Aral)". The latest decree stated that as the result of earlier actions measures had been undertaken to combat desertification and improve conditions in the Amu Dar'ya delta and to improve the sanitary-epidemiological situation in the most seriously affected parts of the Aral Sea basin (the Karakalpak ASSR and Khorezm Oblast in the Uzbek SSR; Tashauz Oblast of the Turkmen SSR; Kyzl-Orda Oblast of the Kazakh SSR). It noted that between 1988 and early 1991, 1900 km of main and distributary water supply pipelines were layed, 300 desalinating installations to provide drinking water for

580,000 people were placed in operation, and hospitals with 2,200 beds and clinics for 1,500 visits were built. Nevertheless, the Supreme Soviet severely criticized the manner and pace of implementation of the Aral improvement effort and considered it insufficient in all respects.

The decree is similar in tone to that promulgated by the Communist Party and Soviet government in September 1988. It stressed the extreme seriousness of the ecological, medical/health, and general living situation in the Aral region and gives directives for improvement to national and governmental ministries and committees, to governmental agencies of the Central Asian republics and Kazakhstan, and to the Academy of Sciences, both national and republican. It is noteworthy that this time there is no call for participation by Communist Party organizations in alleviating problems, a reflection no doubt of their declining importance and the public distaste for them. Because of its timeliness and importance, the paragraphs containing the directives of the decree are translated below.

(1) It is an All-Union task to radically improve the sanitary-epidemiological conditions of life for the population and the social-economic and ecological conditions in the near Aral region, to stabilize the level of the Aral Sea and, then, to restore it in stages. To accomplish this the national ministries jointly with the highest state management agencies of the Central Asian republics and Kazakhstan are directed in the first half of 1991 to prepare and present to the Supreme Soviet a conceptual plan for the preservation and the staged restoration of the Aral, linked with conditions of social-economic development of the Central Asian republics and Kyzl-Orda Oblast of Kazakhstan. These organizations are to develop and confirm by the end of the third quarter of 1991 a long-term union-republic program, covering the period 1991-1995, for the radical improvement of social-economic and sanitary-epidemiological conditions in the near Aral region and for the restoration of the Aral Sea. Considering the severity and rapidly worsening ecological situation in the region, as a first step of the long-term program, the union-

republic program of urgent measures for 1991-1992 to improve medical-sanitary conditions and the social-economic and ecological situation in the near Aral region must be finalized in one month. Financing of the Aral program, including scientific research, will be obtained from both the All-Union and republic budgets but there will be centralized allocation of material-technical resources.

(2) USSR ministries along with the highest organs of state management of the republics of the region are directed in the first half of 1991 to prepare a normative document determining the boundaries and status of the zone of ecological catastrophe in the near Aral region and a position on supplementary measures for compensating the population here depending on the degree of influence of desertification and other factors which are negatively affecting people's health, including the introduction and raising of the regional wage coefficient. As part of this effort, there needs to be developed in 1991 a model law on the social protection of citizens suffering from the consequences of the ecological catastrophe in the near Aral region. In order to preserve the Aral Sea as a natural object and protect the people and ecology of the lower Amu Dar'ya and Syr Dar'ya, measure must be taken to increase the guaranteed flow [see the discussion above on the 1988 decree] into it during the period 1991-2000.

(3) The proposal of the republics of Central Asia and Kazakhstan to create an interrepublican commission for the restoration of the Aral and an aid fund for the population of the near Aral region is approved. A long-term interrepublican agreement on the rationale use of the water resource of the Aral Sea basin should be drafted and signed in 1991.

(4) Measures must be taken by the republics of the region to ensure the population of the near Aral region with decent food and to increase the pace of health improvement measures. It is necessary to include in the long-term program for the Aral a section "Nourishment of the population of the near Aral region" and a medical/health subprogram "Children of the Aral". Special attention must be given to developing a network of health protection agencies, strengthening medical cadries, ensuring the

availability of medicines and medical equipment and broadening scientific research on the medical-biological prophylaxis of illness. Practical measures must be taken to speed-up the guaranteeing of the population of the lower Amu Dar'ya and Syr Dar'ya with good quality drinking water, considering the possibility of bringing clean water from outside sources and also the construction of a bottled water plant. USSR ministries must provide help in carrying out these programs.

(5) It is recommended to the Supreme Soviets of the Central Asian republics, including the Karakalpak ASSR, that they strengthen their control over implementation of earlier decisions for the transition of agriculture in the Aral Sea basin to a strictly scientific basis with a proper regard for the use of nature and the rational use of water, land, and vegetative resources. They also need to implement measures to stop the discharge of polluted water into the Amu Dar'ya and Syr Dar'ya, to reduce and put in proper order the use of pesticides, to improve public health, and to ensure the conducting of phyto- reclamation and soil protection work. They need to show all-around help to local health protection, soviet, and scientific organizations in these matters.

(6) The USSR Academy of Sciences and State Committee for Science and Technology are directed, in 1991, to complete the establishment of an Institute of Ecology and Water Problems for the Aral Sea of the Academy of Sciences, USSR, on the base of the Nukus section of NIKTs [Scientific-research Coordinating Center] "Aral". They are to strengthen the scientific and informational basis of the social-economic development of the region and to coordinate the activities of scientific research organizations of the Central Asian republics and Kazakhstan related to these matters. They should consider the establishment of branch divisions of the institute in Tashauz, Aral'sk, and Urgench. These organizations, jointly with ministries and departments of the USSR, as part of the conversion of defense industries, should take measures to develop modern systems of ecological monitoring for the near Aral region with the employment of the existing possibilities of the Baykonur Cosmodrome and scientific capabilities of

the republics. They also are to develop an integrated, interagency all-union program for scientific research on the Aral problem.

(7) The role of the basin water management associations "Amu Dar'ya" and "Syr Dar'ya" [see section 2.53] in the management of the water resources of the Aral Sea basin should be strengthened with the broad employment of automated systems of control. To provide for the raising of the status of these agencies, their workers should be given the powers of state inspectors. In 1991, water management operational organizations and water withdrawal facilities of hydro complexes and reservoirs along the Amu Dar'ya and Syr Dar'ya should be transferred to the basin associations as specified in earlier governmental decisions.

(8) It is recommended to the ministries of the USSR and higher authorities of the union republics to examine the matter of creating an organ of state management and giving it the function of interrepublican distribution of water resources and control over water use in the country.

(9) The Procurator-General of the USSR is directed to establish in 1991 an interrepublican nature protection Office of the Public Prosecutor for the Aral Sea basin.

(10) The Committees of the USSR Supreme Soviet for Ecology and Rational Use of Natural Resources and for International Affairs jointly with the Ministry of Foreign Affairs is directed to ask the head of UNEP for assistance in the development and implementation of projects for restoring the Aral Sea and for including the problem of the near Aral region in the U.N. program for combatting desertification.

