2. KYRGYZ REPUBLIC

2.1. Optimization of the Syr Darya Water and Energy Uses under Current Conditions, A. Zyryanov and E. Antipova

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1. Water and energy complexes of the Syr Darya river basin

1.1. Formation of the Naryn-Syr Darya cascade of water reservoirs and its influence on the development of irrigation and hydropower industry

Designing of the Toktogul Hydraulic System was called for by the targets set by the government of the former Soviet Union. These targets were aimed at high-speed raising of cotton production in the country from 4.3 million tons in 1960 to 8 million tons in 1970 and to 10-11 million tons in 1990.

Increased cotton production required an extensive program of irrigation construction. In the implementation of the target of great importance was development of irrigation in the Syr Darya river basin, the most important region of cotton farming in Central Asia.

It was anticipated to increase the irrigated lands in the Syr-Darya basin from 2.1 million hectares in 1960 to 4.1 million hectares in 1980, and in the long run - to 6.4 million hectares.

However as early as in 1960 the total water diversion in the basin amounted to over 30 billion m^3 exceeding the actual flow of the river in years with low water. At that time the irrigation capacity of the basin sources did not meet the demand in water in certain periods. Upstream the Kairakkum water reservoir irrigation depended on the nature of the river municipal flow because there were no any regulating reservoirs .

The program anticipated also to increase irrigated areas in the Naryn river basin from 141 thousand hectares in 1960 to 194 thousand ha in 1970 and to 267 thousand ha in 1980.

By that time in the Syr Darya basin there were three hydraulic systems available: the Kairakkum Hydraulic System with the regulating storage of 2.6 billion m^3, and the Farkhad and Kyzylorda Hydraulic Systems. Construction of the Char Darya Hydraulic System with the reservoir effective storage capacity of 4.7 billion m^3 was under completion. In parallel more intensive was the construction of main and distributing canals: the Big Fergana Canal, the North-Fergana Canal named after Kirov, mechanical irrigation canals and other ones.

Because of poor coordination of the areas under development and low efficiency of irrigation systems the discrepancy in the irrigation capacities of almost all watercourses in the basin became most acute.

In order to improve available water supply, construction of the Charvak water reservoir with the effective storage capacity of 1.2 billion m^3 started at the Chirchik river and of the Kampyravatsky reservoir with the effective capacity of 1.6 billion m^3 at the Kara-Daria river.

However seasonal flow control of the Syr Darya river and its tributaries did not solve the problem of stable water supply because of significant discrepancies of anticipated and actual levels in low water years.

On these grounds it was decided to implement long-term flow control through construction of the Toktogul reservoir at the Naryn river with the effective storage capacity of 14.0 billion m^3 being determined by the requirements of irrigation. In that case the use of the hydraulic system for the power industry was considered as a side application and energy control had to be implemented in the water reservoir because that did not contradict the irrigation.

The area of the Naryn river basin amounts to 59.9 thousand km^2. Natural borders of the basin in the south and east are the mountain ridges of Akshiyrak and Talassky and in the west - Fergansky. Absolute levels in the mountainous region vary broadly: from 800 m at the foothills to 5,000 m and higher - at main ridges.

The Naryn river, 578 km long, is formed by confluence of the Big Naryn river and Small Naryn river with glacial feed, and in the lower reaches a number of tributaries with snow-glacial and snow feed fall into the Naryn.

The average annual flow rates at the gate of the Toktogul dam vary from 650 m^3/sec. to 218 218 m^3/sec. with the average long-term inflow of 11.2 billion m^3.

The main flow of the Naryn river falls on April-September and amounts to nearly 80 % of the annual value.

The maximum average long-term flow falls on June and July, and in average 40 % of the annual flow come in these two months.

Long-term annual turbidity in the Naryn river is 1,350 g/m^3, with the maximum values of up to 5,890 g/m^3 observed in June while the mean value in this month is 2,130 g/m^3.

The water reservoir with the full storage capacity of 19.5 m^3, formed due to water backup with a dam 215 high, extends through the canyon of the Naryn river and covers the Ketmentiube depression and the valleys of the right-side tributaries of the Naryn river - the rivers of Uzunakhmat, Chichkan and Torkent.

The water reservoir with the total area of 284 km^2 has the depth of effective storage drawdown of 63 m.

In selecting the parameters of the Toktogul Hydraulic System, the maximum firm water yield from the reservoir has been estimated as 90 % of water availability, in order to enable water management authorities to ensure economically expedient allocation of water through the territory of the basin.

Reasoning from this, the Institute "Sredazgiprovodkhlopok" has reserached the prospects of irrigation development in the Syr Darya river basin based on flow control in the Toktogul reservoir, and taking into consideration the water balance, actual probability to ensure water consumption has been confirmed.

The calculations show that with the effective storage of 14 billion m^3 the firm water resources in the middle and lower reaches of the Syr Darya river rise by 4.5 billion m^3, i.e. compared to the municipal flow of the river - more than by 30 %.

At the same time the Central-Asian Department of the Institute "Gidroprojekt" studied the economic expediency and necessity of constructing a hydroelectric plant at the Toktogul Hydraulic System. That study was performed with regard for the fact that the irrigation significance of the hydraulic system was limited only by the framework of the Syr Darya basin while the economic development based on power industry the whole Central-Asian economic region including South-Kazakhstan and Almaty oblasts.

The efficiency of the Toktogul Hydraulic System is confirmed by the design engineering and economic figures as follows:

a) Irrigation:

- firm water supply to the existing irrigated lands in the basin getting water directly from the Syr Darya river in the area of 800 thousand hectares;
- water supply to new irrigation lands covering 480 thousand ha;
- firm water yield for irrigation in the central part of the basin amounting to 19.5 billion m^3 instead of 15.0 billion m^3.

b) Power industry:

- rated capacity of the hydropower plant - 1,200 MW
- guaranteed capacity of the hydropower plant - 260 MW
- average long-term output of electric power - 4.4 billion kWh
- annual hours of operation with rated capacity -3650 hours.

Apart from this, construction of the Toktogul HPP and outlet high-voltage power transmission lines of 500 kV enabled to close the loop of HVL-500 kV in the Central- Asian Energy Pool and to raise considerably the reliability and quality of power supply to consumers in the republics.

For the Toktogul reservoir 28.4 thousands hectares of land have been allotted including 12 thousand ha of arable land with 10.7 thousand ha of irrigated areas, and 3,767 houses with yards have been moved from the area of flooding.

Principles of integrated utilization of the Syr Darya basin water to the benefit of all Central-Asian countries which were the basis of the Toktogul Hydrosystem development were subsequently used in the Deatiled Program of Integrated Utilization and Protection of the Syr Darya Basin Water elaborated by the "Sredazgiprovodkhlopok" Institute in 1983.

In 1985, when working over the Program, the Institute has developed the Requirements to the Operation of Naryn-Syr Darya Cascade of Reservoirs approved by the sector top management of the Soviet Union. The Requirements stipulated the procedure of fill and drawdown of all reservoirs of the Naryn-Syr Darya Cascade, and first of all - of the Toktogul Reservoir, as well as draft regimes along the Syr Darya river at separate gate sites and water delivery to the Aral Sea.

The Requirements specify that, in accord with the irrigation regime on the whole, the drawdown of the Toktogul Reservoir in a nongrowing season is 180 m^3/sec. providing for electricity generation at the minimum level of load. At the same time the irrigation regime, while maintaining maximum quantities and stages of water in the reservoir, ensures maximum total rated power yield not only in separate years but as well for the whole hydrological period of alternating high and low-water years.

When fulfilling the Requirements, the river flow and sanitary drafts regime is set, mostly close to the natural one, enabling not only to preserve the environment but also to create conditions maintaining the required land reclamation conditions in the areas adjacent to the river.

The Toktogul reservoir was commissioned in 1974, and for a long period of time it could not be filled up to the maximum level. Its storage did not exceed 5-6 km^3, and only with the beginning of the cycle of years abundant with water, in August 1998, the reservoir storage reached 19.5 billion m^3. By the year 1990 in the Syr Darya Basin a water management system has been set up in accord with the designed water usage regime .

By that period, irrigation areas in the Syr Darya basin reached 3.30 million hectares, the level specified by the program of the development.

Water flow in the basin is regulated with a number of big-size reservoirs of long-term and seasonal control: Toktogul, Kairakkum, Char Darya, Andojan and Charvak designed for operation under the conditions of irrigation water consumption for Central-Asian republics.

2. Present state of water and energy complex in the Syr Darya basin

2.1. Present state of water and energy complexes in the basin and their relationships

2.1.2. Energy complex

The Kyrgyz energy system comprises 17 operating power plants with the total capacity of 3,586.5 thousand kW including 15 hydroelectric plants (HEP) (2,948.5 thousand kW) and 2 thermal electric power plants (TEPP) (638 thousand kW), 65.6 thousand km of power transmission lines with the voltage of 500-0.4 kV, 513 transformer substations with the voltage of 500-35 kV and total capacity of 10,189.75 MVA and 19,048 transformer substations with the voltage of 10/0.4 kV.

In the areas of the republic referred to the Syr Darya basin, the operating HEPs include 5 big HEPs (Toktogul, Kurpsai, Tashkumyr, Shamaldysai and Uch-Kurgan) located in the lower reaches of the Naryn river. The total rated capacity of these hydroelectric plants is 2,870 thousand kW and average long-term output of electric power - 10 billion kWh. The Syr Darya basin includes also the Atbashy HEP located at the Atbashy river, the Naryn tributary, with the capacity of 40 thousand kW and average long-term output of electric power of 130 million kWh.

Other 10 small-size diversion-type HEPs with the total capacity of 40 thousand kW and total annual output of 120 million kWh are located in the north of the republic outside the Syr Darya basin.

Thermal power plants in Bishkek (588 thousand kW) and Osh (50 thousand kW) with the total design output of 4.1 billion kWh/year are run on natural gas, fuel oil and coal (Thermal Electric Power Plant (TEPP) in Bishkek).

The given data show that in the total energy balance of the energy system hydroelectric plants account for 82 % of the rated capacity and 71 % of the electric power output, and actually the share of HEPs in the electric power generated exceeds 90 %.

However in the HEP balance over 97 % of the capacities are concentrated at the Lower-Naryn Cascade with a common watercourse, controlled by the Toktogul Reservoir, with the full storage capacity of 19.5 billion m^3 and effective storage capacity - 14 billion m^3.

Other HEPs have small-size water reservoirs of daily control of discharges coming from upstream HEPs.

Basic characteristics and parameters of the Naryn HEPs located in the Syr Darya basin are given in Table 1 below.

Table 1. Basic parameters of the Naryn HEPs Cascade

Parameters description	Units	Naryn HEPs Cascade							Atbashi HEP
		Toktogul HEP	Kurpsai HEP	Tashkumyr HEP	Shamaldy-sai HEP	Uch-Kurgan HEP	Under construction: Kambara-tinskaya HEP-1	Under construction: Kambara-tinskaya HEP-2	
1	2	3	4	5	6	7	8	9	10
1.Rated capacity	MW	1,200	800	450	240	180	1,900	360	40
2.Annual output of electric power (average long-period)	million kWh	4,100	2,630	1,555	902	820	5,114	1,148	150
3.Average long-period municipal flow	m^3/sec.	359	391	439	438	429	317	317	32.8
4.Typical levels of reservoir a. designed full supply level (DFSL)	m	900	724	628	572	539.5	1,190	955	1,904
b. dead storage level (DSL)	m	837	721.6	626.5	569.9	536.5	1,098	952.5	1,888
5.Typical heads a. maximum	m	180	106	58.5	31	36	235	54.8	74
b. minimum	m	110	90.5	40	25.2	18.5	136.8	45	62.3
c. estimated	m	140	91.5	53	26	29	166.5	47.5	70.4
6. Reservoir area at DFSL	km^2	284.3	12.0	7.8	2.4	4.0	56	3.3	1.0
7.Full storage capacity at DFSL	million m^3	1,9500	370	140	39.4	52.5	4,650	70	9.6
8.Effective storage capacity	-	14,000	35	10	5.42	20.9	3,430	8	6.5
9.Dam type		gravity-concrete	gravity-concrete	gravity-concrete	soil materials	earth-concrete	homogenous blast-filled		loose soil
10.Dam height	m	215	113	75	37	56	275	60	79
11.Dam crest length	-	292.5	360	336.5	250	concrete -118, earth - 2882	280	190	55

1	2	3	4	5	6	7	8	9	10
12 Type of control		long-period	weekly	weekly	weekly	daily	seasonal	weekly	weekly
13.Number of turbines	pcs	4	4	3	3	4	4	3	4
14.Type of turbines		РО170\865-В-535	РО115-В-515.6	РО75\3123-В-620	ПЛ40\567а-В-680	h/u 1.3.4 ПЛ577-ВБ-500 h/u 2 ПЛ-707-ВБ-500	РО230\2733-МБ-560	РО75/841в В-580	РО-697 ВМ-140
15.Design flow rate per turbine	m^3/sec.	250	243	319	345	190	288	280	17.8
16.Max. flow rate through turbines	-	960	972	957	1,035	760	1,000	840	70.4
17. Unit flow rate of water per 1 kWh at $H_{estimated}$	m^3/kWh	2.95	4.4	7.7	15.6	14.0	2.45	8.85	6.3
18.Flow rate through water passage structures at DFSL, total:	m^3/sec/	3,500	2,537	3,293	3,090	3,250			
including bottom spillway	-	2,340	1,037	2,093	3,090	2,296			
transfer spillway	-	1160	1500	1200	-	954			
19.Date of units commissioning unit 1		14.01.75	21.02.81	22.12.85	01.07.92	30.12.61	-	-	18.12.70
unit 2		27.11.75	19.12.81	30.08.86	12.02.94	03.06.62			19.12.70
unit 3		10.01.76	15.04.82	30.09.87	30.12.95	07.09.62			20.12.70
unit 4		10.01.76	04.11.82	-	-	05.11.62			22.1270

2.1.3. Usage of water resources of the basin for irrigation and power industry and relationship of the sectors

2.2. National and regional interests of the states in the use of water and energy of the basin

Most of the electric power generated at hydroelectric plants of the Naryn Cascade at irrigation drafts in summer periods before 1990 was transmitted to neighboring republics. Kyrgyzstan in summer-autumn periods received from the Energy Pool and Central-Asian republics electric power, natural gas, coal and fuel oil for thermal power stations. Values of fuel consumption and electric power production by TEPP are summarized in Table 2. The scheme existing at that time ensured operation of fuel-and-power sectors and water complexes of all republics (Fig. 1).

