# Environmental Policy and Technology Project

Contract No. CCN-0003-Q-12-3165-00

**NEW INDEPENDENT STATES**

## ISSUE PAPER NO. 4

**Optimization of Water Use:**
**The Naryn-Syr Darya Cascade**
**January, 1997**
**Almaty, Kazakstan**

**by Daene C. McKinney**
**Delivery Order 12, Task 6**

Prepared for:
Central Asia Mission
**U.S. Agency for International Development**

Prepared by:
Central Asia Regional EPT Office in Almaty, Kazakstan
Environmental Policy and Technology Project
For the New Independent States of the Former Soviet Union
A USAID Project Consortium Led by CH2M Hill

ENVIRONMENTAL POLICY AND TECHNOLOGY PROJECT

A Project Financed by the U.S. Agency for International Development

Проект финансируемый Агентством по Международному Развитию США

Serving Countries of the Former Soviet Union

Служит странам бывшего Советского Союза

Managed by CH2M HILL

Под руководством CH2M HILL

USAID

ENVIRONMENTAL POLICY AND TECHNOLOGY PROJECT
Central Asian Republics Regional Office

ПРОЕКТ ПО ПРИРОДООХРАННОЙ ПОЛИТИКЕ И ТЕХНОЛОГИИ
Региональный офис республик Средней Азии

This report was done as part of Task 6 of Delivery Order 12.

This report has been reviewed for content and approved for distribution to USAID

Barbara Britton — May 22, 1997
**EPT Program Manager** Date

[signature] — 5/28/97
**EPT Regional Director** Date

This report has been reviewed for content and approved for distribution.

Barbara Britton — May 22, 1997
**EPT Program Manager** Date

[signature] — 5/28/97
**EPT Regional Director** Date

Ulitsa Abai 4, Suite 112, Almaty 480024, Kazakstan. Telephone: (7-3272) 65-46-95, Fax: (7-3272) 64-68-49

Казахстан 480024, Алматы, ул.Абай 4, комн.112. Тел.: (7-3272) 65-46-95, Факс: (7-3272) 64-68-49

## Section 1
# Issues

The Toktogul reservoir is currently (1996) being operated by the Kyrgyz Republic in a hydropower generation mode, which requires large wintertime releases of water. The system was originally designed for, and the downstream countries of Uzbekistan and Kazakstan depend on, the operation of the system in an irrigation mode, which requires large summertime releases of water. This paper explores several alternative scenarios for the operation of Toktogul reservoir which offer a compromise between the power generation and the irrigation modes of operation and form the basis of a long-term agreement on the sharing of the water and energy resources of the Naryn-Syr Darya Cascade.

## Section 2
# Background

One of the major sources of the Syr Darya River is the Naryn River, which forms in the mountainous Kyrgyz Republic. This source is controlled by cascade reservoirs in the Kyrgyz Republic, of which the Toktogul reservoir is the major water storage and hydroelectric facility. The other reservoirs operate at constant volume and only provide power generation, not flow regulation or storage. Compared to the Toktogul reservoir, the downstream countries do not have extensive water storage facilities, but they do have large irrigated lands. These countries rely on releases from Toktogul to satisfy these water demands. Under the Soviet Union, the management of the Syr Darya river basin was an intra-national issue managed by a central authority for the combined benefit of the entire region. The primary benefit derived from the management of the river was the provision of water for irrigated agriculture in Uzbekistan and Kazakstan. Upon the collapse of the Soviet Union in 1991, the river basin was split into four sovereign nations with competing interests in the waters of the Syr Darya River.

The Kyrgyz Republic's primary objective in managing the Toktogul reservoir is to provide wintertime production of hydroelectric power. Their preferred release of water from Toktogul during the April to September vegetation period is less than the downstream irrigation requirement. In conflict with this are the objectives of the downstream countries, Uzbekistan and Kazakstan, which are seeking to provide water for summertime irrigation. Their preferred release pattern generates summertime hydroelectric power in excess of Kyrgyz demand, and wintertime shortages of hydroelectric power. Under recent international agreements, the Kyrgyz Republic has been selling excess summertime hydroelectric power to Uzbekistan and Kazakstan to compensate for the fuel cost of wintertime thermal power plant operation. In addition, Uzbekistan supplies the Kyrgyz Republic with natural gas in the winter, and Kazakstan is supposed to supply the Kyrgyz Republic with coal in the winter. However, due to recent privatization of the energy sector in Kazakstan, wintertime deliveries of coal to the Kyrgyz Republic have ceased, creating a major breakdown in the existing international agreements over the operation of the Toktogul Reservoir.