(11) Oversight responsibilities for this decree are assigned to the Supreme Soviet Committees for Ecology and Rational Use of Natural Resources and for Health Protection.

It is obviously too early to say what will be the effect of the new decree. It is more comprehensive in its approach to the multiplicity of issues constituting the "Aral Problem" than the 1988 decree, and appropriately focuses primary efforts in the near term on improving the health and welfare of the region's people. The decree's call in paragraph (6) for putting into operation in the near future research institutes on the Aral in the most severely affected parts of the sea's basin should enhance local research capabilities, the lack of which have been a sore point with Central Asians. The directives promoting inter-republican cooperation on the Aral and in water management (3), enhancing the water management role of the river basin water management associations (7), and recommending creation of a strong, All-Union agency for inter-republican water allocation (8), if implemented, would be a major contribution to developing an integrated, comprehensive approach to the "Aral Problem" and water management in the Aral Sea basin.

On the other hand, financing of Aral improvement efforts is vague. Paragraph (1) calls for funding from the All-Union and republican budgets but gives no indication of the amounts or proportions to be taken from each. Without a major monetary commitment, even the best plans will go nowhere. The call for not only stabilizing the Aral's level but restoring the sea in stages is laudable. But how and where to obtain the water for this in the near future (as the decree seems to imply is possible), as explained earlier, is an acute problem. As with the 1988 decree and others that have followed, the new decree is another major step in the right direction. But its impact will depend on financing, political stability in the USSR, cooperation between the central government and the Aral Sea basin republics, and a willingness on the part of the key Soviet players to look honestly at the situation in the Aral Sea basin as it is, not as they would like it to be.

Summary and Conclusions

Central Asia has a severe water management crisis. Although the region has an arid climate, the Amu Dar'ya and Syr Dar'ya formerly carried considerable water across the deserts and into the Aral Sea. The flow of these has been almost completely depleted by heavy withdrawals for irrigation. This is the most important zone of irrigated agriculture in the Soviet Union. But the future of irrigation, the economic foundation of Central Asia, is in grave doubt because of the over-taxing of water resources. The problem is compounded by a large and rapidly growing population. Means must be found to ensure an adequate water and food supply as well as employment opportunities for the current as well as much larger population expected in the next century. 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 drastic, solution. Yet most ethnic Central Asians have no desire to move to these regions with a climate, language, and culture so different from their native lands.

In the absence of large-scale out-migration what can be done to alleviate the situation? Increased water use efficiency in irrigation, which has been historically very wasteful, is an obvious need. Major efforts have been underway since the early 1980s to improve irrigation efficiency. These were intensified after Gorbachev came to power in 1985. 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 the intent to introduce irrigation water pricing in 1991. Improvements may have lowered per hectare withdrawals for irrigation, on average, as much as 27% between 1980 and 1986.

The potential for further water savings in Central Asia is disputed. Critics of irrigation, most of whom have little or no formal training or experience in the water management field, contend large quantities of water can still be freed (35 to 50 km^3/yr). Water management specialists, on the other hand, in the absence of draconian measures that would disrupt the economic and social fabric of Central Asia, forecast much smaller savings, perhaps a net gain as small as 10 km^3/yr (less than 10% of current withdrawals for irrigation) at a cost of tens-of-billions of rubles. Both sides no doubt exaggerate their case, but available evidence seems to indicate, at least in the foreseeable future, realistic savings closer to the lower figure.

There are additional local measures which can be employed to deal with the water supply problem. Replenishable water supplies could be increased by greater use of ground water, reuse of irrigation drainage, more regulation of river flow, reduction of flood plain water losses, and the use of water collected in small natural basins and ephemeral streams. Another possibility is to fundamentally alter the economic structure of Central Asia away from water intensive irrigation and toward low water use industries (e.g., textile and clothing production and electronics). This seems a promising strategy but would require increased capital investment, an improved educational system with massive retraining of the populace, and a cultural/social reorientation of the Central Asian ethnic majorities from a rural based, agricultural society to an urban, industrial one. Such a fundamental change will not only be wrenching, but require decades. Furthermore, it would not solve the problem of the need to increase local food production.

The Aral Sea problem makes an already difficult situation even worse. Between 1960 and 1989 the level of this huge lake fell over 14 m while its area shrank by over 40%, volume decreased two-thirds, and salinity rose from 10 to near 30 g/l. The pronounced reduction of inflow from the Amu Dar'ya and Syr Dar'ya, primarily a consequence of irrigation, has caused the sea's recession. 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, and is having, severe adverse impacts. Salt and dust transported by the wind from the dried bottom for hundreds of kilometers is damaging prime agricultural and ecological zones and harming human health. Rising salinity has destroyed the sea's fishery. The deltas of the Amu Dar'ya and Syr Dar'ya have been severely degraded and lost much of their former economic and ecological importance. The climate of the region around the sea has grown more extreme as the waterbody shrank and lost its moderating influence. Living conditions around the Aral have become much more difficult as clean water supplies have disappeared or become polluted, medical and health conditions deteriorated, and employment opportunities vanished. The zone adjacent to the Aral Sea is experiencing large net emigration.

Although the "Aral Problem" was neglected and hidden from the public for many years, its resolution become a national priority by the late 1980s. A committee to save the Aral was formed by the Uzbek Writers' Union which publicized the sea's plight and pushed the government for action. The USSR Council of Ministers and Central Committee of the Communist Party issued a decree on the Aral at the end of September 1988 based on the findings and recommendations of a high-level study Commission. The decree ordered the implementation of a comprehensive program based on local water resources to stabilize sea level around 34 m, 5 m below its 1989 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 its water delivery provisions for the Aral, even if met, would leave a polluted and, compared to 1960 conditions, much shrunken waterbody with a salinity nearly double that of the ocean's.

Projects that require much less than natural (i.e., pre-1960) inflow to preserve the Aral have been proposed. These would dike-off and preserve parts of the Aral as a circulating water body (i.e., with inflow and outflow) with sufficiently low salinity to make them ecologically viable while letting the rest of the sea dry or salinize. Another plan focuses on saving the deltas of the Amu Dar'ya and Syr Dar'ya by constructing shallow reservoirs in front of them.

Until the mid 1980s, hopes to resolve Central Asia's water problems rested on future massive water transfers from Siberian rivers to the north. The project was in the final engineering design phase and was scheduled for construction by the late 1980s or early 1990s. 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; fears of potential adverse environmental effects played a secondary role.

The Siberian scheme is, again, being pushed by Central Asian political leaders as essential to the region's future. They argue there is not sufficient water in the Aral Sea basin to permit an adequate level of irrigation, meet the water needs of industry and a growing population, and preserve the Aral Sea as an ecologically valuable entity. Their case is convincing for the foreseeable future. It is true that the economic structure of Central Asia could be reoriented toward less water-intensive types of production, perhaps meeting regional needs and still providing enough water to restore the Aral, partially, to what it was prior to the 1960s. But this would require huge investment and fundamental socio-economic and cultural changes spanning many decades. Given the trend toward largely sovereign republics, even if the central government listens to the pleas from Central Asia (for example, as an inducement for the Central Asian republics to remain in the Union), any transfer would have to be approved by the Russian Republic. The government and majority of citizens of the latter continue to be adamantly opposed to diversions.