The situation changed drastically when independent states were established in Central Asia. Starting from 1991, because of complications in intergovernmental relations and settlements, introduction of national currencies, growing prices of oil, coal, natural gas and railroad carriages, the supply of fuel and electricity to Kyrgyzstan was cut and this radically affected the structure of its fuel-and-energy balance. Because of decreased production of fuel in the country, the output and distribution of thermal power from TEPP fell two times and organic fuel consumption reduced. That gave rise to electric power consumption by population for heating of residential and public premises, hot water supply and cooking. With the changes in the structure, the share of electricity consumption in autumn-summer periods increased from 50 % of the annual amount (1990-1991) to 75 % (1996-1999) (Fig. 2).

Under these conditions, to provide for the schedule of electric power consumption in the republic, the mode of the Toktogul Hydraulic System operation was switched from irrigation to power generation. In this situation the Toktogul HEP, being the main power plant in the cascade of five Naryn HEPs, including Toktogul, Kurpsai, Tashkumyr, Shamaldysai and Uch-Kurgan HEPs with the total designed capacity of 2.87 million kW, provides for the average long-period generation of electricity amounting to 5.0 billion kWh. This amount equals 45 % of the energy balance of the Kyrgyz Republic.

The control of river flow into the reservoir and water drafts through the units of the Toktogul HEP started from the year 1991 with regard for the fuel-and-energy balance formed.

The share of HEP in the total balance of electric power generated in the republic did not exceed 70 % prior to 1990. However in subsequent years it rose up to 91 % and the amount of water drafts from the Toktogul reservoir for the power industry in autumn-summer periods increased from 2.8 billion m^3 to 8.5 billion m^3 and average daily flow rates - from 180 m^3/sec. to 750 m^3/sec. (Fig. 3).

Intensive usage of water resources along with changes in the river regime entailed serious complications in the Syr Darya basin both in summer and winter periods comprising a wide range of interrelated problems.

The years 1991 through 1994 and 1999 were especially typical for deviations from the earlier pattern of using the water resources of the Naryn river. In that period supply of energy carriers to Kyrgyzstan fell more than two times compared to 1990.

When the Toktogul reservoir was converted to the power generation mode, the whole water economic situation in the Syr Darya basin changed drastically.

The downstream reservoirs - Kairakkum and Char Darya - were not able to receive the increased drafts from the Toktogul reservoir in nongrowing seasons, and in order to prevent flooding of the lower reaches of the Syr Darya river, water discharges into the Arnasai depression were arranged. As early as by the vegetation of 1994, the induced discharges to the depression exceeded 8.0 billion m^3, increasing its storage up to 25 billion m^3.

Table 2. Fuel consumption and electric power production at TEPP in 1988-1999

Fuel description	Units	Years											
		1988	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Coal total	thousand tons	1,383.2	1,337.8	1,043.6	1,016.3	1082.2	948.5	776.2	770	460.2	503.6	366.5	340.4
including Kyrgyz	thousand tons	746.3	794.3	568.5	426.5	628.9	465.5	110.5	36.5	41.5	98.1	40.9	23.0
Fuel oil	thousand tons	380.7	420.2	373.5	317.0	136.5	125.9	85.1	45	5.4	37.1	31.6	36.9
Natural gas	million m^3	718.0	844.4	1,016.6	1,034.8	740.8	504.8	203.9	300	464.6	632.1	563.5	223.1
Electric power output	million kWh	4,108	4,287	4,202	3,914	2,603	2,090	1,140	1,169	1,428	1,656	1,631	981.7
Thermal power output	thousand Gcal.	5,145	5,668	5,688	5,806	5,153	4,311	3,013	2,957	3,195	2,795	2,716	2,054

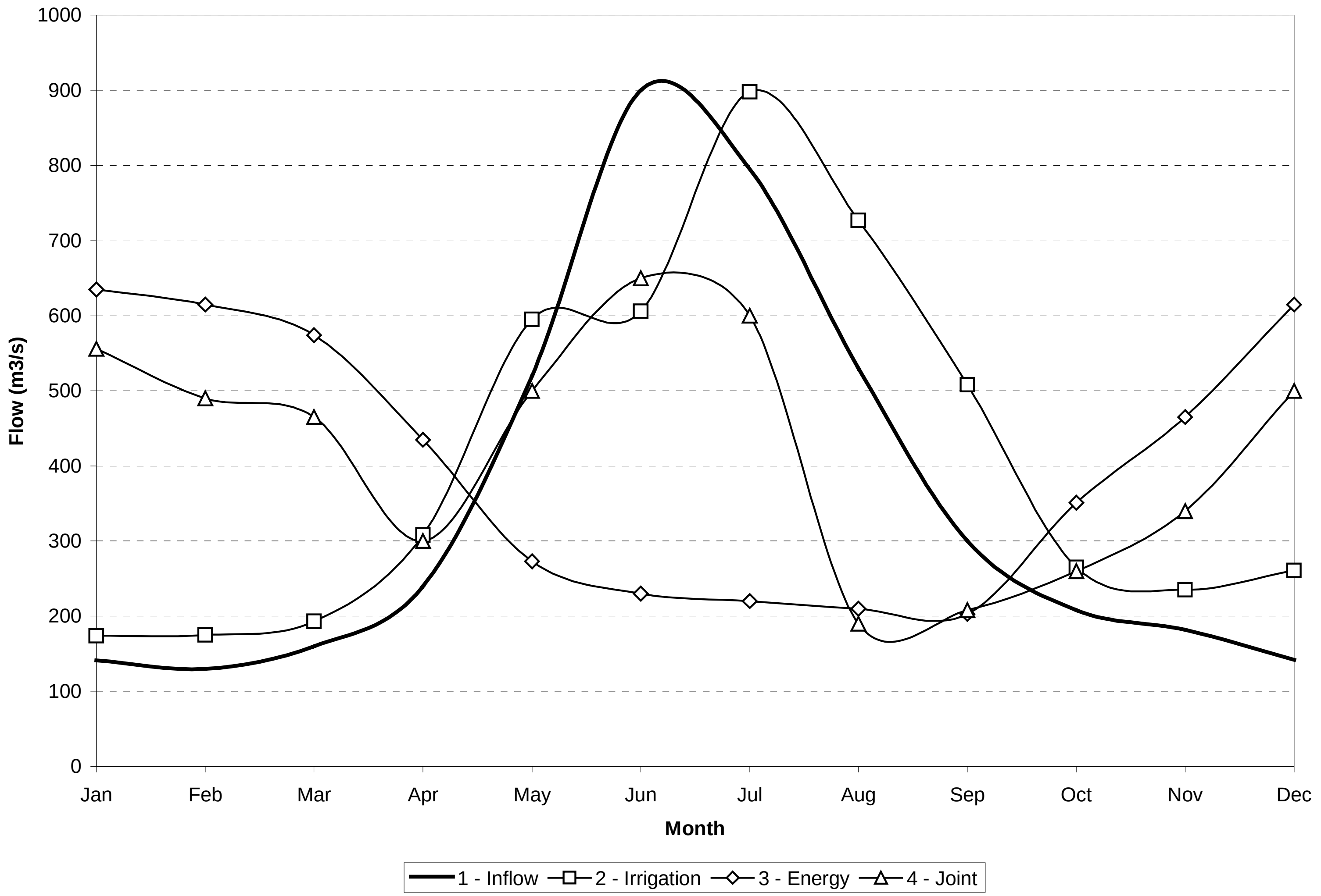


Figure 1. Water consumption from the Toktogul reservoir under different regimes 1 - irrigation; 2 - energy; 3 - joint; 4 - average annual inflow into the reservoir

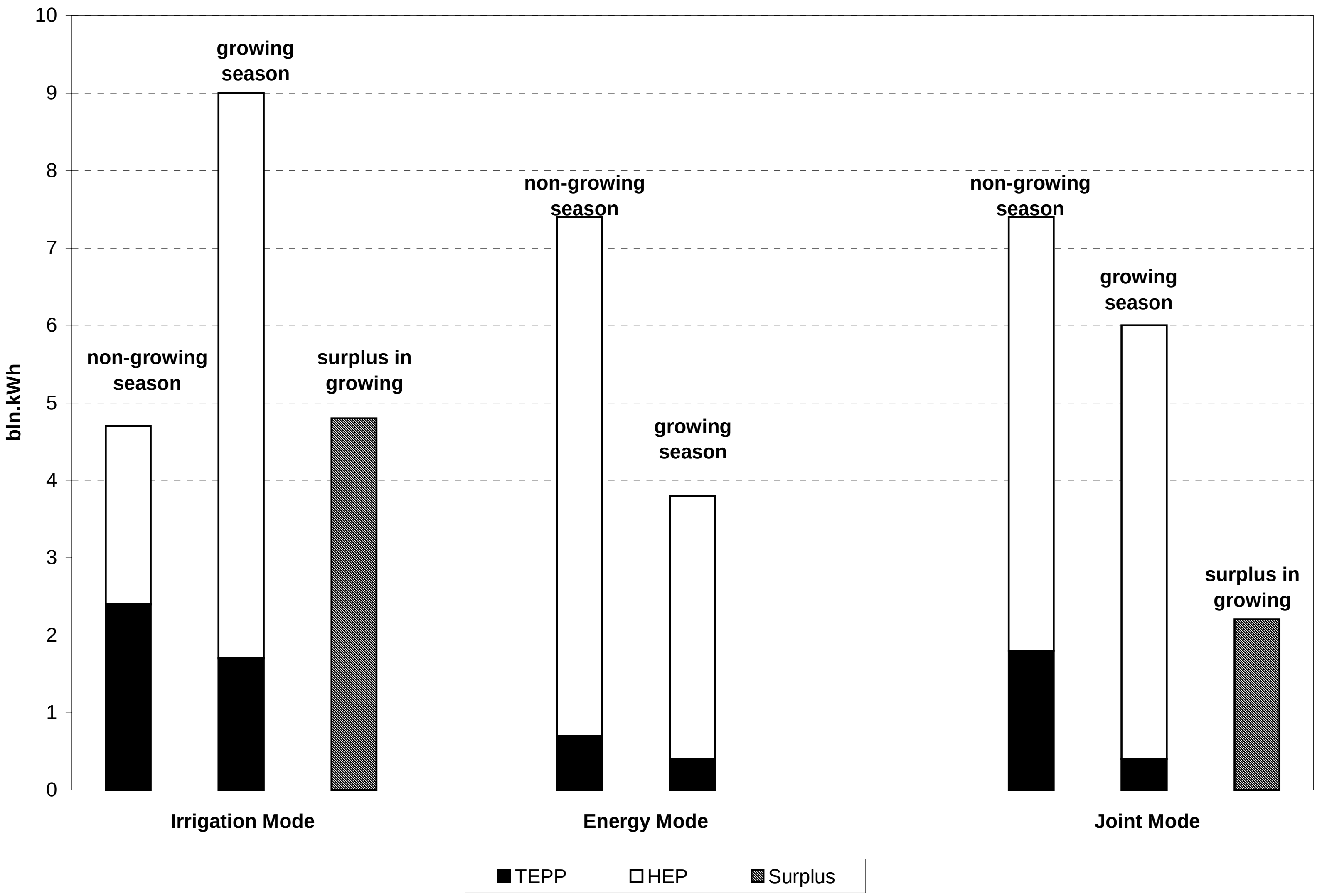


Figure 2. Structure of energy balance under different conditions: a – irrigation; b – energy; c – joint; - 1 – electric power output in the non-vegetation period; 2 – electric power output in the cegetation season; 3 – extra electric power in the vegeation period.

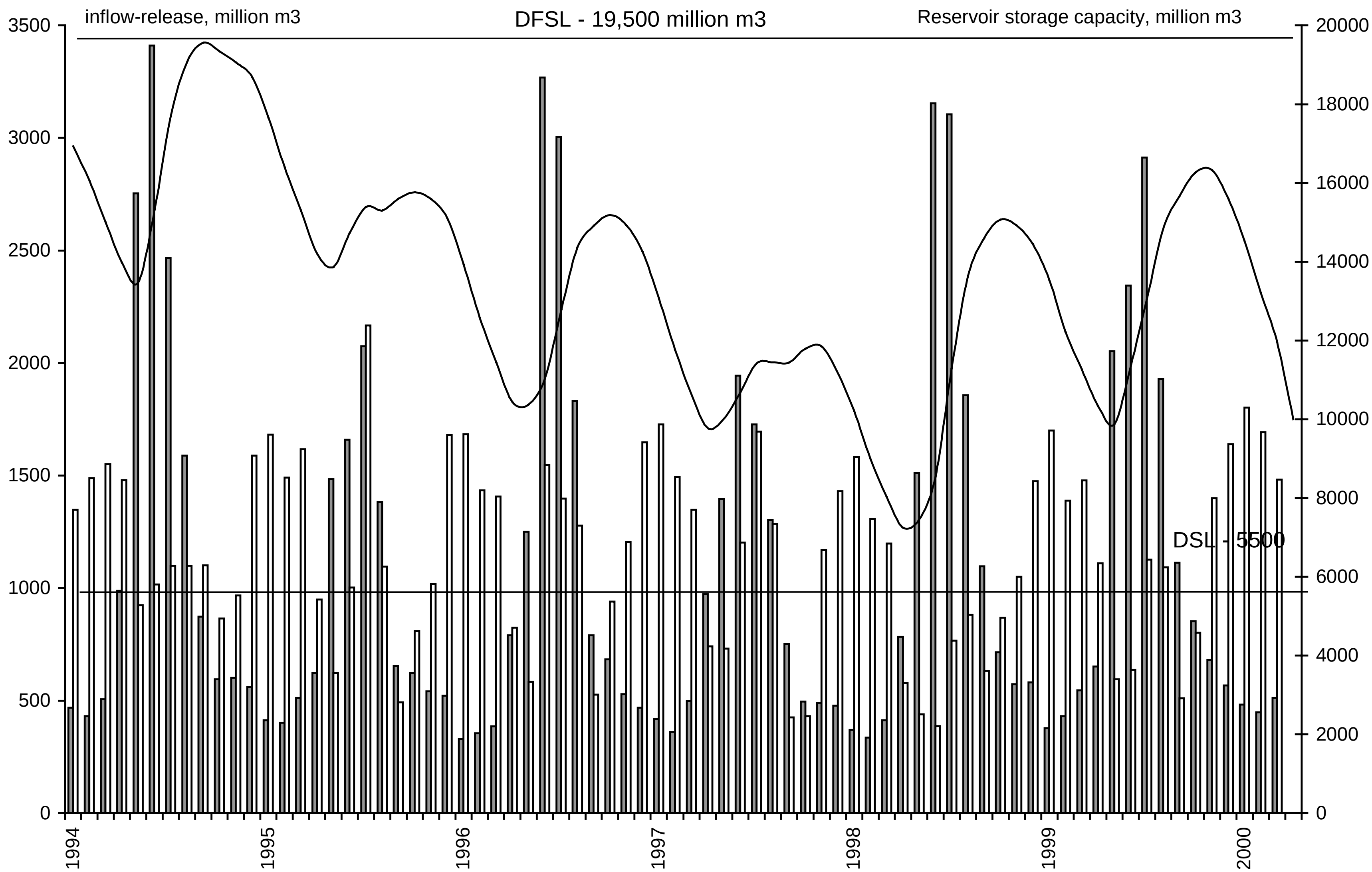


Figure 3. Dynamics of Toktogul reservoir utilization in 1994-1999: 1 - Diagram of variations of the Toktogul reservoir storage; 2 - inflow into the reservoir; 3 - volume of discharge through the gate of the Toktogul HEP.