## Section 3
# Activities During Assignment

The USAID EPT project is assisting the Kyrgyz Republic and the republics of Uzbekistan, Tajikistan, and Kazakstan to develop a long-term water and energy sharing agreement for the Naryn-Syr Darya cascade. As part of this effort, a policy analysis tool has been developed to help decision makers develop this long-term agreement. This multi-criteria decision analysis tool can be used to promote an understanding of the tradeoffs between water releases made for agricultural production and those made for hydroelectric power generation.

A variety of activities were undertaken in support of the objectives of the current project under DO12. These included:

- Attending meetings with the Regional Policy Coordinator of the EPT Central Asian Regional Office and other consultants to prepare for the meeting of the Regional Water and Energy Uses Roundtable;
- Attending a meeting of the Sustainable Development Commission of the Central Asian Republics, December 10-12;
- Presenting optimization options to a working group of the Regional Water and Energy Uses Roundtable, December 17 - 20 , 1996, in Almaty, Kazakstan to present the work done under this project.

## Section 4
# Accomplishments to Date

A mathematical optimization model has been developed to aid in the identification of efficient and sustainable water allocation options for the republics that rely on the Syr Darya river for their water resources and the Toktogul reservoir for their hydroelectric power. The goal has been to construct a screening tool which can be used to easily and quickly identify reasonable alternatives for water management under different scenarios that can then be discussed, debated, modified, and modeled in greater detail.

The model considers the water management objectives of power generation in the upstream country (Kyrgyz Republic) and irrigation water supply in the downstream countries (Kazakstan and Uzbekistan). The model includes the following objectives which may each receive different weight depending on the option being analyzed:

- Maximize total power generation during the planning period;
- Minimize power deficit in winter periods;
- Maximize satisfaction of irrigation water demand; and
- Evenly distribute water deficits to irrigation districts.

The model was constructed considering the network of existing water allocation and power generation facilities in the Syr Darya basin. Primary model data included (1) water supplies (including surface water and groundwater), (2) water storage facilities (including the main stem reservoirs of Toktogul, Kayrakum, and Chardara, as well as the tributary river reservoirs of Andijan, Charvak, and Bugun), (3) water demand data (including irrigation, municipal-industrial, and Aral Sea flow), and (4) energy demand data for the Kyrgyz republic.

Using the model, three scenarios were examined in detail, each with a different objective:

1. satisfaction of irrigation demands;
2. satisfaction of irrigation demands and Kyrgyz power demands; and
3. maximization of power production.

The scenarios all assume the flow to the Aral Sea to be at least 7.17 $km^3$/year and all reservoirs in the basin are full at the beginning of the modeled period (five years). Flow to the Aral Sea during the 1995-96 year was 5 $km^3$. For each scenario, several items were calculated: the total supply and deficit of water to agricultural production, the total amount of power generated and any resulting deficit of power, the net benefits resulting from agricultural production, power generation and the flow to the Aral Sea, and the volume of water in storage at Toktogul reservoir after two growing (vegetation) seasons. The net benefit calculations were based on the unit benefit and cost values given in Table 4-2 (J. Keith and R. Anderson, personal communication, 1996). The results of the scenario analyses are given in Table 4-1 below.