Perhaps a compromise could be reached, involving a much smaller than originally planned transfer (10 to 15 km^3/yr?) with fewer negative impacts on Western Siberia. Water would be delivered directly into the Aral and, along with implementation of local measures, could preserve the sea near its 1989 size while lowering salinity to ecologically tolerable levels, without any significant reduction of the irrigated area. The agreement could stipulate that all feasible technical measures be taken to reduce losses in transport and that no Siberian water be used for irrigation, encouraging Central Asians to make every effort to use regional water resources carefully. Central Asia could compensate the Russian

Republic for the water and ecological and environmental damages associated with diversions by supplying food, cotton, and other products to them. This concept has a low probability of implementation and, in any case, it would take years to build the transfer facilities.

The prognosis for the Aral Sea and Central Asia over the foreseeable future remains gloomy. Conditions are continuing to deteriorate. There are sincere efforts to improve the situation, but they are trivial compared to the number and magnitude of problems. It is encouraging that the plight of the Aral Sea and its surrounding region has not only attracted national but international concern, including the holding of conferences and the provision of technical advice from the United Nations. But, unfortunately, a well-founded, adequately funded, and coordinated national effort to solve the problem is still largely absent.

Appendices A & B follow.

A - figures 1 through 9 are on pages 88-97
B - tables 1 through 8 are on pages 98-106