2.3. Basic problems in the intergovernmental relations in the basin in joint usage of water and energy resources of the Syr Darya river

Starting with 1995, in order to overcome the arising contradictions, a number of intergovernmental agreements were signed by Republic of Kazakhstan, Kyrgyz Republic and Republic of Uzbekistan relating to the usage of water and energy in the Syr Darya basin. These agreements specified the amounts of drafts for vegetation from the Toktogul reservoir to meet the demands of the irrigation farming in the basin and of compensative supplies of energy resources (natural gas, electric power, fuel oil and coal) from Uzbekistan and Kazakhstan to Kyrgyzstan in autumn-winter periods instead of extra energy transmitted to those republics. That extra energy was generated by HEP on extra drafts of water in summer (Figs. 1 and 2).

Every year the amounts of potential mutual supplies are reviewed by working groups of the participating republics at the level of top-management of concerned sectors of power industry, water economy, fuel industry, regional departments of UDC "Energia" and BVO "Syr Darya". Then the elaborated proposals are ratified in intergovernmental agreements. In such a way, for five years (1995-1999) Kyrgyzstan in the vegetation periods transmitted to the neighboring republics 7.2 billion kWh of electric power generated by hydroelectric plants of the cascade on extra water released from the Toktogul reservoir. At the same period, under the conditions of mutual settlements, Kazakhstan and Uzbekistan supplied in autumn-winter periods to the Kyrgyz energy system the electric power amounting to 1.5 billion kWh and such energy carriers as natural gas - 1.73 billion m^3, Karaganda coal - 2.17 million tons and fuel oil for the Bishkek TEPP operation in winter.

However partial alteration of the water usage mode does not solve the problem on the whole. Seasonal redistribution of water for the needs of power industry and irrigation without a comprehensive approach leads steadily to the decrease in the Toktogul reservoir storage. So, in 1995-1997, by the beginning of the vegetation period of 1998, its amount was cut to 7.2 billion m^3 (dead storage - 5.5 billion m^3). Incomplete fulfilment of earlier agreements also contributed to that (Fig. 3).

The fulfilment of annual intergovernmental agreements of 1995 through 1999 is characterized as follows:

1995

Proceeding from Article 4 of the Agreement concluded by the governments of Kazakhstan, Uzbekistan and Kyrgyzstan on trading and economic cooperation in 1995, Protocol of 12 May 1995 and Agreement of 22 June 1995 were signed. These documents specified water drafts from the Toktogul reservoir and mutual supplies of electric power and coal.

In accord with that Agreement, Kyrgyz Republic has to provide in vegetation periods (April-September) water drafts of 6.5 billion m^3 from the Toktogul reservoir for irrigation purposes of Uzbekistan and Kazakhstan and electric power transfers amounting to 2.2 billion kWh, 1.1 billion kWh to each republic.

The obligations of Kazakhstan were to deliver additionally in July-August 285 thousand tons of Karaganda coal to the Bishkek TEPP. The total amount of Karaganda coal supply according to the Protocol and Agreement, had to be 985 thousand tons.

The Republic of Uzbekistan had to deliver 200 million m^3 of natural gas to Kyrgyzstan against mutual supplies.

Kyrgyzstan has provided in the vegetation period (April-September) water drafts from the Toktogul reservoir amounting to 6.3 billion m^3, including in the period from 22 June to 22 August - 3.4 billion m^3, and electricity transfers to Kazakhstan making up 782 million kWh and to Uzbekistan - 928 million kWh.

The amount of Karaganda coal supplied to the Bishkek TEPP under the Protocol and Agreement made up 450 thousand tons or 45.7 %. To ensure operation of the Bishkek TEPP in the first and forth quarters, extra 325 thousand tons of Karaganda coal were purchased through commercial firms.

Uzbekistan supplied to Kyrgyzstan 200 million m^3 of natural gas and 415 million kWh of electric power.

1996

At the meeting of representatives of fuel-energy and water economy complexes of the Republic of Kazakhstan, Kyrgyz Republic and Republic of Uzbekistan held on 19-21 December 1995, a protocol was made up relating to the use of water and energy of the Toktogul cascade in 1996. The protocol was submitted to the governments of the republics.

According to that protocol, on 6 May an agreement was signed by the governments of Uzbekistan and Kyrgyzstan stipulating that Kyrgyzstan had to ensure drafts of water in vegetation periods from the Toktogul reservoir amounting to 6.5 billion m^3 and electricity transfer of 1.1 billion kWh. Uzbekistan in its turn had within the year to deliver 500 million m^3 of natural gas to the Bishkek TEPP and to return to Kyrgyzenergoholding 635 million kWh of electric power in winter.

The Kyrgyz Republic has fulfilled its obligations on the delivery of 1.1 billion kWh of electric power and performed water drafts from the Toktogul reservoir in accord with the schedule.

The Republic of Kazakhstan has supplied 476 million m^3 of natural gas to the Bishkek TEPP in 1996, and returned 635 million kWh of electric power to Kyrgyzstan.

The same protocol stipulated that Kyrgyzstan, along with the vegetation drafts of water, would supply 1.1 billion kWh of electric power to NEC "Kazakhstanenergo". In this case NEC "Kazakhstanenergo" would receive and pay for 1.1 billion kWh by delivering 600 thousand tons of coal through the state-owned energy company "Karagandashakhtugol".

The Kyrgyz Republic has actually fulfilled its obligations and supplied 995 million kWh of electric power to Kazakhstan.

However the Kazakhstani party failed to fulfill the obligations undertaken in the agreement for the Karaganda coal supply to the Bishkek TEPP. The supplied amounts made up only 202 thousand tons or 33.6 %. That was the reason of underproduction of 785 million kWh electricity at the Bishkek TEPP in quarter IV and extra consumption of water from the Toktogul reservoir amounting to 940 million m^3. To ensure the TEPP operation according to the thermal power schedule, additional agreements were signed with commercial firms and 305 thousand tons of coal were delivered. The agreements did not stipulate transfers of electric power from Kazakhstan to Kyrgyzstan.

1997

On 24 December 1996 the Kyrgyz Republic and Republic of Uzbekistan have signed an Intergovernmental Agreement for the year 1997. On the basis of that Agreement contracts were concluded by JSC "Kyrgyzenergo", the Energy Ministry of Uzbekistan and State Association "Uztransgas" for supply to Uzbekistan in the vegetation period of 1.1 billion kWh of electric power. That electricity was generated by the Toktogul HEP Cascade on the coordinated irrigation drafts of water. According to the Agreements, Kyrgyzstan was to receive 500 million m^3 of natural gas and 400 million kWh of electricity for that amount of electric power.

On 29 July 1997 in Tashkent "Agreement on Extra Measures Providing for Fulfilment of the Agreement between the Government of the Kyrgyz Republic and the Government of the Republic of Uzbekistan on the Usage of Water and Energy of the Naryn-Syr Darya HEP Cascade in 1997". According to that Agreement, the Republic of Uzbekistan undertook additionally to supply 302 million m^3 of natural gas in 1997-1998.

The terms and conditions specified in these Agreements for the year 1997 have been fulfilled on the whole. In the vegetation period JSC "Kyrgyzenergo", along with irrigation drafts, supplied to Uzbekistan 1,615.1 million kWh of electric power, and Uzbekistan supplied to the Bishkek TEPP 632 million m^3 of natural gas compared to 630 million m^3 planned for 1997, and electricity in the amount of 433.5 million kWh. The debt of JSC "Kyrgyzenergo" to the Energy Ministry of Uzbekistan for the received gas as of 1 January 1998 came to 6.5 million US dollars.

Because of the refusal of Kazakhstan, the republics did not sign the agreement for 1997 on joint and integrated usage of water and energy of the Naryn-Syr Darya Cascade of reservoirs.

However the Kazakhstani party has signed a contract with JSC "Kyrgyzenergo" for receiving electric power amounting totally to 410.4 million kWh. But an agreement and contract for supply of Karaganda coal in 1997 were not concluded.

In 1997 on the whole the Kyrgyz Republic supplied to Kazakhstan 709.5 million kWh of electric power, and the annual electricity transfer from Kazakhstan amounted to 11.4 million kWh. In 1997 Karaganda coal was supplied in insignificant amounts only by bilateral contracts with commercial firms. On the whole, due to short deliveries of coal, the Bishkek TEPP was unable to have full load in the autumn-winter period of 1997-

1998. That caused extra loads on the Cascade HEPs and increased drafts of water from the Toktogul reservoir by 1.1 billion m^3 above the planned figures.

1998

On 25 December 1997 the governments of Kyrgyzstan and Uzbekistan signed an agreement for the year 1998 "On Joint Integrated Use of Water and Energy of the Naryn-Syr Darya Cascade of Reservoirs". That agreement stipulated to supply in the vegetation period 1.1 billion kWh of electric power from Kyrgyzstan to Uzbekistan and to ensure coordinated irrigation drafts.

Under the conditions of mutual payments, Uzbekistan had to supply to Kyrgyzstan 600 million m^3 of natural gas, 20 thousand tons of fuel oil and electricity transfer amounting to 200 million kWh. Apart from this, in compliance with the Intergovernmental Agreement of 29 July 1997, Uzbekistan had to supply 172 million m^3 of natural gas, the amount carried over to the year 1998.

In 1998 the terms and conditions of that Intergovernmental Agreement were fulfilled by the parties only partially. Favorable hydrologic and weather conditions contributed to reduced irrigation water demand for Uzbekistan. Due to this, Kyrgyzstan in the vegetation period supplied 489 million kWh of electric power to Uzbekistan instead of planned 1.1 billion kWh.

Uzbekistan has fulfilled completely its obligations on natural gas supply - of scheduled 772 million m^3 of gas, 747.9 million m^3 have been supplied to JSC "Kyrgyzenergo". Therefore, as of 1 January 1999 the debt of JSC "Kyrgyzenergo" to the Energy Ministry of Uzbekistan amounted to 25.9 million dollars.

Fuel oil has been supplied in the amount of 23.8 thousand tons, and electric power transfers made up 74.9 million kWh.

On 25 December 1997 the governments of Kyrgyzstan and Kazakhstan have signed an agreement for the year 1998 "On Joint Integrated Use of Water and Energy of the Naryn -Syr Darya Cascade of Reservoirs". That Agreement stipulated to supply from Kyrgyzstan to Kazakhstan in the vegetation period 1.1 billion kWh of electric power to ensure coordinated irrigation drafts. For this amount of electricity received from Kyrgyzstan, Kazakhstan had to supply 250 million kWh of electric power to the Talas region and 566.7 thousand tons of Karaganda coal to the Bishkek TEPP.

The parties have fulfilled the conditions of the Intergovernmental Agreement only partially because of the same hydrological and weather conditions. Due to this Kyrgyzstan supplied to Kazakhstan in the vegetation period only 468.6 million kWh of electric power instead of scheduled 1.1 billion kWh.

Kazakhstan supplied Karaganda coal in the amount of 150.4 thousand tons, and the electric power transfer was equal to 150 million kWh.

In total the amount of water drafts through the Toktogul HEP in the vegetation period was 3.7 billion m^3, instead of 6.5 billion m^3 stipulated by the Agreement.

1999

On 17 March 1998 Kazakhstan, Kyrgyzstan and Uzbekistan have signed a long-term agreement on joint integrated use of water and energy of the Naryn-Syr Darya Cascade of reservoirs.

On the basis of that agreement the governments of Kazakhstan, Kyrgyzstan and Uzbekistan have signed in April 1999 a three-lateral Agreement on joint integrated use of water and energy resources of the Naryn and Syr Darya cascade of reservoirs in 1999.

That Agreement stipulated to provide the electric power transfer of 1.1 billion kWh from Kyrgyzstan to Uzbekistan in order to ensure specified irrigation drafts, and to supply 500 million m^3 of natural gas from Uzbekistan to Kyrgyzstan on the basis of mutual settlements.

Within the year 1999, on the basis of mutual settlements for forthcoming transfers of electric power in the vegetation period, 331 million m^3 of natural gas were supplied from Uzbekistan to the Bishkek TEPP and Osh TEPP.

Within the framework of the agreements achieved, the transfer of electric power in the vegetation period from Kyrgyzstan to Uzbekistan amounted to 970 million kWh.

On the basis of the three-lateral agreement, a bilateral intergovernmental agreement has been signed with Kazakhstan in May 1999.