**Table 4-1**
**Results of Three Modeled Scenarios**

| | Irrigation | Irrigation + Power | Power |
|---|---|---|---|
| Agriculture ($km^3$/yr) | | | |
| Supply | 38.3 | 37.9 | 32.0 |
| Deficit | (5.5) | (5.8) | (11.8) |
| Power (GWh/yr) | | | |
| Generated | 9656 | 9752 | 10690 |
| Deficit/Surplus | (108) | 0 | +2265 |
| Net Benefits (million $/yr) | | | |
| Agriculture | 3715 | 3703 | 3165 |
| Power | 95 | 98 | 84 |
| Aral Sea Flow | 269 | 269 | 269 |
| Total | 4079 | 4069 | 3518 |
| Toktogul Storage ($km^3$) | | | |
| At the end of 2 vegetation periods | 12 | 9 | 3 |

The irrigation scenario provides the most water to the agricultural sector and the greatest net benefits of the three scenarios. The 5.5 $km^3$ agricultural water deficit is shared evenly (in terms of percent of total demand) among the irrigation districts. Toktogul reservoir storage is 12 $km^3$ at the end of two vegetation periods. A 108 GWh power deficit occurs in February



5

and power surpluses occur during March through May. Under this scenario, as much water as possible is stored in the Toktogul reservoir to release for agriculture during the vegetation period.

**Table 4-2**
**Benefits and costs of various water uses in the Syr Darya Basin**

| Use | Benefit ($/km$^3$) | Cost ($/km$^3$) |
|---|---|---|
| Hydropower | 0.01 | 0.01 |
| Agriculture | 0.1 | 0.003 |
| Aral Sea | 0.0375 | 0.0 |

The irrigation + power scenario results in a 5.8 $km^3$/year agricultural water deficit, which is 0.3 $km^3$/year greater than the irrigation scenario. The Toktogul reservoir storage is 9 $km^3$ at the end of two vegetation periods, a 3 $km^3$ decrease from the irrigation scenario. There are no power deficits under this scenario. The downstream reservoirs are operated in conjunction with Toktogul to capture and store water released from Toktogul for power generation in the winter period for later release for agricultural production. It should be noted that the slight increase in the agricultural water deficit could be offset by modest increases in irrigation system efficiencies.

The power scenario provides the greatest power generation, 10690 GWh/year. However, when compared to the irrigation + power scenario, this comes at the expense of 6 $km^3$/year in agricultural water deficit and 2265 GWh/year deficit in peak period power. Toktogul releases water continuously under this scenario, maximum releases (up to 2.2 $km^3$ per month) occur during the vegetation period. Toktogul reservoir storage is 3 $km^3$ at the end of two vegetation periods. This scenario requires draining the reservoir to make large power generation releases and the capacity is not available in downstream reservoirs to capture and store all of these flows.

## Section 5
# Findings

A meeting of the Regional Water and Energy Uses Roundtable was held in Almaty, Kazakstan on December 18-20, 1996. This meeting was organized by the Interstate Council of the Republic of Kazakstan, the Kyrgyz Republic, and the Republic of Uzbekistan (ICKKU) and the USAID EPT Project Central Asian Regional Office. The outcome of the meeting resulted in good progress toward the development of a long-term water and energy sharing agreement between the countries affected by the management of the Toktogul Reservoir.

The objectives of the Roundtable were to present CAR participants with information regarding:

- American and international experiences with international water and energy sharing agreements;

- current concepts related to the estimation and allocation of costs and benefits associated with river basin management; and
- institutional arrangements that have been used in other international water sharing agreements.

Other objectives were to present and discuss the results of the model developed for the optimal operation of the Toktogul reservoir, and most importantly, to draft a set of principles for a multi-year interstate agreement on managing the Naryn-Syr Darya Cascade (referred to hereafter as "the Agreement").

During the Regional Water and Energy Uses Roundtable meeting there was considerable discussion of the use of the model presented by Dr. McKinney to support the Agreement. Mr. Khamidov, Head of the BVO Syr Darya, made several comments on the timeliness of the data used in the model. He presented two alternative scenarios for the management of the Toktogul reservoir over the next two to three years. One scenario centered on the concept of storing as much water as possible for summertime release for irrigation purposes. This scenario shows a very stable volume of water maintained in the reservoir for use in the event of a severe drought. The other scenario represented the results of conforming to the current Kyrgyz Republic scheme of large releases from storage during the winter to generate electricity. These scenarios reasonably represent the modes of operation possible with this reservoir cascade under current political conditions. The second scenario demonstrates the immediate need to reach an interstate agreement before the reservoir's long-term, overyear storage is depleted. This reservoir took approximately ten years to fill after its construction, and, once depleted, it can only be refilled through operation in the irrigation mode during several years of high flows in the basin, an unlikely event in the near future. The purpose behind having such a large volume reservoir is to provide storage of water for release during several years of extremely low flows (drought) in the basin. The current regime of releases planned by the Kyrgyz Republic will lead to the elimination of this overyear storage, and, in the event of an extreme drought in the near future, devastation of the agricultural economies of Uzbekistan and Kazakstan.