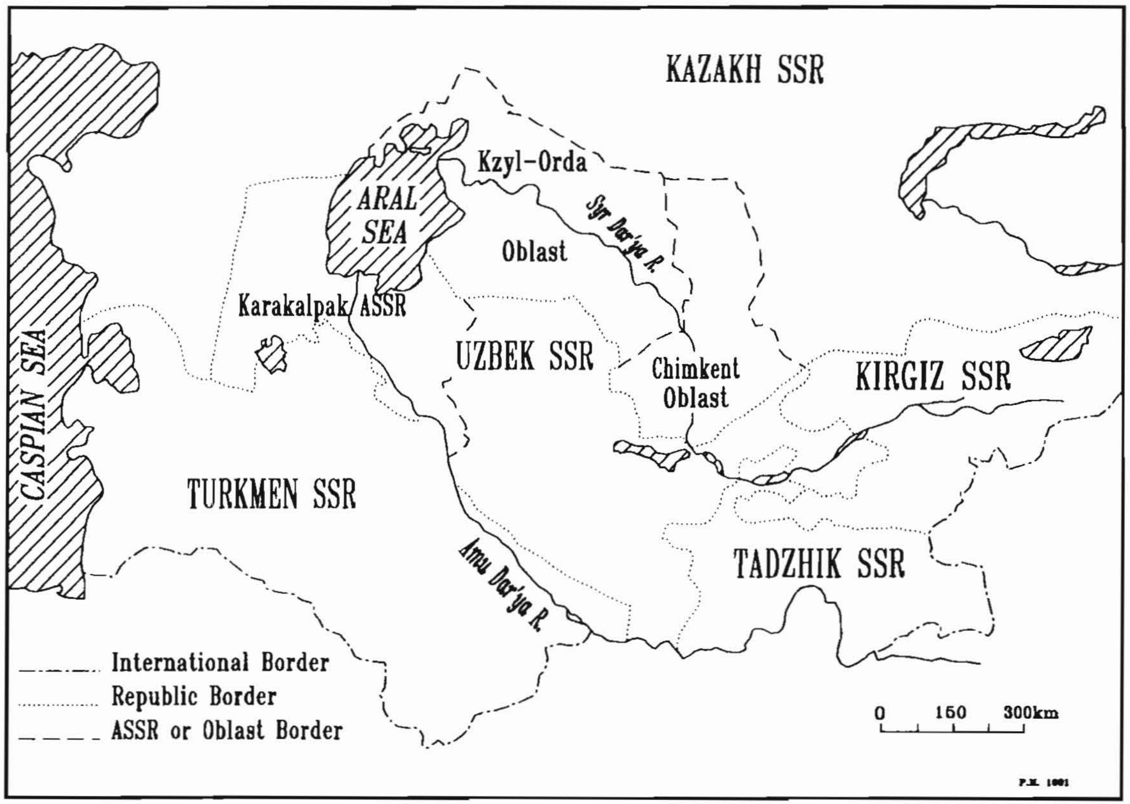


Figure 1. Central Asia: Administrative Divisions

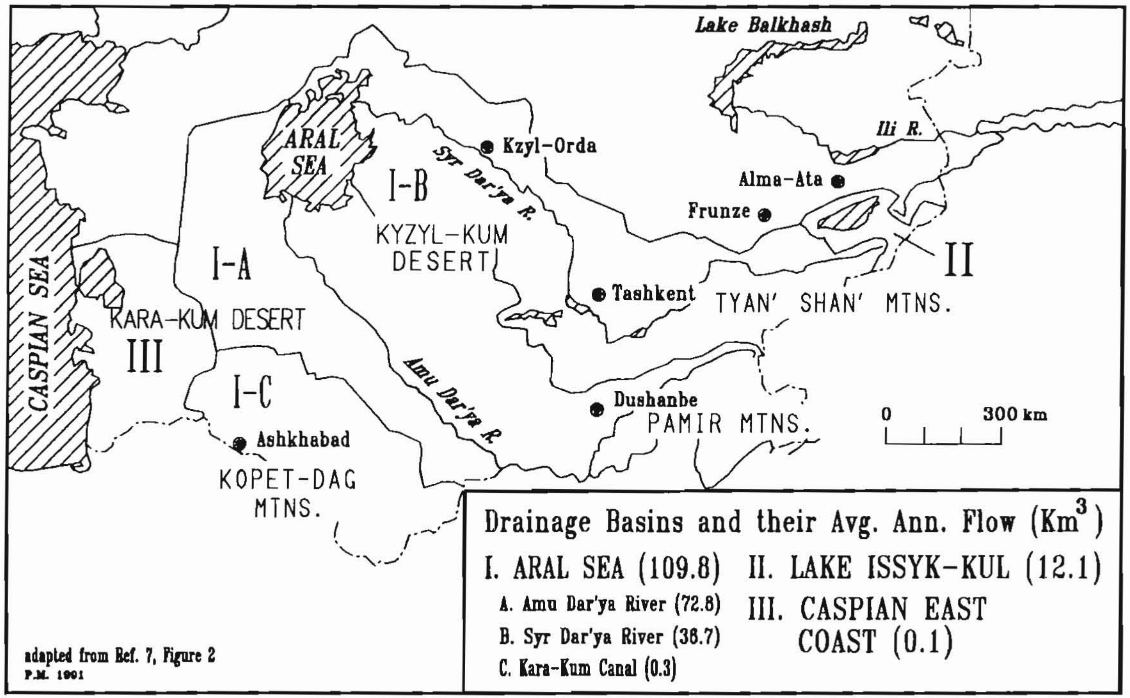


Figure 2. Central Asia: Drainage Basins