That agreement stipulated the transfer of electric power from Kyrgyzstan to Kazakhstan in the amount of 1.1 billion kWh, and from Kazakhstan to Kyrgyzstan - supply of 566.7 thousand tons of Karaganda coal and 250 million kWh of electric power on the basis of mutual settlements.

During 1999, within the framework of the agreements achieved, the transfer of electric power from Kyrgyzstan to Kazakhstan made up 585 million kWh.

Supply of Karaganda coal to Kyrgyzstan for the Bishkek TEPP amounted to 572 thousand tons.

Because of hydrological and weather conditions in the basin entailing decrease in water demand for irrigation, water drafts from the Toktogul reservoir in the vegetation period came to 5.06 billion m^3 instead of 6.5 billion m^3 stipulated by the agreement.

On the whole after the vegetation period the debt of JSC "Kyrgyzenergo" to Uzbekistan for natural gas amounted to USD 11.8 million taking into account the debt of JSC "Kyrgyzgas".

In this connection on 24 September 1999 natural gas supply to the Bishkek TEPP has been terminated under an intergovernmental agreement. It happened despite the fact that the contracts did not envisage unilateral cancellation of supplies. Numerous trips of the "Kyrgyzenergo" management to Uzbekistan and appeals of the Kyrgyz government were fruitless.

Uzbekistan resumed natural gas supplies to the Bishkek TEPP only on 14 February 2000.

Resulting from this situation, in the past autumn-winter period, due to underloading of Bishkek TEPP and Osh TEPP, the HEPs of the Toktogul Cascade were loaded additionally and water drafts were increased. In this period extra drawdown of water from the Toktogul reservoir rose by 1.5 billion m^3 compared to the same period in 1998-1999.

For the current year Kyrgyzstan and Uzbekistan have signed on 21 March 2000 an intergovernmental protocol on the use of water and energy resources.

An intergovernmental document to be signed with the Republic of Kazakhstan is being elaborated at present.

Table 3 below summarizes the data on the energy resources supplies stipulated by intergovernmental agreements for 1995-1999.

Because of incomplete fulfilment of the obligations by the parties, a complicated situation can arise both for the power industry of Kyrgyzstan and water users in the neighboring republics due to unbalanced utilization of the Naryn river water for a long period.

In our opinion, this problem can be solved at the first stage by more complete meeting of the Bishkek TEPP demand in fuel and setting up of a stock of fuel for the periods of low water. Later it could be joint funding and construction of the Kambaraty HEP 1 and HEP 2 with the capacity of 2,26 million kW with a reservoir of seasonal control located upstream the Toktogul Hydraulic System and operating in the mode of a seasonal energy compensator of the power system. These HEPs would compensate for reduced electricity output and the capacities of the Lower Naryn HEPs in winter. In that case the Toktogul reservoir will function as a counter-regulator of energy consumption and will be able to operate in an irrigation mode. Construction of the Kambaraty HEPs in the middle reaches of the Naryn was stipulated earlier by the Scheme of the Naryn Energy Use elaborated by the Tashkent Institute "Girdoroject".

The technical project of the Kambaraty HEPs construction has been developed by this institute. In 1986-1991 the work on the main facilities of HEP-2 started, and nearly 25% of construction work have been done, while on HEP-1 - some preliminary work. However, implementation of this project requires considerable investments with the involvement of all states concerned.

In searching for joint solutions for the near future the heads of the governments of Kazakhstan, Kyrgyzstan and Uzbekistan have signed on 17 March 1998 a long-term framework agreement "On the Use of Water and Energy of the Syr Darya Basin". Later the Republic of Tajikistan joined this agreement.

In the arrangement of meetings to elaborate the initial draft program significant assistance was rendered by the USAID consultants. At present they go on with the assistance in the program of elaborating a computer-aided model of optimization of usage of the Syr Darya basin water. For this purpose in 1998 technical groups have been arranged including specialists from the concerned sectors and regional authorities of all Central-Asian republics.

Development of an adequate model was necessitated by the fact that the existing pattern of relationships in the water and power sector does not meet the interests of any of the states of the Syr Darya basin and is not optimal for the region on the whole.

Table 3. Implementation of intergovernmental agreements on the use of water and fuel-energy resources in 1995-1999

Parameters	Year		1995		1996		1997		1998		1999	
	Units of measurement											
Toktogul	Storage											
1 January	bln.m^3		17.7		13.9		13.0		10.2		13.5	
1 April			14.2		10.4		9.8		7.3		10.4	
31 Dec.			15.6		15.2		11.8		15.1		14.5	
Veg. period release	bln.m^3	Plan	6.5		6.5		6.5		6.5		6,5	
		Actual	6.3		6.2		6.1		3.7		5.06	
Electric Power Export	million kWh	Plan	2200		2200		2200		2200		2200	
			Uzb	Kaz	Uzb	Kaz	Uzb	Kaz	Uzb	Kaz	Uzb	Kaz
		Actual	928	782	108	995	1615	710	489	469	970	585
Supply to Kyrgyzstan: Natural gas	million M^3	Plan	200	-	500	-	630	-	772	-	500	-
		Actual	200	-	476	-	632	-	748	-	331	-
Karaganda Coal	Thous tons	Plan	-	985	-	600	-	0	-	567	-	567
		Actual	-	450	-	202	-	0	-	150	-	572
Fuel oil	Thous tons	Plan	-	-	-	-	-	-	20		-	
		Actual	-	-	-	-	-	-	24			
Electric Power	million kWh	Plan	-	-	-	-	400	0	200	250	-	250
		Actual	-	-	-	-	434	11.4	75	150	-	-

Receiving energy resources as compensation for seasonal control of the flow through the Toktogul reservoir, Kyrgyzstan does not only reduce its capabilities in long-period control, but sometimes is forced to discharge the long-period stock of the reservoir decreasing by that the efficiency of the flow use and electricity generation at HEPs.

Though Kazakhstan and Uzbekistan give compensation to Kyrgyzstan for extra use and control of water, these republics, without respective compensation, do not have guarantees of firm water supply on a long-period basis.

The model under development would be a complex of models to assist in solving the tasks of optimal flow control with regard for the national and regional benefits and with subsequent agreement on the regimes at the intergovernmental level in order to enter into bilateral and multilateral long-term economic agreements.

To improve cooperation in the use of water and energy in 1998, "Statute of the International Water and Energy Consortium" has been signed by the governments of Kazakhstan, Kyrgyzstan and Uzbekistan. On the basis of that document draft papers have been made up relating to the establishment of the International Water and Energy Consortium "Naryn-Syr Darya".

At the same time, in 1999 the governments have ratified the documents stipulating parallel operation of national energy systems of all Central-Asian states.

Resulting from this, a base has been set up for stable regional cooperation of the Central-Asian states in balanced usage of water and fuel-energy resources. That base provided as follows:

- Implementation of coordinated water and energy policy of the republics aimed at joint development and operation of fuel-energy and water resources.
- Elaboration of the cooperation program specifying a new structural and regional policy in the development of water and fuel-energy sectors.
- Setting-up of a common market of energy resources.
- Elaboration of regulatory legal documents and setting-up of intergovernmental market-type structures.
- Attraction of investments of private and national capital both from Central-Asian republics and other CIS and overseas countries.

However, practical implementation of the economically justified long-term mechanism of water and energy use requires huge joint work. This joint work has to be carried out in the engineering, legal and organizational directions for the purpose of bridging the gap between national legislative acts guiding of relationships of the participants with different forms of ownership.

3. Optimization of present usage of water and energy resources of the Syr Darya basin

3.4. Basic provisions and principles of optimization of usage of water and energy resources in the Syr Darya basin

3.4.1. Problem definition and general requirements to the model

The water and energy model has been developed with the help of the GAMS-system for the purpose of solving water and energy problems of the Kyrgyz energy system taking into account national benefits and irrigation requirements.

The model includes two parts: the water part and the energy part.

The water part is based on the model of BVO Syr Darya and incorporates water reservoirs, hydroelectric plants at reservoirs, water sources (tributaries), water users (water intakes), and the river mouth (point of completion of calculation).

With the help of this program, taking into account the initial data and set constraints, all water information is specified including flow rates through the gate sites of HEP, balances of reservoirs, and as well water supply to the users and river mouth and the output of hydroelectric plants.

The electric part of the model performs calculation of the most efficient load of the generating plants providing for the required output with regard for internal consumption and electricity transfers.

The energy part is a transportation task. An economic index in these calculations is the cost value of the energy produced and tariffs for electric power transfers.

The water and energy parts are interconnected via the output of hydroelectric plants. Since the plants of the Toktogul Cascade are located on one and the same water course, they are presented in the energy part as a single plant with the total output of all plants of the cascade.

3.4.2. Initial data

The suggested model has been developed for the Kyrgyz energy system. The water part includes the entities as follows:

- Five water reservoirs (Toktogul, Kurpsai, Tashkumyr, Shamaldysai, Uch-Kurgan).
- Three water sources (inflow to the Toktogul reservoir, lateral inflow to the Kurpsai reservoir and lateral inflow to the Tashkumyr reservoir).
- Two users (water diversions from the Uch-Kurgan reservoir - left-bank BN and Namangan Big Canal).
- River mouth - Transmission of water of Uzbekistan at the lower pond of the Uch-Kurgan HEP.

The water diagram of the model is shown in Fig.5.

The energy part of the model includes the entities as follows:

- Generating plants (HEP and TEPP) which loads are specified on the basis of the program calculation taking into account the cost value and constraints imposed.
- Off-design plants which loads are specified and remain unchanged in all calculations
- Single consumer as the internal consumption of the republic
- Exit to the energy system of Central Asia.

Fig. 6 presents the diagram of energy balance.

The model entities and initial information included in the program are listed in the tables below.

Entity description	Initial Information
Inflows (sources - "I")	• Values of average long-period inflow for every designed time interval for every source.
Water reservoirs ("V")	• Curves of reservoir storage capacities (reservoir storage capacities as a function of water levels). • Constraints (maximum and minimum) on every reservoir storage. • Reservoir storage value at the beginning of calculation. • For the Toktogul reservoir, total water discharge for a given period of time (year or vegetation season) can be set.
Hydroelectric plants ("C") – in the water part of the model. Hydroelectric plant ("G") in the energy part of the model	• Constraints on the conveying capacities of turbine units. • Downstream water elevation as a function of water drafts through HEP. • Hydropower unit efficiencies with regard for losses in the feeding path, turbine and generator. • Cost value of electric power.
Thermal power plants ("H")	• Constraints on the output for a design time interval (maximum and minimum). • Cost value of electric power.
Off-design plants ("X")	• Average output of off-design plants for a rated time interval.
Electric power consumers ("A").	• Internal consumption of the Kyrgyz Republic for a designed time interval.
Export-import of electric power or connection with ODTs // of Central Asia	• In our task transfers of electric power can be both set and designed values. • Tariffs for electric power transfers.
Water intakes (users –"U")	• Water requirements for every designed time interval for every user.
River mouth ("R")	• When solving the problems of water flow control constraints on water drawdown can be set both for a given designed time interval, and a specified period (year, vegetation season).