Mr. Mambetov, Deputy Chairman of the ICKKU, presented a discussion on the planned Kambarata reservoirs. These reservoirs would be built upstream of the existing Toktogul reservoir. Kambarata 1 would have a large hydroelectric generating capacity (1600 MWh) and a reasonably large active storage capacity (5 $km^3$). The mode of operation of these reservoirs would be to release water during the winter period to generate electricity; this water would then be captured downstream at Toktogul reservoir and stored for summertime release for irrigation. This project is under consideration for financing by the Islamic Development Bank. "Draft Principles for a Multi-year Interstate Agreement on Management of the Naryn-Syr Darya Cascade" were prepared and presented to the Roundtable participants at the meeting.

## Section 6
# Constraints

The major constraints related to this work include:

- Lack of up-to-date data and information on the system's physical properties and operation. This information is not available outside of the local region, and gaining access to it requires close cooperation and contact with local officials.
- Time was critical in the development of this work. Given additional time and resources, much more detailed and accurate calculations could be performed.
- The ability of local officials to understand and accept the decision analysis tool developed here is unknown at this time. It is unclear what current methods were used to compute projected releases from Toktogul reservoir.
- The ability of local officials to implement integrated watershed planning in the Syr Darya basin is critical to the success of any long-term agreement. The many and varied objectives of the four countries must be accommodated in this agreement, and methods of conflict resolution must be provided for. The decision analysis tool developed in this work may aid in the resolution of such disputes.

## Section 7
# Outlook and Possible Resolutions

The countries of the Syr Darya basin seem interested in finding a resolution to their mutual problems. They may even be willing to accept some increased expense in order to reach an agreement that avoids catastrophic conflict and economic hardship in the future. However, at the present time, the Kyrgyz are exploring various options, including: selling power to Pakistan; the construction of Kambarata 1 and 2, financed by the Islamic Development Bank; and selling power to, and developing water resources in concert with, China.

Under previous agreements fossil fuels (Uzbek natural gas and Kazak coal) were to be provided to the Kyrgyz Republic during the winter season to fuel thermal power plants and eliminate the need for hydroelectric power generation. However, the privatization of the Kazakstani energy sector in the past two years has disrupted the delivery of coal from Kazakstan. This has forced the Kyrgyz to operate the Toktogul reservoir in a winter power production mode with little or no consultation with the downstream countries. This leaves the downstream countries, Uzbekistan and Kazakstan, with no assurance that the Toktogul reservoir will have adequate storage for summertime irrigation releases. Thus, these countries keep the downstream reservoirs, Kayrakum and Chardara, as full as possible during the winter, resulting in flooding and diversion into the saline Arnasai depression when large winter releases are made from Toktogul.



8

Given the existing situation of the energy sector in Kazakstan and the results of the irrigation + power scenario presented above, it seems necessary to provide some means of allowing wintertime releases of water from Toktogul reservoir to satisfy Kyrgyz winter power demand. In order for this to be successful, the downstream reservoirs must be operated in an integrated fashion with Toktogul in order to capture wintertime releases and store them for summer release. In other words, all of the water resource facilities of the Syr Darya basin must be operated in an integrated manner to reduce conflict in the basin and to provide the maximum net benefits to the countries of the basin.

Section 8

# Recommendations

## 8.1 Develop Improved Model

The Draft Principles state that the Agreement specifies that maximization of net benefits to all riparian states from the management of the Naryn-Syr Darya Cascade should be the fundamental basis for setting the timing and releases from the Toktogul reservoir. It is known that current methods of calculation of the releases from the Toktogul reservoir do not take into consideration the costs and benefits resulting from these releases. The model developed here forms the basis for performing these economic calculations and represents standard international practices in performing such calculations. This model may be viewed as one alternative for performing analyses to support this aspect of the Agreement. Lacking any alternative regional water allocation model for the Syr Darya basin, it is recommended that this model be further developed in order to be more responsive to the needs of the Agreement.