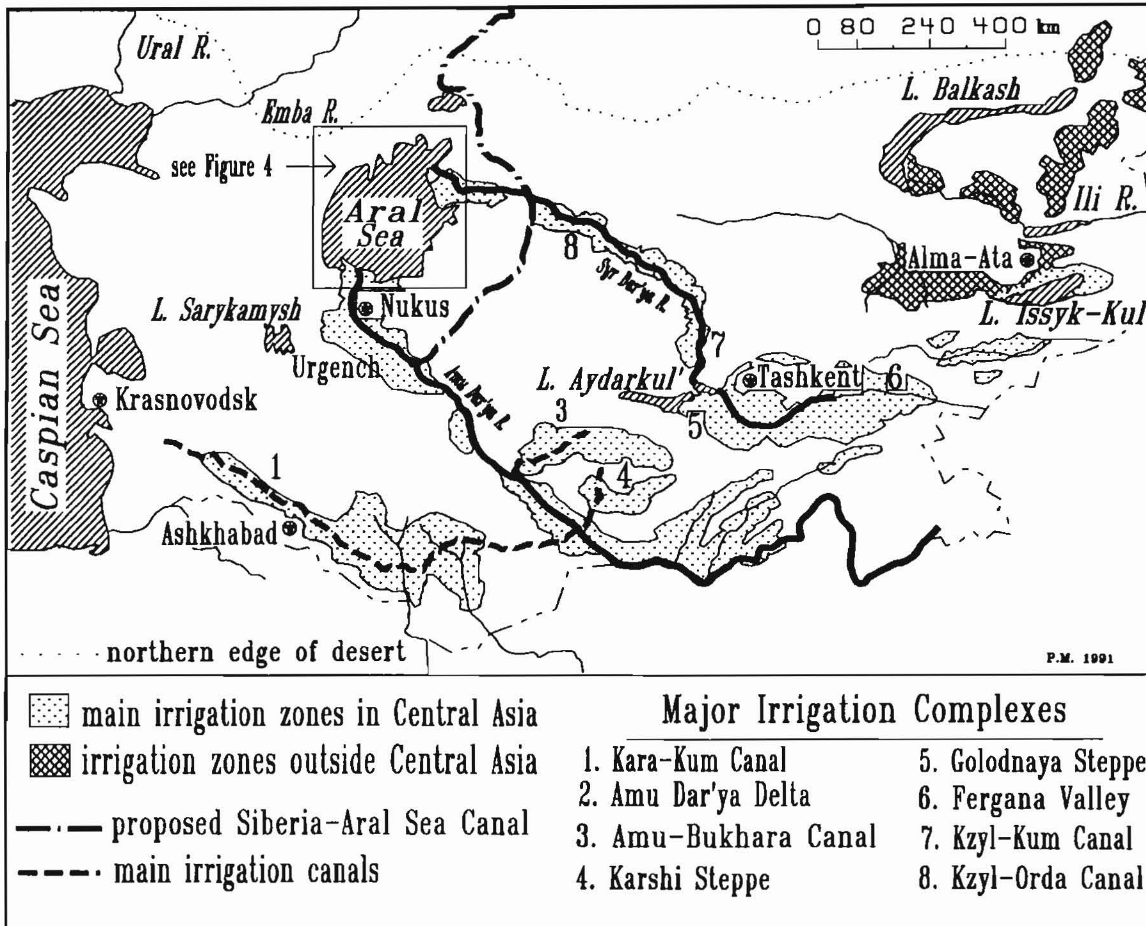


Figure 3. Central Asia: Irrigation Development

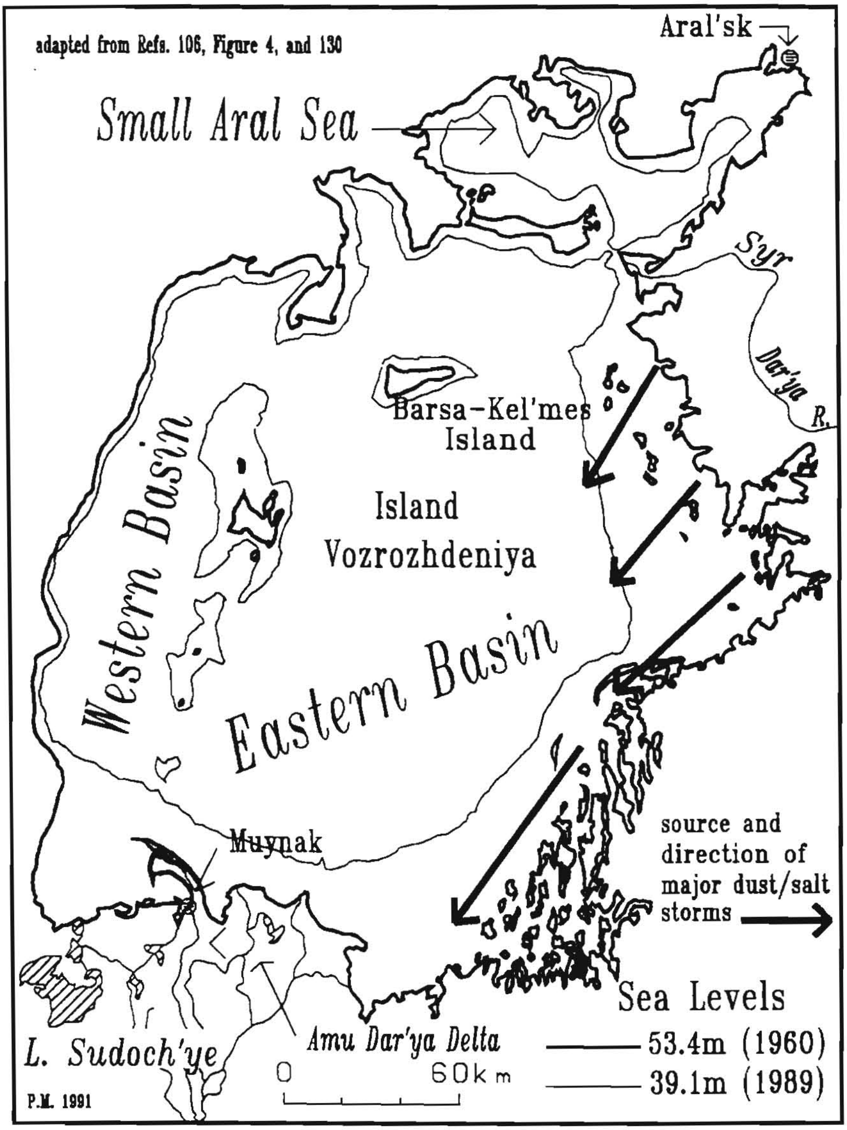
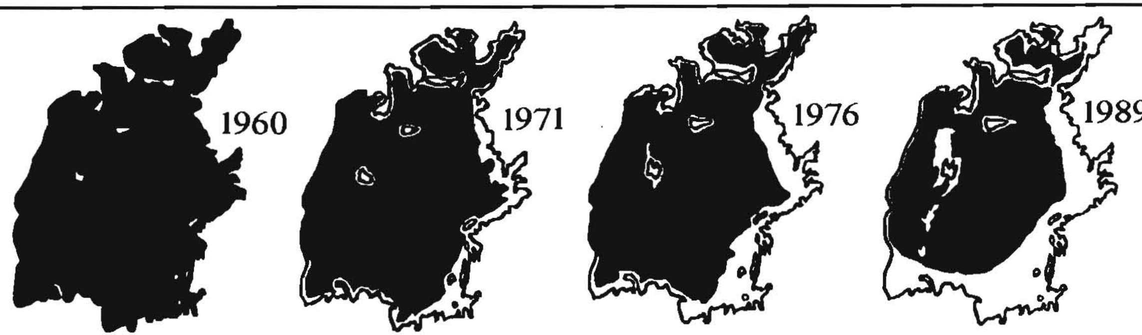
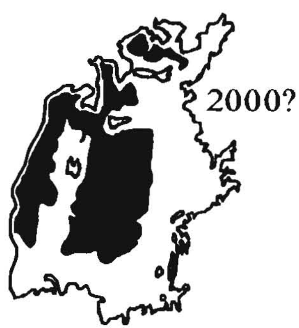