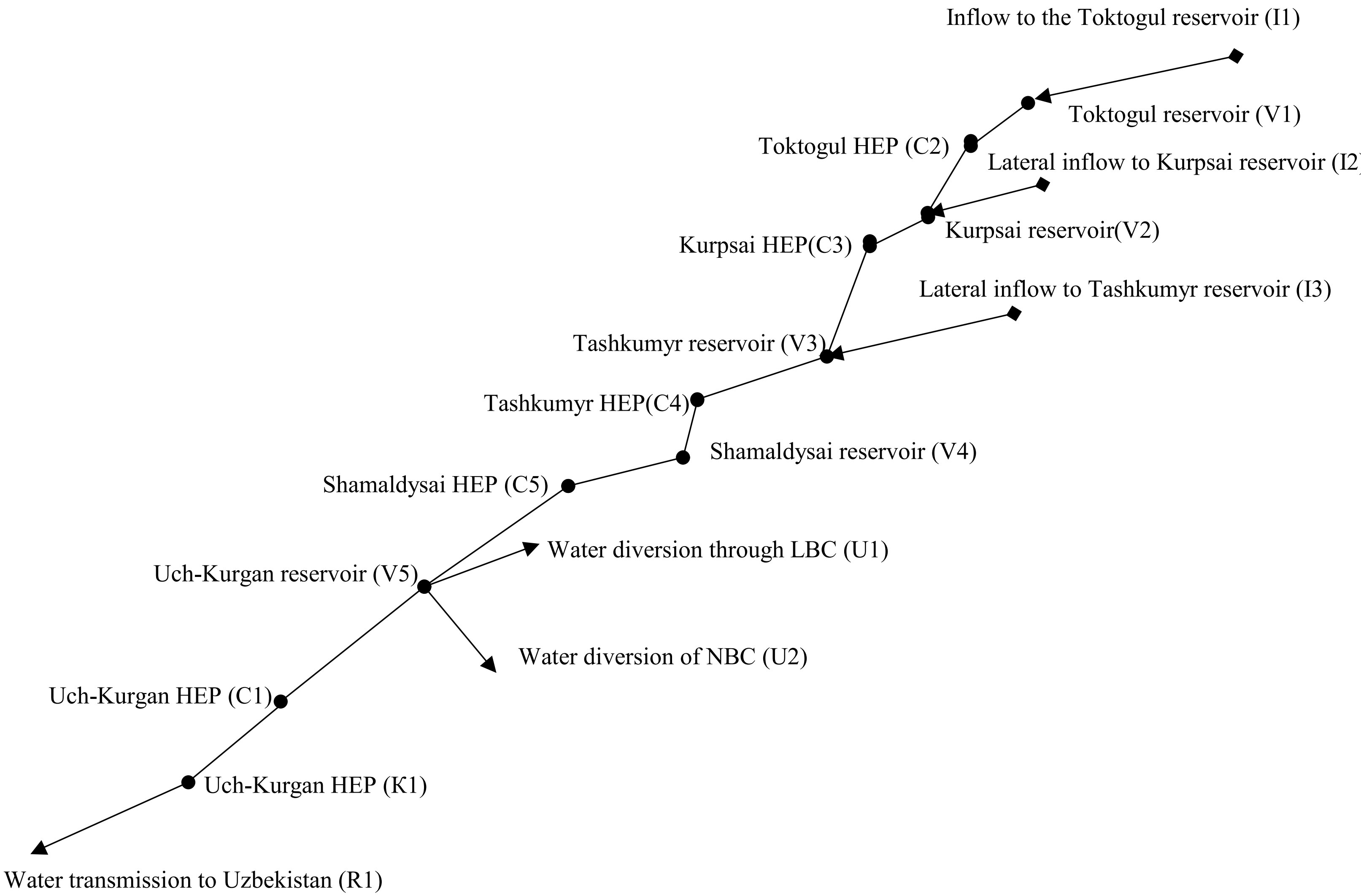


Figure 5. Diagram of the Toktogul HEP Cascade at the Naryn river

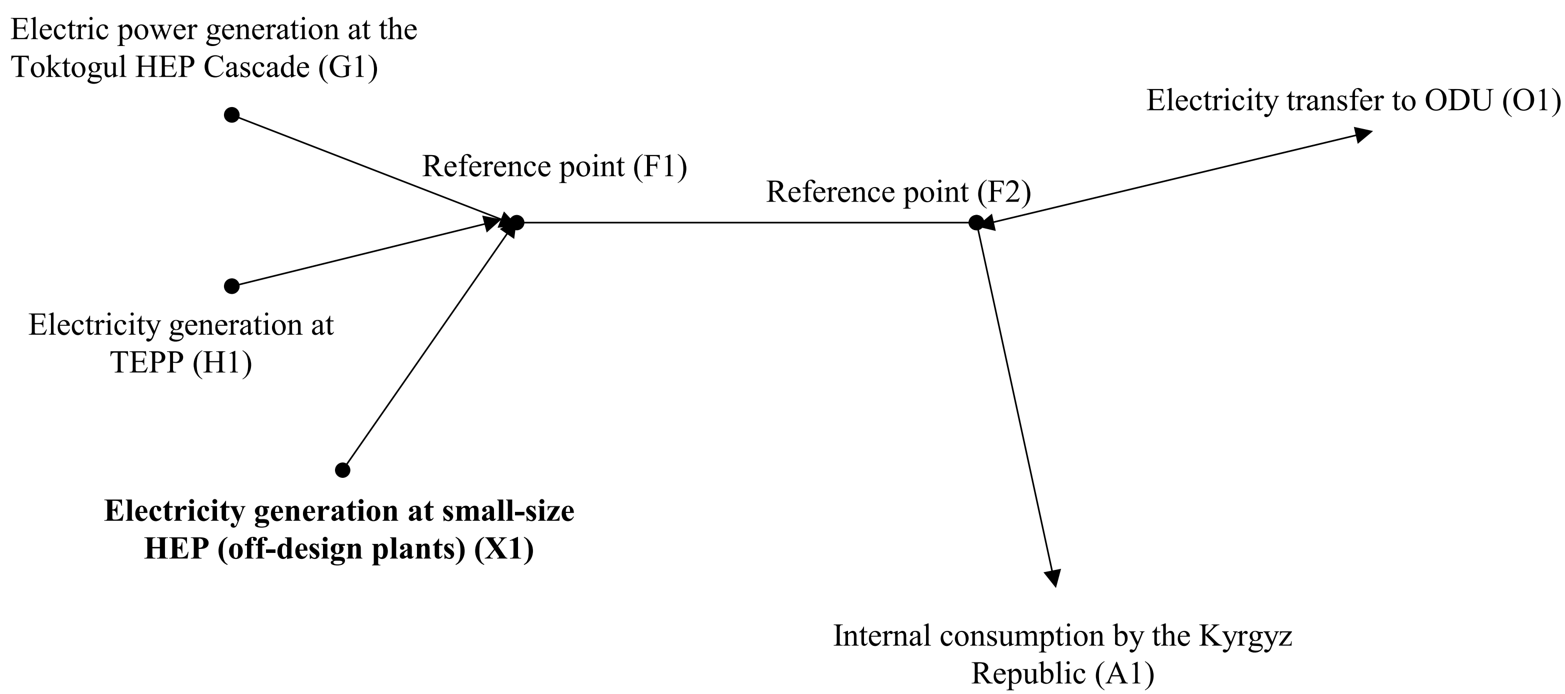


Figure 6. Diagram of energy balance of the Kyrgyz Republic

Parameter	Design time intervals (months)											
	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Conversion factors of flow rates (m^3/sec.) into monthly drawdown	2.6784	2.592	2.6784	2.6784	2.592	2.6784	2.592	2.6784	2.592	2.6784	2.6784	2.592

Average long-period inflows (sources)

No	Entity description		Design time interval (months)											
		Units	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
1.	Inflow to Toktogul reservoir	m^3/sec.	208	182	142	139	137	157	230	540	870	840	520	300
		million m^3	557.1	471.7	380.3	372.3	331.4	420.5	596.2	1,446.3	2,255.0	2,249.9	1,392.8	777.6
2.	Lateral inflow to Kurpsai reservoir	m^3/sec.	10	9	8	11.5	11.5	12	12.8	24	34	50	35	13
		million m^3	26.8	23.3	21.4	30.8	28.8	32.1	33.2	64.3	88.1	133.9	93.7	33.7
3.	Lateral inflow to Tashkumyr reservoir	m^3/sec.	40	39	33	23.5	23.5	33	103.2	139	117	58	51	48
		million m^3	107.1	101.1	88.4	62.9	58.9	88.4	267.5	372.3	303.3	155.3	136.6	124.4

Average long-period values of water diversion (water users)

n\n	Entity description	units	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
			Design time interval (months)											
1.	Water diversion of left-bank canal (LBC)	m^3/sec.	5	5	5	5	5	5	15	15	15	15	15	15
		million m^3	13.4	13.0	13.4	13.4	12.1	13.4	38.9	40.2	38.9	40.2	40.2	38.9
2.	Water diversion of Big Namangan Canal (BNC)	m^3/sec.	15	10	10	10	10	15	25	30	30	40	40	20
		million m^3	40.2	25.9	26.8	26.8	24.2	40.2	64.8	80.4	77.8	107.1	107.1	51.8

Data on water reservoirs and hydroelectric plants

	Water reservoir	Storage (million m^3)			Reservoir elevations / (m)		Hydropower unit efficiency (%)	Maximum conveying capacity of hydroturbines (m^3/sec.)
		Full	effective	dead	DFSL	DSL		
1.	Toktogul	19,500	14,000	5,500	900	837	87	960
2.	Kurpsai	370	35	335	724	721.6	90	972
3.	Tashkumyr	140	10	130	628	626.5	85	957
4.	Shamaldysai	39.4	5.4	34	572	569.9	80	1,035
5.	Uch-Kurgan	20.3	5.9	14.4	539.8	538.8	80	720

Elevations as a function of reservoir water storage

Toktogul reservoir		**Kurpsai reservoir**		**Tashkumyr reservoir**		**Shamaldysai reservoir**		**Uchkurgan reservoir**	
Upstream water elevation (h)	Storage (W)	Upstream water elevation (h)	Storage (W)	Upstream water elevation (h)	Storage (W)	Upstream water elevation (h)	Storage (W)	Upstream water elevation (h)	Storage (W)
m	million m^3	m	million m^3	m	million m^3	m	million m^3	m	million m^3
759	0	630	0	570	0	540	0	536	0
767	78	650	10	580	7	545	1	536.5	8.3
771	118	670	50	585	10	555	7	537	9.5
783	321	680	73	590	14	556	8	537.5	10.8
786	405	685	92	595	18	557	10	538	12.0
795	779	690	111	600	23	558	11	538.2	12.6
802	1,204	695	136	605	33	559	13	538.4	13.2
810	1,885	700	161	610	44	560	14	538.6	13.8
814	2,297	705	195	612	48	561	16	538.8	14.4
827	3,921	710	229	614	54	562	18	539	15.0
838	5,585	715	267	616	61	563	20	539.1	15.7
839	5,750	716	274	618	77	564	22	539.2	16.3
850	7,717	717	287	620	87	565	25	539.3	17.0
855	8,690	718	300	622	100	566	26	539.4	17.7
863	10,336	719	312	623	107	567	28	539.5	18.3
867	11,198	720	325	624	115	568	31	539.6	19.0
875	13,003	721	337	625	122	569	33	539.7	19.6
882	14,676	722	349	626	129	570	35	539.8	20.3
891	16,961	723	360	627	137	571	38	539.9	20.9
900	19,458	724	372	628	144	572	41	540	21.6
Equation $W = a*h^{b}+H_0$									
a = 0,4063979 b = 2,1779534 H_0 = 758		a = 0.0005979 b = 2.8718144 H_0 = 620		a = 0.0003101 b = 3.0309964 H_0 = 554.4		a = 0.0169624 b = 2.2192806 H_0 = 538.7		a = 0.0000028 b = 5.2041841 H_0 = 519.11	

Downstream water elevations as a function of water flow rate through the // of HEP

Toktogul HEP		Kurpsai HEP		Taskumyr HEP		Shamaldysai HEP		Uchkurgan HEP	
Downstream water elevation (h)	Flow rate Q	Downstream water elevation (h)	Flow rate Q	Downstream water elevation (h)	Flow rate Q	Downstream water elevation (h)	Flow rate Q	Downstream water elevation (h)	Flow rate Q
m	m^3/sec.	m	m^3/sec.	m	m^3/sec.	m	m^3/sec.	m	m^3/sec.
721	100	624	70	569	150	541	150	506	190
722	200	625	150	570	210	541.7	300	507	310
723	350	626	250	571	320	542	400	508	650
724	500	627	400	572	410	542.5	575	509	1,000
725	650	628	550	573	620	543	750		
726	900	629	700	574	810	543.5	900		
726.5	1000	630	972	575.5	960	543.7	1,040		
Equation $W = aQ^2+bQ^b+C$									
a = 0 b = 0.0095 c = 720		a = 0 b = 0.0100 c = 623.3		a = 0 b = 0.0100 c = 567.5		a = 0 b = 0.003 c = 540.6		a = 0 b = 0.005 c = 505	

Average monthly internal consumption of electric power in Kyrgyzstan (table potr (j,m)

n\n	Entity description		Design time intervals (months)											
		unit	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
1.	Internal consumption	million kWh	746	1,121	1,520	1,666	1,394	1,366	917	635	535	550	547	532

Average monthly values of generating plants output (e (j,m)).

n\n	Entity description		units	Design time intervals (months)											
				M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
1.	TEPP	max	million kWh	345	345	345	345	345	345	100	45	45	45	45	45
		мin	million kWh	60	125	125	130	130	125	60	15	15	15	15	15
2.	Off-design power plants	actual	million kWh	16	18	19	16	15	19	16	21	20	25	25	20
3	HEP	max	million kWh	2,135	2,066	2,135	2,135	1,929	2,135	2,066	2,135	2,066	2,135	2,135	2,066
		мin	million kWh	283	274	283	283	255	283	274	283	274	283	283	274

Cost values of electric power at power plants and rates of transfers from Central Asian UDC (price(j))

Type of power plants	TEPP	HEP	Small HEP
Cost value (tiin/kWh)	92	1.3	3.7

Transfers from UDC	
Rate (tiin/kWh)	100

3.4.3. Optimization criteria

The optimization criterion in this model is the provision of the republic's internal consumption with minimum expenses and taking into account the Toktogul reservoir operation in the electricity generation or irrigation modes. This criterion is included in the optimization function as minimization of the square of difference between the set and estimated consumption and electricity production costs for thermal and hydroelectric plants.

$$\Sigma_j (Э_j * C_j) + \Sigma_m (Э_{design\ internal\ consmp} - Э_{actual\ internal\ consmp.})^2 \Rightarrow min$$

In the objective function of the model it has the form as follows :

- **(1000* sum(j,$ma(j),sun(m,((potr(j,m)-potr_f(j,m))*(potr(j,m)-potr_f(j,m)))))**
- **0,1*sum(j$me_H(j),price(j)*sum(m,e(j,m)**
- **0,001*sum(j$me_G*sum(j$me_H(j),price(j)*sum(m,e(j,m)**
- **sum(m,(iii(‘o1,f2’,m)*price(j)));**

For water users the optimization criterion is similar to that in the model developed by specialists at BVO "Syr Darya".

3.4.4. Formulation of the mathematical model

The introductory part of the model is a sequential arrangement of five reservoirs and five plants of the HEP cascade with lateral inflows and water diversions. For every reservoir, water storage balances are observed as follows:

$$\Sigma W_{inflow} - \Sigma W_{consumption} = \triangle W_{reservoir}$$

For reference points the volume of inflow is equal to the volume of consumption, i.e.

$$\Sigma W_{inflow} = \Sigma W_{consumption}$$

The capacity of every HEP of the Naryn Cascade is calculated according to the following equation:

$$N_{HEP} = 9,81 * \text{hydropower unit efficiency} * Q * H$$

Where Q - water flow rate through hydropower units (m^3/sec.), and
H – full head (difference between upstream and downstream water elevations).

The output of electric power at HEP for the design period is calculated according the following equation:

$$Э_{HEP} = time(m)/3600 * N_{HEP}$$

where time(m) – number of seconds in the design period.

In the introductory part the equation evaluating the electric power output for every HEP is written in the GAMS language as follows:

```
                Power_prod(n1,m)$V(n1)..

        power(n1,m) =e= 9,81*time(m)/3600*kpd(n1)*
        sum(duga$conec_udp(n1,duga), flow(duga,m))/ time(m)*
          (
        ( cc1(n1)*
        (0,5*(vol(n1,m) + vol(n1,m-1)$(ORD(M) gt 1 ) + v_beg(n1)$(ORD(M) eq 1 ))
        **dd(n1) + hh(n1))
          )
                -(
        k_nba(n1)*
        sum(duga$conec_udp(n1,duga), flow(duga,m))/ time(m)*
        sum(duga$conec_udp(n1,duga), flow(duga,m))/ time(m) +
        k_nbb(n1)*
        sum(duga$conec_udp(n1,duga), flow(duga,m))/ time(m) +
        k_nbc(n1)
                )
          );
```

All entities of the energy part of the model are connected with one equation as follows: total output of all generating plants is equal to the internal consumption and balance of transfers from UDC "Energia"

$$Э_{HEP} + Э_{TEPP} + Э_{SHEP} = Э_{internal\ consmp.} + Э_{export} - Э_{import}$$

Since the plants of the Toktogul HEP Cascade are located on one and the same water course, they are all represented in the energy part as a single HEP with the total output equal to the output of all plants of the cascade being evaluated in the introductory part of the model.