## 8.2 Improve BVO Syr Darya Capacity

Since the BVO Syr Darya would seem to be the likely regional institution to perform the analyses required to support the Agreement, their modeling capabilities should be reviewed. In the event that they are found to have insufficient capacity to perform these analyses, then they should be aided in developing this capacity, should they desire it.

## 8.3 Transfer Model to BVO Syr Darya

The model developed under this project can be immediately transferred to the BVO Syr Darya. Three things would be required to accomplish this task:

- Purchase and deliver to the BVO appropriate computer hardware to run the model. A 200 MHZ class Pentium computer is recommended, although 166 MHZ would be adequate.
- Purchase and deliver to the BVO the General Algebraic Modeling System (GAMS) software to run the model.
- The training of BVO personnel in the development and execution of GAMS programs. Approximately one week of training would be required to ensure that the BVO personnel could sustain and enhance the model. This is the same

modeling software is intended to be used under the World Bank Aral Sea Program, Project 1.1 Regional Water Management Strategy. Clearly, training in the use of this software would benefit the region.

## 8.4 Verify and Update Data

If the model developed under this project is to be used to support the Agreement, then it is imperative that the data used in the model be updated and verified and that the record of recent operation of the Naryn-Syr Darya Cascade be obtained for model calibration. It is impossible to acquire these data without the cooperation of the relevant institutions and personal visits to these institutions are the only means of establishing this cooperation. These visits would entail approximately 2-3 days in Tashkent at the BVO Syr Darya and 2-3 days in Bishkek at the Ministry of Melioration and Water Management and Kyrgyzenergoholding.