Figure 4. The Aral Sea





YEAR	AVERAGE LEVEL (meters)	AVERAGE AREA (sq.-km)	AVERAGE VOLUME (cu.-km)	AVERAGE SALINITY (grams/liter)
1960	53.41	68,000	1090	10
1971	51.05	60,200	925	11
1976	48.28	55,700	763	14
1989	39.07	40,394	370	30
2000	33.00	25,500	166	~70

P. M. 1991

adapted from Refs. 130 and 184, Figure 4

Figure 5. The Changing Profile of the Aral Sea

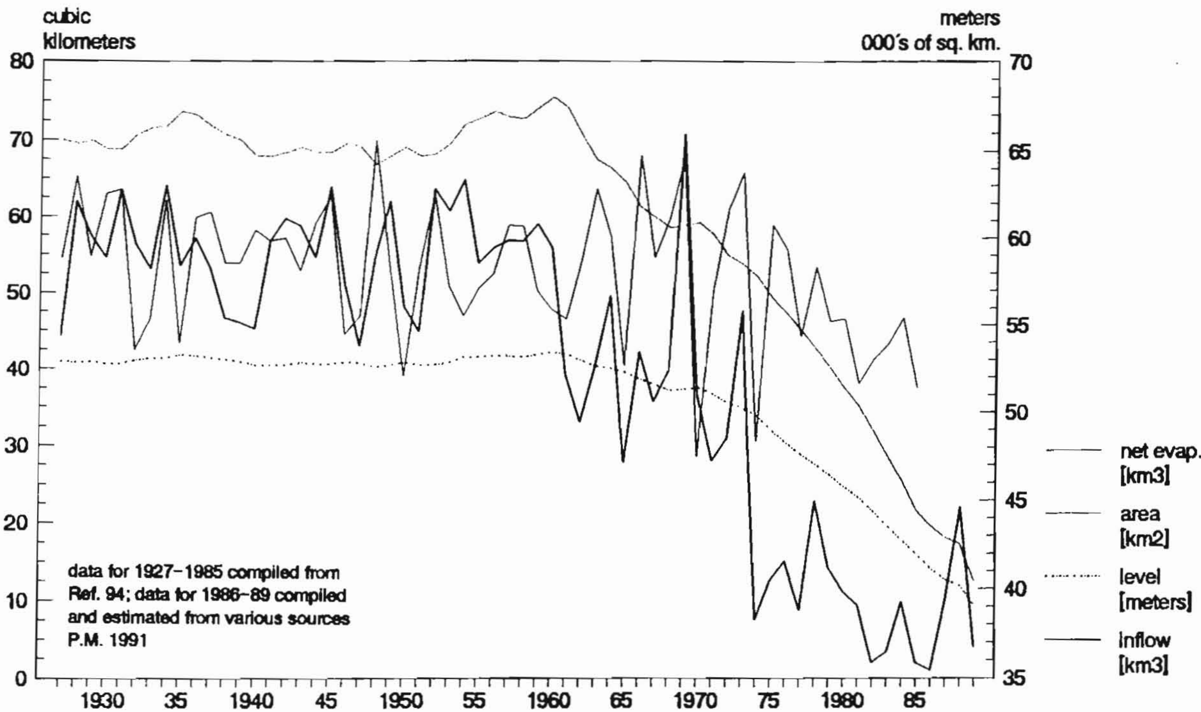


Figure 6. Water Balance Parameters of the Aral Sea, 1927-1989

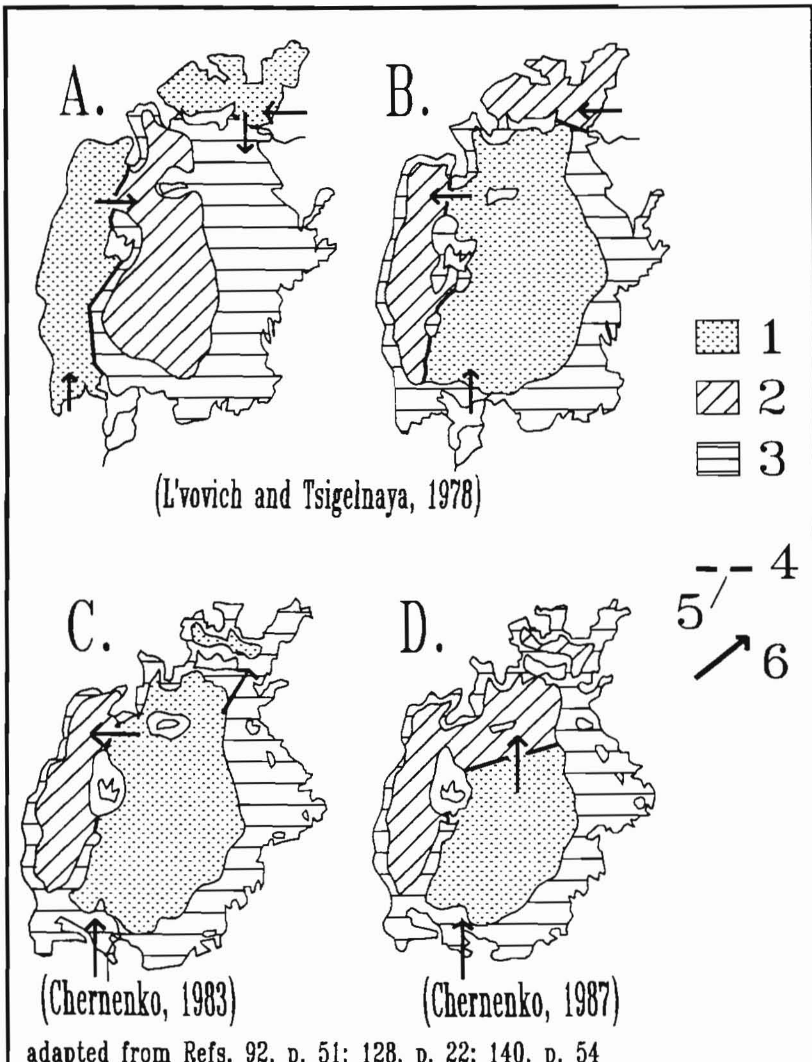


Figure 7. Schemes to Partially Preserve the Aral

Legend for Figure 7

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 km^2; volume-293 km^3; level-53 m (small sea) and 46.5 m (large sea); salinity-5 to 6 g/l by 2050; surface inflow-30 km^3; outflow-15 km^3.

B. Isolation of northern part of sea in 1980 and western part in 2000. Average annual physical characteristics of active sea: area-30,000 km^2; volume-285 km^3; level-46.6 m; salinity-13 to 15 g/l by 2050; surface inflow-30 km^3; outflow-15 km^3.

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 km^2; level-38 m; salinity-12 g/l; surface inflow-24.4 km^3; precipitation on sea surface-2.5 km^3; groundwater inflow-2 km^3; outflow -10.3 km^3; evaporation from sea surface-18.6 km^3.

D. Separation of central and southern part of eastern sea. Average annual physical characteristics of active sea: area-12,000 km^2; level-38 m; salinity-12 g/l; minimum surface inflow-8.05 km^3; precipitation on sea surface-1.51 km^3; groundwater inflow-1.6 km^3; outflow-dependent on inflow above minimum; evaporation from sea surface-11.6 km^3.

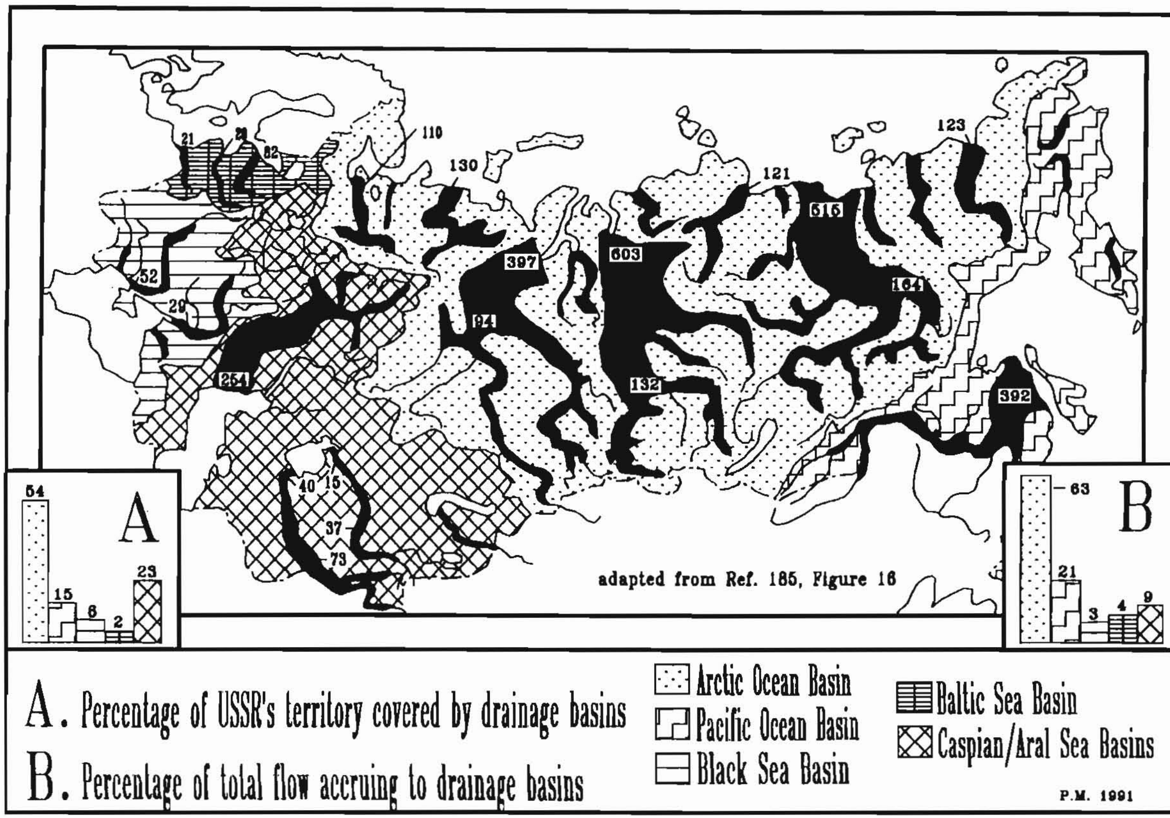


Figure 8. Mean Flow of USSR Rivers (cubic kilometers/year)