The relationship of the water part and the energy part is as follows:

```
          Water(j,m)$(G(j)

                              Sum(n1$V(n1),power(n1,m)   =e=   e(j,m)
```

In order to provide for compulsory minimum load of TEPP (according to the heat schedule), constraints on the electric power output are introduced. These constraints can be changed depending on the availability of energy carriers (coal and gas) in the republic.

Apart from this, other constraints and settings have a significant effect on the calculation of the water and energy balance, including:

- constraints on the volume of water drawdown from the Toktogul reservoir (annual, in vegetation or any other period)

- tariffs for electricity connected with transfers to UDC
- setting of transfers etc.

Without constraints the model finds the optimal solution while in setting a considerable number of constraints, it is just a balance model

3.4.5. Examples of calculation and justification of reliability of the results

To verify the reliability of the elaborated model, the balance and optimal estimation of the Toktogul reservoir operation mode has been performed. The estimation is based on actual data of 1998-1999. The initial information is the actual energy balance of JSC "Kyrgyzenergo from October 1998 through October 1999 (Table 4), as well as actual upstream elevations of reservoirs and actual inflow into the Toktogul reservoir. Lateral inflows remain average annual. The program finds the optimal solution.

The calculation gives the operation mode of the reservoirs and electric power output for every plant of the Naryn cascade. According to the results of the calculation, analysis of the operation mode only for the Toktogul reservoir was performed because all other reservoirs have daily or weekly control and variations in their elevations and storage are insignificant. The information on the actual and estimated operation mode of the Toktogul reservoir is summarized in Table 5, and the values are presented in Figures 4, 5 and 6. The difference in the volumes of water drawdown from the Toktogul reservoir, according to the estimated and actual values, amounted to 270 million m^3, being 2.9 % of the actual value.

In addition, analysis of the electric power output of every plant was performed (Table 6). The analysis of the calculation results allows to suggest that at the section of Shamaldysai HEP - Uch-Kurgan HEP, apart from the set values of water diversions, there are extra water losses because the designed output exceeds the actual. In this case other power plants show the opposite trend - the unbalance of the output there is supposedly connected with inaccurate setting of lateral inflows. Since there is no hydropost at the Kara-Su river (right-bank tributary) and no data on the full lateral inflow to the Kurpsai reservoir, the lateral inflows to the Kurpsai and Taskumyr HEP are taken as average annual, and the year 1999 is considered a year with moderate water availability. To get a final solution of this problem requires more reliable information on the lateral inflow rate, water diversions and water drawdown through the gate of the Uch-Kurgan HEP.

The diagrams according to the estimated and actual values are plotted in Fig, 7.

Table 4. Electric power balance of JSC "Kyrgyzenergo" (KE) in 1998-1999

Parameters	1998				1999												
	Oct.	Nov.	Dec.	Quarter4	Jan.	Feb.	March	Quarter 1	Apr.	May	June	Quarter 2	July	Aug.	Sept.	Quarter 3	year
Consumption	739	1.036	1.452	3.227	1.625	1.309	1.328	4.263	895	621	525	2.040	529	534	517	1.580	11.110
Output of TEPP of JSC KE:	58	121	191	369	197	158	157	512	62	28	15	105	14	14	28	55	1041
Total output of JSC KE	858	1.055	1.470	3.383	1.641	1.327	1.400	4.368	999	664	662	2.326	1.093	1.021	536	2.650	12.727
Including NHEP Cascade	776	917	1.262	2.954	1.426	1.152	1.228	3.805	937	637	647	2.164	1.079	1.008	508	2.521	11.444
Output of small-size HEP	24	18	17	60	19	18	15	51	13	22	22	57	29	19	26	74	242
Deficit (-)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Export	119	19	18	156	16	18	72	106	104	43	137	284	564	487	19	1.070	1.617

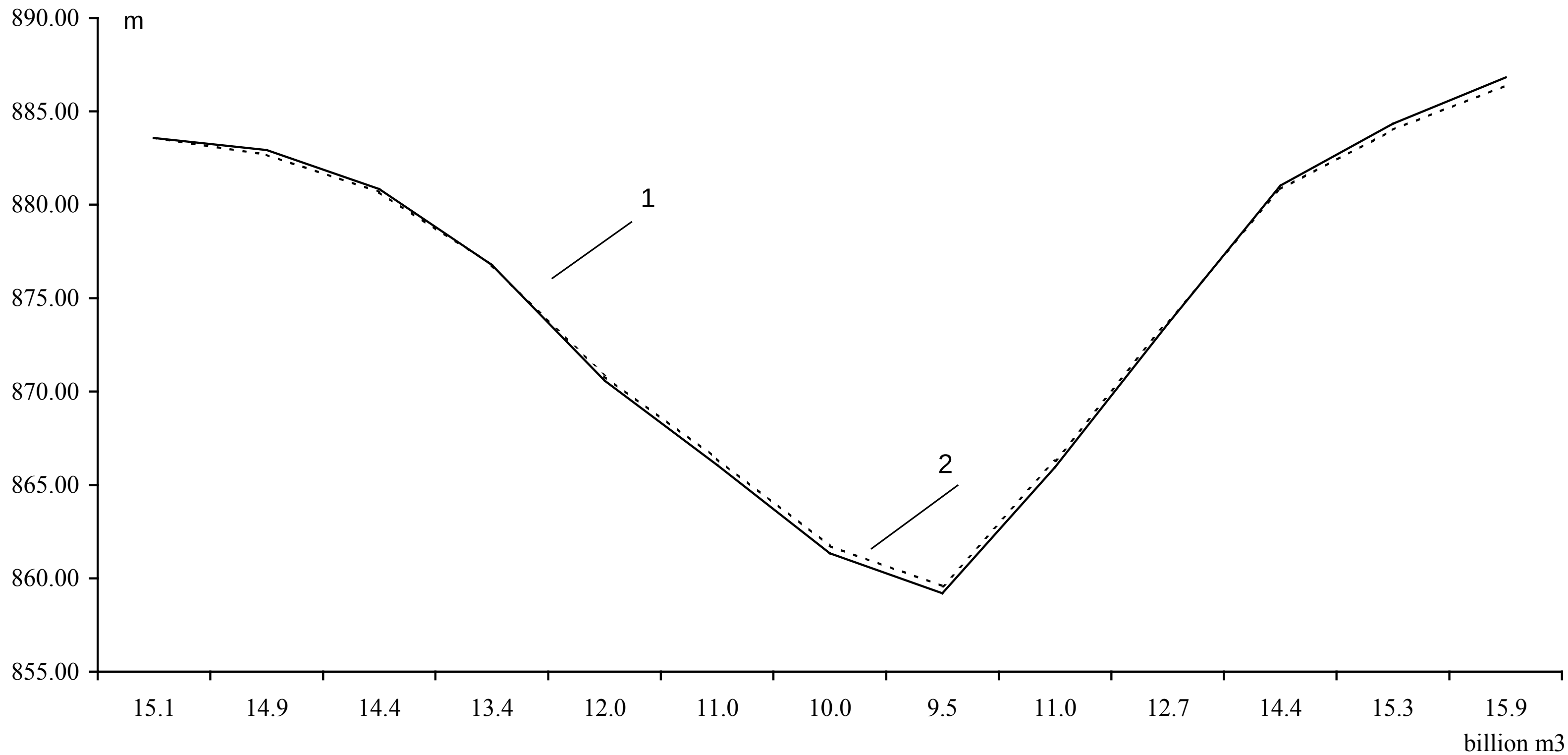


Figure 4. Verification of estimated and actual values of the volume curve of the Toktogul reservoir: 1- upstream water elevation by estimation; 2- upstrem water elevation by table

Table5. Verification of water regime in the Toktogul reservoir operation

Year and month	Elevation			Storage capacity		Inflow		Consumption				Drawdown-filling	
	m			billion m^3		m/s	million m^3	actual		estimated		actual	estimated
	actual	estimated	per table	actual	estimated			m^3/s	million m^3	m^3/s	million m^3	million m^3	million m^3
1.10.1998	883.58			15.069	15.069								
Oct.	882.97	882.67	882.93	14.916	14.907	267	716.1	324	868.5	326	872.6	-152	-157
Nov.	881.03	880.68	880.84	14.402	14.393	221	571.5	405	1.049.8	419	1.085.2	-478	-514
Dec.	877.31	876.78	876.77	13.545	13.416	217	581.5	551	1.475.5	582	1.559.1	-894	-978
Quart. IV	877.31	876.78	876.77	13.545	13.416		1.869.09		3.393.8		3.516.9	-1.525	-1.648
1.01.1999	877.31	876.78	876.77	13.545	13.416								
Jan.	871.60	870.82	870.59	12.223	11.994	141	377.7	635	1.699.5	672	1.799.4	-1.322	-1.422
Febr.	867.31	866.41	866.06	11.266	10.996	178	431.8	574	1.388.2	591	1.430.0	-956	-998
March	863.00	861.73	861.35	10.258	9.988	204	547.4	552	1.477.6	581	1.555.2	-930	-1.008
Quart. I	863.00	861.73	861.35	10.258	9.988		1.356.84		4.565.3		4.784.6	-3.208	-3.428
April	860.83	859.58	859.21	9.813	9.543	252	652.1	428	1.109.4	423	1.097.4	-457	-445
May	867.63	866.29	865.95	11.239	10.969	766	2.052.6	222	594.6	234	626.5	1.458	1.426
June	875.18	873.76	873.62	12.954	12.683	905	2.344.9	246	636.6	243	630.3	1.708	1.715
Quart. II	875.18	873.76	873.62	12.954	12.683		5.049.6		2.340.6		2.354.2	2.709	2.695
July	882.63	880.83	881.01	14.703	14.432	1.088	2.913.3	420	1.126.1	435	1.164.2	1.787	1749
August	885.96	884.02	884.34	15.532	15.261	720	1.929.6.	408	1.092.0	425	1.100.7	838	829
Sept.	888.30	886.38	873.62	16.161	15.891	429	1.113.0	197	510.8	181	483.8	602	629
Quart. III	888.30	886.38	873.62	16.161	15.891		5.955.9		2.728.9		2.748.7	3.227	3.207
Year	888.30	886.38	873.62	16.16	15.89		1.4231.5		13.028.6		13.404.5.	1.202.9	827.0

Table 6. Verification of HEP output of JSC "Kyrgyzenergo"

Electric power output. million kWh															
Year and month	Toktogul HEP		Kurpsai HEP		Tashkumyr HEP		Shamaldysai HEP		Uch-Kurgan HEP		Total for Naryn Cascade HEP		Small HEP	Total HEP	
	actual	estim.	actual	estim.	actual	estim.	actual	estim.	actual	estim.	actual	estim.	actual	actual	estim.
1.10.1998															
October	337.3	3309	222.7	218.7	113.3	111.1	37.8	42.0	64.4	73.3	775.4	776.0	24.3	799.7	800.3
November	407.1	406.3	259.6	251.9	128.5	125.8	44.2	48.3	77.4	83.8	916.9	916.0	18.0	934.8	934.0
December	561.7	566.8	357.8	351.3	176.7	167.4	58.9	64.6	106.9	112.0	1.261.9	1.262.0	16.8	1.278.7	1.278.8
Quart. IV	1.306.0	1.303.9	840.1	822.0	418.5	404.3	140.8	154.9	248.7	269.0	2.954.2	2.954.0	59.0	3.013.2	3.013.0
1.01.1999															
January	629.0	626.6	408.8	401.9	210.0	197.0	67.2	71.4	110.5	125.2	1.425.6	1.422.0	18.6	1.444.2	1.440.6
February	492.7	487.1	333.1	326.8	175.0	173.3	56.0	59.0	94.7	104.8	1.151.6	1.151.0	17.7	1.169.3	1.168.7
March	514.2	511.4	363.4	352.1	192.1	187.9	64.4	64.3	93.9	113.3	1.228.1	1.229.0	14.7	1.242.8	1.243.7
Quart. I	1.635.9	1.625.1	1.105	1.080.7	577.2	558.2	187.7	194.7	299.1	343.2	3.805.2	3.802.0	51.0	3.856.2	3.853.0
April	371.4	356.1	266.1	255.7	149.1	160.2	56.0	56.8	82.2	95.3	924.7	924.0	12.5	937.1	936.5
May	198.1	209.2	186.9	159.1	122.5	125.0	46.0	46.9	61.3	73.9	614.8	614.0	21.9	636.7	635.9
June	225.6	221.0	175.7	165.2	119.2	120.8	47.7	46.8	56.8	71.2	624.9	625.0	22.2	647.1	647.2
Quart.II	795.1	786.2	628.7	580.0	390.8	406.0	149.6	150.5	200.2	240.3	2.164.4	2.163.0	56.6	2.221.0	2.219.6
July	422.8	423.2	288.8	291.5	183.5	169.5	70.4	66.7	84.7	99.2	1.050.1	1.050.0	28.5	1.078.6	1.078.5
August	425.3	413.9	269.8	266.6	160.1	156.4	60.6	60.9	72.9	90.2	988.7	988.0	18.8	1.007.5	1.006.8
September	199.0	187.6	133.3	131.9	82.7	86.5	31.5	33.1	36.0	48.8	482.5	488.0	26.0	508.5	514.0
Quart.III	1.047.1	1.024.6	691.9	690.0	426.3	412.4	162.5	160.7	193.6	238.3	2.521.4	2.526.0	73.2	2.594.6	2.599.2
Year	4.784.2	4.739.8	3.266.0	3.172.7	1.812.8	1.780.9	640.6	660.8	941.6	1.090.8	11.445.2	11.445.0	239.9	11.685.0	11.684.8