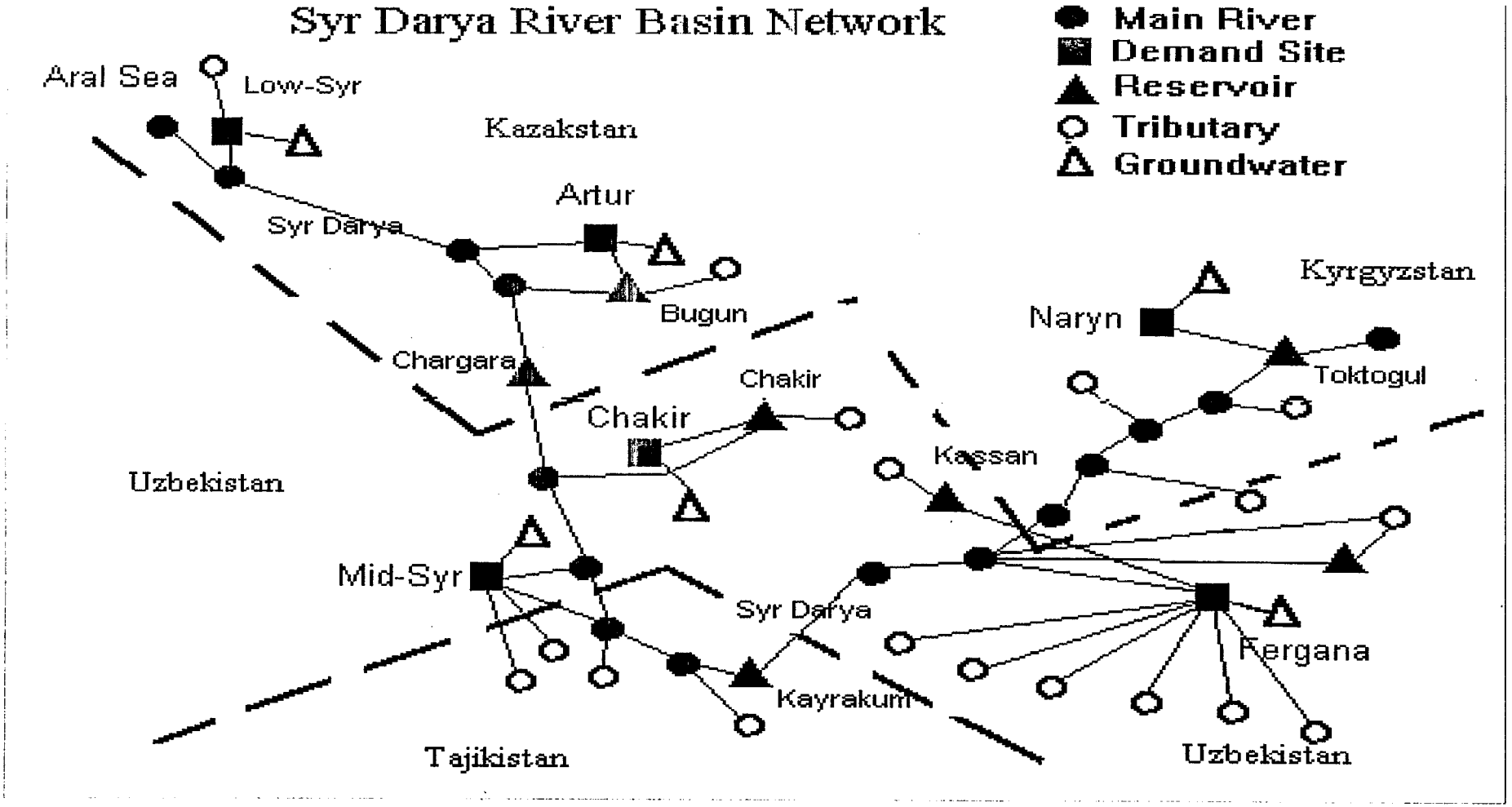
## 8.5 Update Model

In collaboration with the other American consultants on this project, price and cost information relevant to the model was developed during the recent visit to Almaty. However, this information was only applied to the output from the model. In order to truly see the impact of economic instruments (prices and costs) on the allocation of water in the basin, the model must be revised so that these factors are internal to the model.

## 8.6 Include Kambarata Reservoirs in Model

Due to the fact that the Kambarata reservoirs may help to provide a solution to the problem at hand, it is recommended that these reservoirs be included in the model and that an options analysis be performed to determine their effect on the optimal allocation of water resources in the basin.

*Dcmnaryn.wpd*


Syr Darya River Basin Network
Main River
Demand Site
Reservoir
Tributary
Groundwater
Aral Sea
Low-Syr
Kazakstan
Artur
Syr Darya
Bugun
Chargara
Chakir
Chakir
Uzbekistan
Kyrgyzstan
Naryn
Toktogul
Kassan
Mid-Syr
Syr Darya
Fergana
Kayrakum
Tajikistan
Uzbekistan

## Appendix B

**Table B-1**
**Itinerary**

| Date | Day | Location | Activity |
|---|---|---|---|
| 9 - 11 Dec 1996 | Mon./Wed. | Travel | Fly Texas to Almaty |
| 11 - 17 Dec 1996 | Wed./Tue. | Almaty - Hotel Peking | Work under DO12 |
| 17 - 20 Dec 1996 | Tue./Fri. | Almaty - Alatau Hotel | Attend Regional Water and Energy Uses Roundtable Meeting |
| 20 - 22 Dec 1996 | Fri./Sat. | Almaty - Alatau Hotel | Work under DO12 |
| 22 Dec 1996 | Sun. | Travel | Fly Almaty to Moscow, stopover in Moscow |
| 23 Dec 1996 | Mon. | Travel | Fly Moscow to Texas |

**Table B-2**
**List of People Interviewed**

| Date | Name | Title/Occupation Agency | Address | Phone, Fax |
|---|---|---|---|---|
| 12-11 | Barbara Britton | Regional Water Policy Coordinator, Environmental Policy and Technology Project | Central Asian Regional Office, Ulitsa Abai 4, Suite 112, Almaty, Kazakstan | 3272-64-58-19 (T)<br>3272-64-67-65 (F) |
| 12-11 | Phillip Micklin | Dr., EPT Advisor | Tashkent, Uzbekistan | |