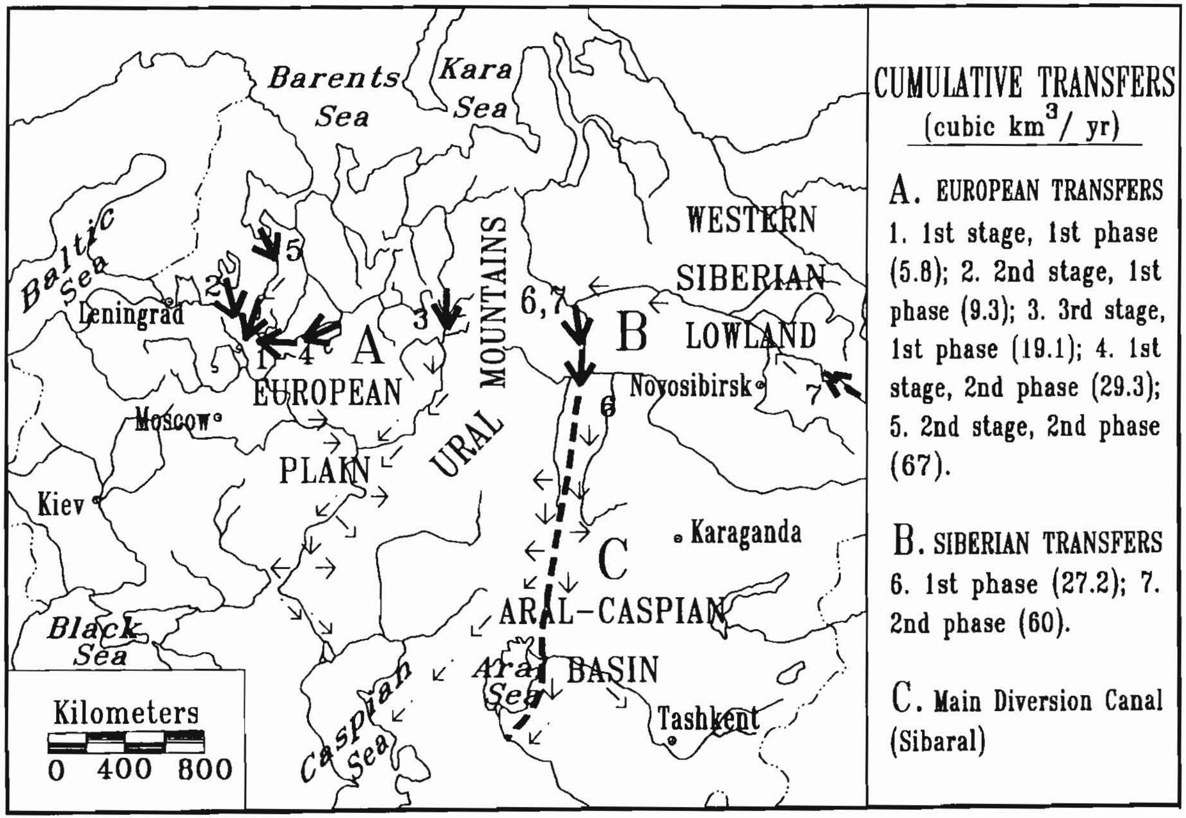


Figure 9. Proposed North-South Water Transfer Schemes in the USSR

Table 1. Central Asia: Area and Population Characteristics

Administrative unit	area (000's of sq. km)	population on 1/12/89 (millions)	% total pop.	1979-1989 avg. ann. natural increase (%)
Uzbek SSR	447.4	19.91	56.37	2.57
Kazakh SSR(1)	344.4	2.48	7.02	1.54
Kzyl-orda Obl.	(228.1)	(0.65)	(1.84)	(1.41)
Chimkent Obl.	(116.3)	(1.83)	(5.18)	(1.58)
Tadzhik SSR	143.1	5.11	14.47	2.96
Kirgiz SSR	198.5	4.29	12.15	2.01
Turkmen SSR	488.1	3.53	9.99	2.49
Total	1621.5	35.32	100.00	2.54

compiled from Ref. 183

(1) Kzyl-Orda and Chimkent oblasts

Table 2. Central Asia: Drainage Basin Characteristics

Characteristic	Drainage Basins [1] Amu Dar'ya	[2] Syr Dar'ya	[3] Kara-Kum Canal	[4] Lake Issyk-Kul	Caspian Sea east coast [5]	Aral Sea Basin [drainage basins [1,2,3]	Central Asia [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) (2)	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)(3)	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 Refs. 6; 227, 7; 182-183 and 226-231
(1) land actually provided with water
(2) for period 1926-76
(3) flow for which the exceedance probability in any year is 95%

Table 3. Central Asia: Water Use by Sector in 1980 (cubic kilometers)

Water consuming sectors	Drainage basin: [1] Amu Dar'ya	%	[2] Syr Dar'ya	%	[3] Kara-Kum Canal	%	[4] Lake Issyk-Kul	%	Caspian Sea east coast [5]	%	Aral Sea Basin [drainage basins 1,2,3]	%	Central Asia [drainage basins 1-5]	%
Municipal														
withdrawal	0.4637	100.0	1.1044	100.0	0.1039	100.0	0.0131	100.0	0.0080	100.0	1.6720	100.0	1.6931	100.0
return	0.2218	47.8	0.7332	66.4	0.0459	44.2	0.0030	22.9	0.0018	22.5	1.0009	59.9	1.0057	59.4
consumptive use	0.2419	52.2	0.3712	33.6	0.0580	55.8	0.0101	77.1	0.0062	77.5	0.6711	40.1	0.6874	40.6
withdrawals as % of drainage basin total		0.8	1.2450	2.0	0.2951	0.7	4.2470	0.8		1.2		1.3		1.3
Industry														
withdrawal	0.7690	100.0	1.7380	100.0	0.2430	100.0	0.0030	100.0	0.1010	100.0	2.7500	100.0	2.8540	100.0
return	0.5790	75.3	1.3620	78.4	0.1750	72.0	0.0020	66.7	0.0770	76.2	2.1160	76.9	2.1950	76.9
consumptive use	0.1900	24.7	0.3760	21.6	0.0680	28.0	0.0010	33.3	0.0240	23.8	0.6340	23.1	0.6590	23.1
withdrawals as % of drainage basin total		1.2		3.1		1.8		0.2		14.6		2.1		2.1
Thermoelectric														
withdrawal	0.9331	100.0	2.5152	100.0	0.7059	100.0	-	-	0.3749	100.0	4.1542	100.0	4.5291	100.0
return	0.8456	90.6	2.3752	94.4	0.6922	98.1	-	-	0.3703	98.8	3.9130	94.2	4.2833	94.6
consumptive use	0.0875	9.4	0.1400	5.6	0.0137	1.9	-	-	0.0046	1.2	0.2412	5.8	0.2458	5.4
withdrawals as % of drainage basin total		1.5		4.5		5.1				54.0		3.1		3.4
Irrigation														
withdrawal	57.8030	100.0	49.3320	100.0	12.6390	100.0	1.5040	100.0	0.2000	100.0	119.7740	100.0	121.4780	100.0
return	23.3160	40.3	16.2920	33.0	6.1930	49.0	0.7070	47.0	0.0090	4.5	45.8010	38.2	46.5170	38.3
consumptive use	34.4870	59.7	33.0400	67.0	6.4460	51.0	0.7970	53.0	0.1910	95.5	73.9730	61.8	74.9610	61.7
withdrawals as % of drainage basin total		93.8		87.3		91.2		94.7		28.8		90.7		90.5
Rural settlements														
withdrawal	1.1551	100.0	1.1318	100.0	0.1121	100.0	0.0379	100.0	0.0089	100.0	2.3990	100.0	2.4458	100.0
return	0.1514	13.1	0.1583	14.0	0.0147	13.1	0.0049	12.9	0.0012	13.5	0.3244	13.5	0.3305	13.5
consumptive use	1.0037	86.9	0.9735	86.0	0.0974	86.9	0.0330	87.1	0.0077	86.5	2.0746	86.5	2.1153	86.5
withdrawals as % of drainage basin total		1.9		2.0		0.8		2.4		1.3		1.8		1.8