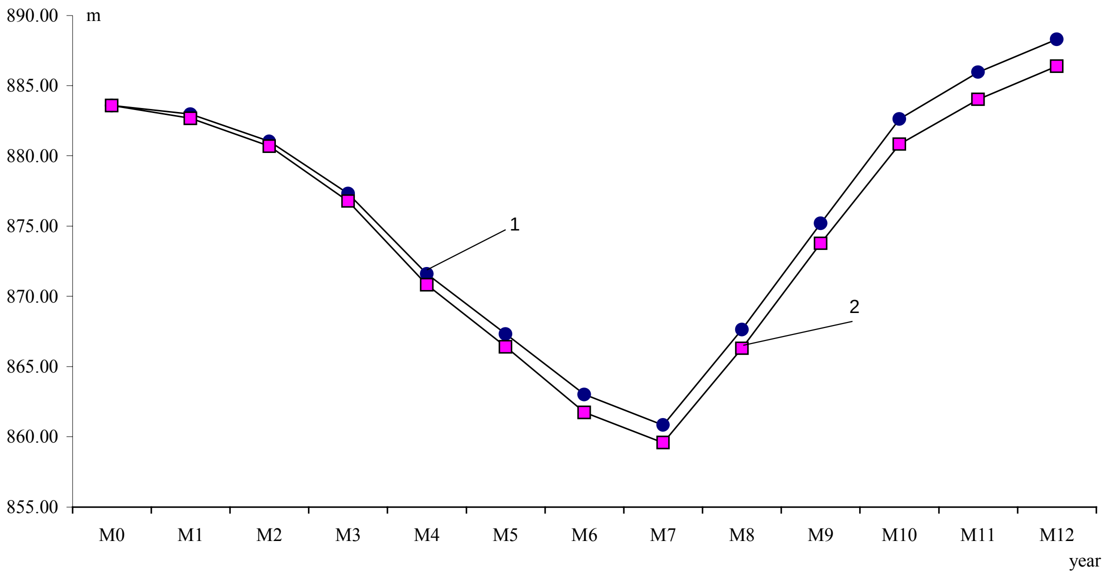


Figure 5. Operation mode of the Toktogul reservoir: 1 - actual elevations of upstream water; 2 - estimated elevations of upstream water

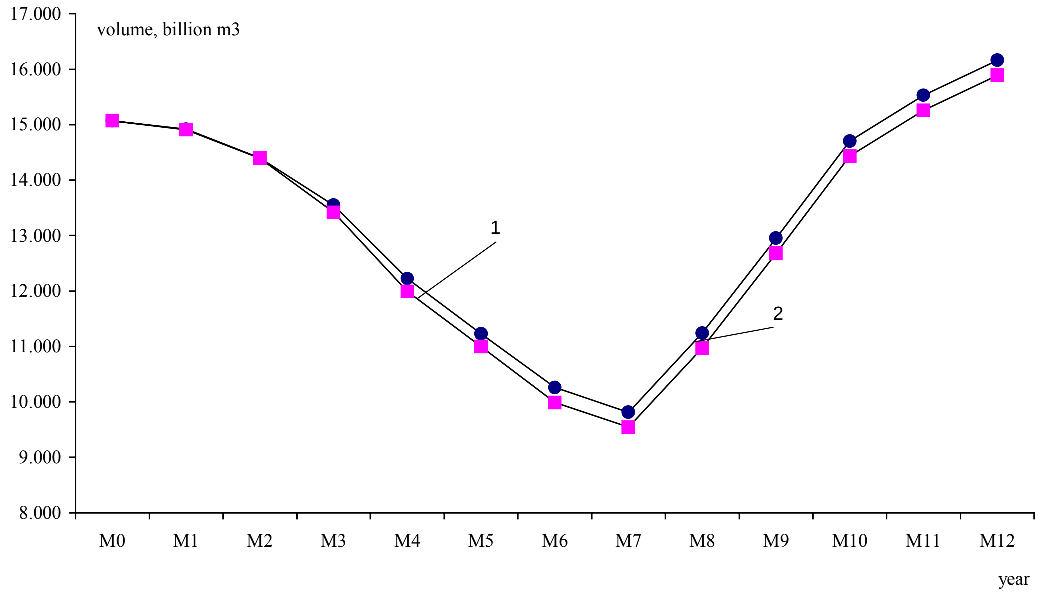


Figure 6. Operation mode of the Toktogul reservoir: 1 - actual storage; 2 - estimated storage

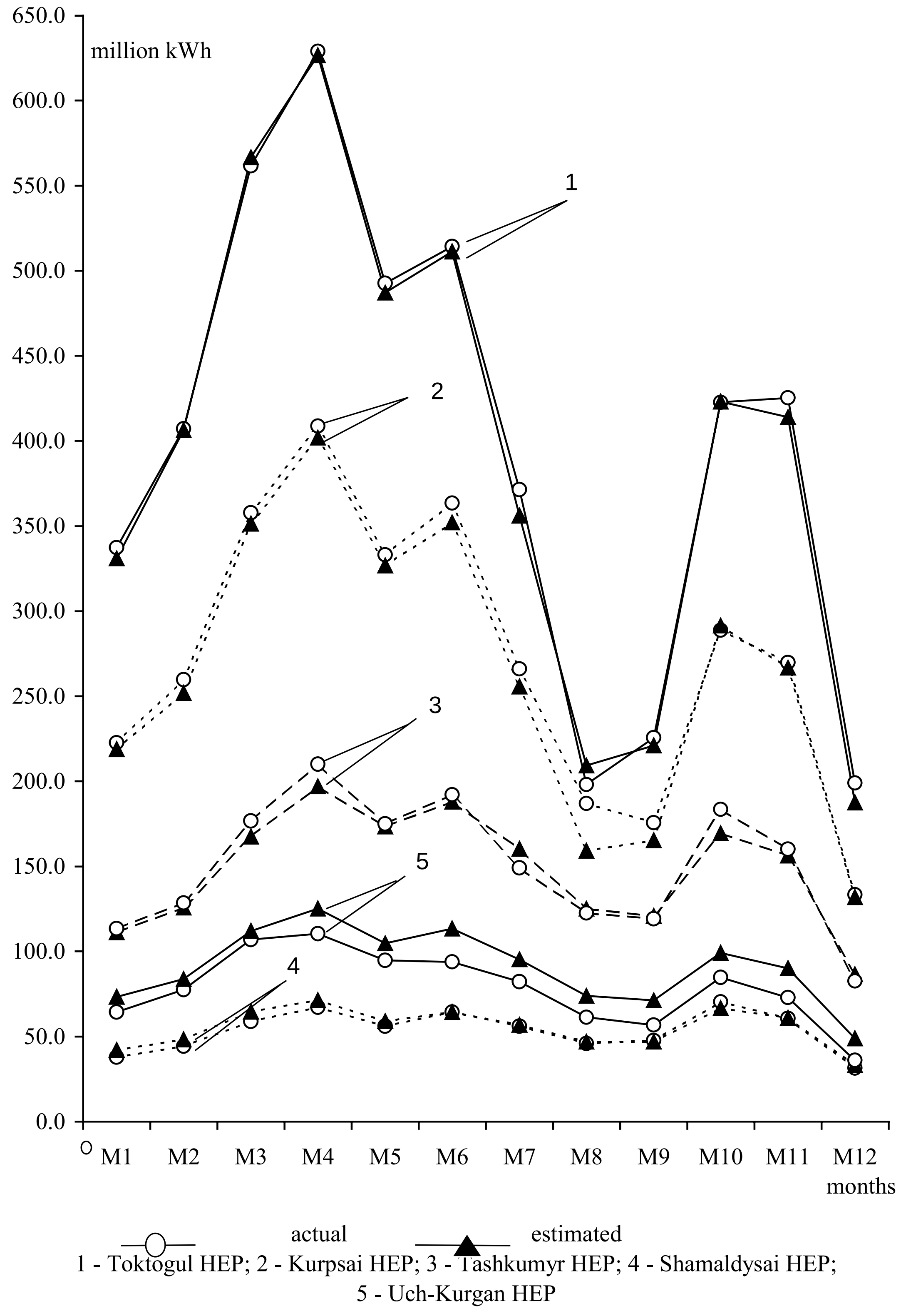


Figure 7. Actual and estimated output of the Naryn Cascade HEP.

Basing on this model, three estimations of several options of water and energy regimes of the Toktogul HEP Cascade and energy system of Kyrgyzstan on the whole have been performed. In all considered options the model found optimal solutions with regard for the specified constraints. The model incorporates the cost value at power generating plants and tariff for electric power export and import.

For all options the following constraints are taken:

- on maximum and minimum monthly output of electric power at TEPP with regard for compulsory mode of thermal loads
- on conveying capacity of hydropower units of the Naryn HEP Cascade
- on maximum and minimum level of reservoirs of the Naryn HEP Cascade.

Option 1 considers the problem of electric power supply to internal consumers with minimum electricity production costs through the energy system. Constraints on electric power transfers are introduced additionally as being equal to 0.

Resulting from the calculation, the electric power output at TEPP amounted to 847 million kWh proceeding from the TEPP operation with the heat schedule of loads. In that case the output of the Naryn HEP Cascade was 10.5 billion kWh and the annual discharge of water through the hydropower units of the Toktogul HEP - 11.6 billion m^3, exceeding insignificantly the annual long-period inflow to the Toktogul reservoir.

Option 2 envisages the operation mode of the Toktogul reservoir according to the irrigation regime in the vegetation period.

In that case additional constraints are introduced:

- on the volume of water discharged through the gate of the Toktogul HEP in the vegetation period
- on electric power transfers:
  a) zero transfer balances in the autumn-winter period (October-March)
  b) positive transfers in the Central Asian UDC in the vegetation period (April-September) to provide for electric power output above the internal consumption.

This option is a simulation of the intergovernmental agreements of 1995-1999.

Resulting from the estimation with regard for the current state of the Tashkumyr and Shamaldysai HEPs, the surplus electric power amounted to 2.71 billion kWh. In that case the Toktogul reservoir practices seasonal control of consumption for irrigation in the Syr Darya basin in Kazakhstan and Uzbekistan in the amount of 6.5 billion m^3. In the autumn-winter period, in order to provide for internal consumption through the Toktogul HEP, the release of 9.0 billion m^3 water is required). The annual output of the Naryn Cascade HEP amounted to 13.0 billion kWh and of TEPP - 1.05 billion kWh.

According to options 1 and 2, TEPP in the autumn-winter period operates with the minimum load, thermal power generation remains minimum and equals 1,875 thousand Gcal. Therefore the internal consumption according to these options can be much higher because the population use heating appliances. This would require raising of the output at the Naryn Cascade HEP and, therefore, will increase water evacuation from the Toktogul reservoir.

This theoretical estimation with an annual water passage through the gate of the Toktogul amounting to 15.5 billion m^3 and with the annual long-period inflow of 11.2 billion m^3 would cause drawdown of the Toktogul reservoir and therefore rather serious problems both in the energy sector of Kyrgyzstan and in the whole integrated water system of the Syr Darya basin.

Option 3 is most of all free from constraints. In this case additionally set are only the constraints on the annual consumption of water through the Toktogul HEP being equal to the annual long-period inflow of the Naryn river to the Toktogul Hydrosystem. This task definition solves theoretically the problem of long-period control of the Naryn river water.

With the use of the same criterion of costs minimization and above mentioned constraints, the estimation gives the results as follows:

- the output of electric power at TEPP amounting to 2.4 billion kWh with the maximum loads in the autumn-winter period
- the output of the Naryn Cascade HEP amounting to 10.5 billion kWh
- import of electric power to Kyrgyzstan in the autumn-winter period amounting to 2.1 billion kWh
- export of electric power from Kyrgyzstan in the vegetation period amounting to 3.7 billion kWh
- annual water discharge through the gate of the Toktogul HEP amounting to 11.2 billion m^3 including 7.4 billion m^3 in the vegetation period
- with regard for total heat demand in the republic of 2.6 thousand Gcal, the gross annual output of TEPP is 6.6 billion kWh.

Tables 7-10 below show the results of estimation according to every option and summarized information.

Table 7. Draft balance of electric power of Kyrgyzenergo" for internal consumption without constraint on the annual discharge through the gate of the Toktogul HEP

Option 1

Parameters	Jan.	Feb.	March	Quart.1	Apr.	May	June	Quar.2	July	Aug.	Sept.	Quar.3	Oct.	Nov.	Dec.	Qar.4	Year
Consumption	1.666	1.394	1.366	4.426	917	635	535	2.087	550	547	532	1.629	746	1.121	1.520	3.387	11.529
Output of JSC KE:	1.666	1.394	1.366	4.426	917	635	535	2.087	550	547	532	1.629	746	1.121	1.520	3.387	11.529
Output of TEPP	147	130	125	402	60	15	15	90	15	15	15	45	60	125	125	310	847
Output of small-size HEP	16	15	19	50	16	21	20	57	25	25	20	70	16	18	19	53	230
Output of Naryn HEP Cascade	1.503	1.249	1.222	3.974	841	599	500	1.940	510	507	497	1.514	670	978	1.376	3.024	10.452
Transfers from Dispatch Center				0				0				0				0	0
" + " export	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
" -" import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average long-period inflow to Toktogul reservoir (million m^3)	372	331	421	1.124	596	1.446	2255	4.298	2.250	1393	778	4.420	557	472	380	1.409	11.251
Drafts from the Toktogul HEP gate																	
In storage (million m^3)	1.844	1.486	1.458	4.788	927	570	447	1.944	465	482	505	1.452	718	1.084	1.588	3.390	11.574
In flow rate (m^3/sec.)	688	614	544		358	213	172		174	180	195		268	418	593		
Toktogul reservoir									At the beginning of estimation 01.10				888.5 16.3				
Elevation at the end of the month	877.4	872.0	867.3		864.1	865.3	871.1		878.4	883.4	885.5		887.6	886.2	882.7		
Storage capacity at the end of the month (billion m^3)	12.9	11.7	10.7		10.3	11.2	13.0		14.8	15.7	16.0		16.1	15.5	14.3		

Table 8. Draft balance of electric power of Kyrgyzenergo with only seasonal control of flow through the Toktogul HEP