Table 3. Central Asia: Water Use by Sector in 1980 (cubic kilometers) [continued]

Water consuming sectors	Drainage basin [1] Amu Dar'ya	%	[2] Syr Dar'ya	%	[3] Kara-Kum Canal	%	[4] Lake Issyk-Kul	%	Caspian Sea east coast [5]	%	Aral Sea Basin [drainage basins 1,2,3]	%	Central Asia [drainage basins 1-5]	%
Livestock														
withdrawal	0.1100	100.0	0.1559	100.0	0.0166	100.0	0.0068	100.0	0.0013	100.0	0.2825	100.0	0.2906	100.0
return	0.0056	5.1	0.0078	5.0	0.0008	4.8	0.0003	4.4	0.0001	7.7	0.0142	5.0	0.0146	5.0
consumptive use	0.1044	94.9	0.1481	95.0	0.0158	95.2	0.0065	95.6	0.0012	92.3	0.2683	95.0	0.2760	95.0
withdrawals as % of	0.1097	99.7	0.1556	-	-	100.0	-							
drainage basin total		0.2		0.3		0.1		0.4		0.2		0.2		0.2
Fish rearing ponds														
withdrawal	0.3815	100.0	0.5327	100.0	0.0368	100.0	0.0236	100.0	-	-	0.9510	100.0	0.9746	100.0
return	0.2705	70.9	0.4124	77.4	0.0241	65.5	0.0228	96.6	-	-	0.7070	74.3	0.7298	74.9
consumptive use	0.1110	29.1	0.1203	22.6	0.0127	34.5	0.0008	3.4	-	-	0.2440	25.7	0.2448	25.1
withdrawals as % of drainage basin total		0.6		0.9		0.3		1.5				0.7		0.7
Drainage basin total														
withdrawal	61.6154	100.0	56.5100	100.0	13.8573	100.0	1.5884	100.0	0.6941	100.0	131.9827	100.0	134.2652	100.0
return	25.3899	41.2	21.3409	37.8	7.1457	51.6	0.7400	46.6	0.4594	-	53.8765	40.8	55.0759	41.0
consumptive use	36.2255	58.8	35.1691	62.2	6.7116	48.4	0.8484	53.4	0.2347	-	78.1062	59.2	79.1893	59.0
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	100.0	59.0260	100.0	19.4973	100.0	1.5884	100.0	0.7149		142.8407	100.0	145.1440	100.0
return	25.3899	39.5	21.3409	36.2	6.7116	34.4	0.7400	46.6	0.4594		53.4424	37.4	54.6418	37.6
consumptive use	38.9275	60.5	37.6851	63.8	12.7857	65.6	0.8484	53.4	0.2555		89.3983	62.6	90.5022	62.4

compiled and calculated from Ref. 7; 212-215

Table 4. Use of Irrigated Land of State Enterprises in Central Asia in 1984 (millions of hectares)

Adminis-strative 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 cblast	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 Ref. 21; 273, and 22; 98

(1) Land with irrigation facilities.

Table 5. Crops Sown on Irrigated Land of State Enterprises in Central Asia in 1984
(millions of hectares)

Administrative unit	sown area	grains	% sown area	technical 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 Ref. 21; 274, and 22; 99

(1) Almost entirely cotton.

Table 6. Average Annual Water Balances for the Aral Sea, 1927 TO 1985 (1)

	1927-60(2)		1961-74(3)		1974-85(4)	
Avg. area (sq. km)	65,765		61,836		51,110	
	cubic km	mm	cubic km	mm	cubic km	mm
Gain(5)	63.6	967.1	45.4	734.2	16.7	327.0
river discharge	55.3	840.9	37.7	609.7	10.1	197.7
precipitation	8.3	126.2	7.7	124.5	6.6	129.2
Loss: evaporation	62.8	954.9	61.2	989.7	53.1	1039.1
Average net volume change	0.8	12.2	-15.8	-255.5	-36.4	-712.1

calculated from Ref. 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

<u>Annual Water Balance Equation for the Aral Sea</u>

$$Qr+Qu+(P*F)/10^6 = (E*F)/10^6 \pm (dh*F)/10^6, \text{ where}$$

Qr = annual river inflow in km^3; Qu = 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

Table 7. characteristics of Proposed North-South Water Transfer Projects in the USSR

Stage/phase (numbers refer to Figure 10)	Water source	Average annual diversion (cubic-km.)	Notes
	EUROPEAN SCHEMES		
lst stage, lst phase (1)	a. lakes Lacha & Vozhe	1.8	1. Construction begun on lst phase in 1985 with completion by 2005. Project halted in 1986. Further design and construction postponed indefinitely. Ecological and economic re-evaluation ordered. Project and proponents bitterly denounced in popular media.
	b. Lake Kubena & upper Sukhona R.	4.0	
lst stage total		5.8	
2nd stage, lst phase (2)	Lake Onega	3.5	
3rd stage, lst phase (3)	upper Pechora R.	9.8	
2nd and 3rd stage total		13.3	
First phase total		19.1	
lst stage, 2nd phase (4)	Lower Sukhona & Malaya Northern Dvina rivers	10.2	2. Construction originally set for early 21st century. Postponed (note 1).
2nd stage, 2nd phase (5)	Onega Gulf reservoir	37.7	3. Construction possible in 21st century (note 1).
Second phase total		47.9	
European diversions total		67.0	
	SIBERIAN SCHEMES		
lst phase (6)	a. Irtysh River at Tobol'sk	17.0	4. Design work on lst phase nearly completed by 1986. Construction seemed imminent. Project halted in 1986 for re-evaluation (note 1). Owing to severe water problems in Central Asia, water management experts and governmental leaders of Central Asia are again calling for project implementation.
	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	

Table 8. Selected Economic and Environmental Characteristics
of the Proposed 1st Phase Siberian Water Transfer Project
(continued)

<u>Major potential harmful consequences of diversion project to Western Siberia</u> (region of water export)

[1] flooding of, and raising of groundwater levels under, prime agricultural lands and commercial forests by reservoirs

[2] resettlement of people

[3] fishery deterioration of the Ob', Irtysh, and Ob' Gulf from hydrological and biological regime changes downstream from points of diversion

[4] longer ice cover on the southern part of Ob' Gulf causing climatic changes (i.e., cooler springs) along and adjacent to its coast as well as hindering navigation

[5] degradation of water quality downstream from points of diversion

[6] deterioration of flood plain meadows with great ecological and agricultural value downstream from points of withdrawal owing to reduced spring flooding

[7] worsened low-flow navigation conditions below points of diversion

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adapted from Ref. 142; 72

(1) according to the project design agency (<u>Soyuzgiprovodkhoz</u>) and the Institute of Water Problems

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

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