Option 2

Parameter	Jan.	Feb.	March	Quar.1	Apr.	May	June	Quar.2	July	Aug.	Sept.	Quar.3	Oct.	Nov.	Dec.	Quar.4	Year
Consumption	1.666	1.394	1.366	4.426	917	635	535	2.087	550	547	532	1.629	746	1.121	1.520	3.387	11.529
Output of JSC KE:	1.666	1.394	1.366	4.426	917	635	850	2.402	1.187	1.415	1.420	4.022	746	1.121	1.520	3.387	14.237
Output of TEPP	158	130	125	413	100	45	45	190	45	45	45	135	60	125	125	310	1.048
Output of small-size HEP	16	15	19	50	16	21	20	57	25	25	20	70	16	18	19	53	230
Output of Naryn HEP Cascade	1.492	1.249	1.222	3.963	801	569	785	2.155	1.117	1.345	1.355	3.817	670	978	1.376	3.024	12.959
Transfers from ODU				0													
" + " export	0	0	0	0	0	0	315	315	637	868	888	2.393	0	0	0	0	2.708
" -" import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average long-period inflow to the Toktogul reservoir	372	331	421	1.124	596	1.446	2.255	4.298	2.250	1.393	778	4.420	557	472	380	1.409	11.251
Releases from the Toktogul HEP																	
In storage (million m^3)	1.767	1.484	1.457	4.708	875	531	796	2.202	1.210	1.519	1.569	4.298	718	1.984	1.590	4.292	15.500
In flow rate (m^3/sec.)	660	613	544		338	198	307		452	567	605		268	765	594		
									At the beginning of estimation 01.10				888.5				
Toktogul reservoir													16.3				
Elevation at the end of the month	874.9	870.0	865.3		864.0	868.2	874.5		878.7	878.2	875		887.4	885.1	880.5		
Storage at the end of the month (billion m^3)	13.0	11.8	10.8		10.5	11.4	12.9		13.9	13.9	13.0		16.1	15.6	14.3		

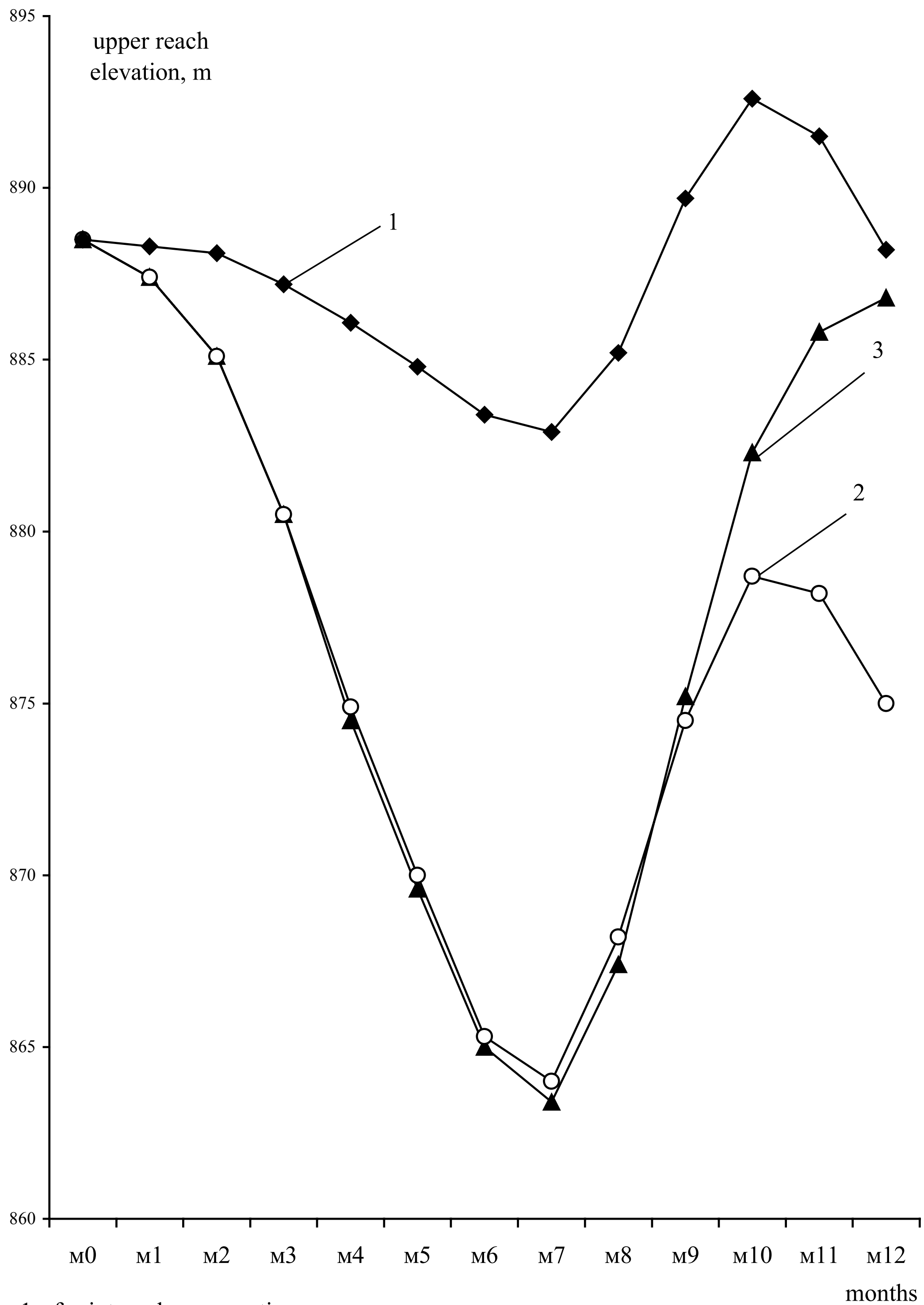
Table 9. Draft balance of electric power of Kyrgyzenergo with annual water evacuation through the Toktogul HEP gate in the amount of 11.2 billion m^3 and optimal load of the plant taking into account the cost value of electric power

Option 3

Parameter	Jan.	Feb.	March	Qar.1	Apr.	May	June	Quar.2	July	Aug.	Sept.	Quar.3	Oct	Nov.	Dec.	Quar.4	Year
Consumption	1.666	1.394	1366	4.426	917	635	535	2.087	550	547	532	1.629	746	1.121	1.520	3.387	11.529
Output of JSC KE	993	1.010	1073	3.076	829	903	1.091	2.823	1.405	1.610	1.584	4.599	802	881	951	2.634	13.132
Output of TEPP	345	345	345	1.035	100	45	45	190	45	45	45	135	345	345	345	1.035	2.395
Output of small-size HEP	16	15	19	50	16	21	20	57	25	25	20	70	16	18	19	53	230
Output of Naryn HEP Cascade	632	650	709	1.991	713	837	1.026	2.576	1.335	1.540	1.519	4.394	441	518	587	1.546	10.507
Transfers from DC				-1.350				736				2.970				-753	1.603
" + " export	0	0	0	0	0	268	556	824	855	1.063	1.052	2.970	56	0	0	56	3.850
" -" import	-673	-384	-293	-1.350	-88	0	0	-88	0	0	0	0	0	-240	-569	-809	-2.247
Average long-period inflow to the Toktogul reservoir	372	331	421	1.124	596	1.446	2.255	4.298	2.250	1.393	778	4.420	557	472	380	1.409	11.251
Releases from the Toktogul HEP gate	1.075	1.088	1.081		1.01	0.98	1.02		1.067	1.1	1.128		1.03	1.04	1.062		
In storage (million m^3)	679.4	707.4	766.5	2.153	724	823	1.049	2.595	1.424	1.700	1.713	4.837	453	539	623.6	1.615	11.200
In flow rate (m^3/sec.)	254	292	286		279	307	405		532	635	661		169	208	233		
Toktogul reservoir									At the beginning of estimation 01.10				888.5 16.3				
Elevation at end of month	886.1	884.8	883.4		882.9	885.2	889.7		892.6	891.5	888.2		888.3	888.1	887.2		
Storage at end of month (billion m^3)	15.8	15.4	15.1		15.0	15.6	16.8		17.6	17.3	16.4		16.4	16.3	16.1		

Table 10. Analysis of energy regime of JSC Kyrgyzenergo and water-and-energy regime of the Toktogul reservoir

Parameters	Units	Option 1			Option 2			Option 3		
		Without control			With seasonal control			With long-period control		
		Estimation for internal consumption			Estimation with release for vegetation 6.5 billion m^3			Estimation for average long-period inflow		
		Autumn-winter period	Vegetation	Year	Autumn-winter period	Vegetation	Year	Autumn-winter period	Vegetation	Year
Consumption	Mln kWh	7.813	3.716	11.529	7.813	3.716	11.529	7813	3716	11529
Output of JSC KE:	Mln kWh	7.813	3.716	11.529	7.813	6.424	14.237	5710	7422	13132
Output of TEPP	Mln kWh	712	135	847	723	325	1048	2070	325	2395
Output of small-size HEP	Mln kWh	103	127	230	103	127	230	103	127	230
Output of Naryn HEP Cascade	Mln kWh	6.998	3.454	10.452	6.987	5.972	12.959	3537	6970	10507
Transfers from UDC "Energia" "+" export ("-" import)	Mln kWh	0	0	0	0	0	2.708	-2103	3706	1603
Average long-period inflow to the Toktogul reservoir	mln m^3	2.533	8.718	11.251	2.533	8.718	11.251	2533	8718	11251
Releases from the Toktogul HEP										
In storage	mln m^3	8.178	3.396	11.574	9.000	6.500	15.500	3768	7432	11200
In flow rate	M^3/sec.	520	215	367	572	411	492	240	470	355
Toktogul reservoir										
Elevation at beginning of the period	M	889	865	888.5	889	865.3	888.5	888.5	883.4	888.5
Storage at the beginning of the period	bln m^3	16.3	10.7	16.3	16.3	10.8	16.3	16.3	15.1	16.3
Elevation at the end of the period	M	865	886.8	886.8	865.3	875	875	883.4	888.2	888.2
Storage at the end of the period	bln m^3	10.7	16	16	10.8	13	13	15.1	16.4	16.4
Annual "-"drawdown. "+"filling "	bln m^3			-0.3			-3.3			0.1

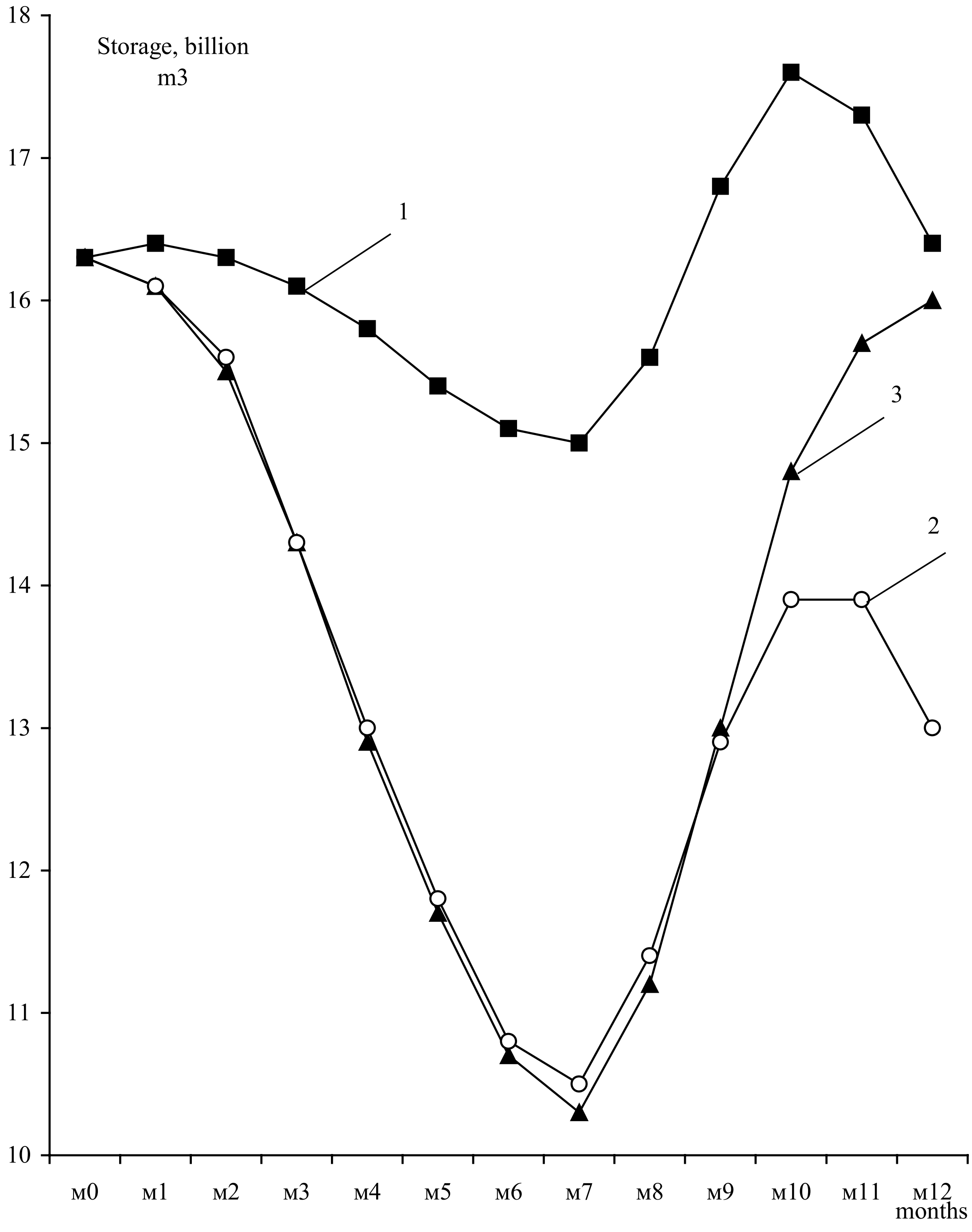


1 - for internal consumption

2 - with regard for consumption for irrigation in the vegetation period

3 - with regard for long-term control.

Figure 8. Modes of operation of the Toktogul reservoir with average annual inflow



1 - for internal consumption

2 - with regard for consumption for irrigation in the vegetation period

3 - with regard for long-term control.

Figure 9. Modes of operation of the Toktogul reservoir with average annual inflow

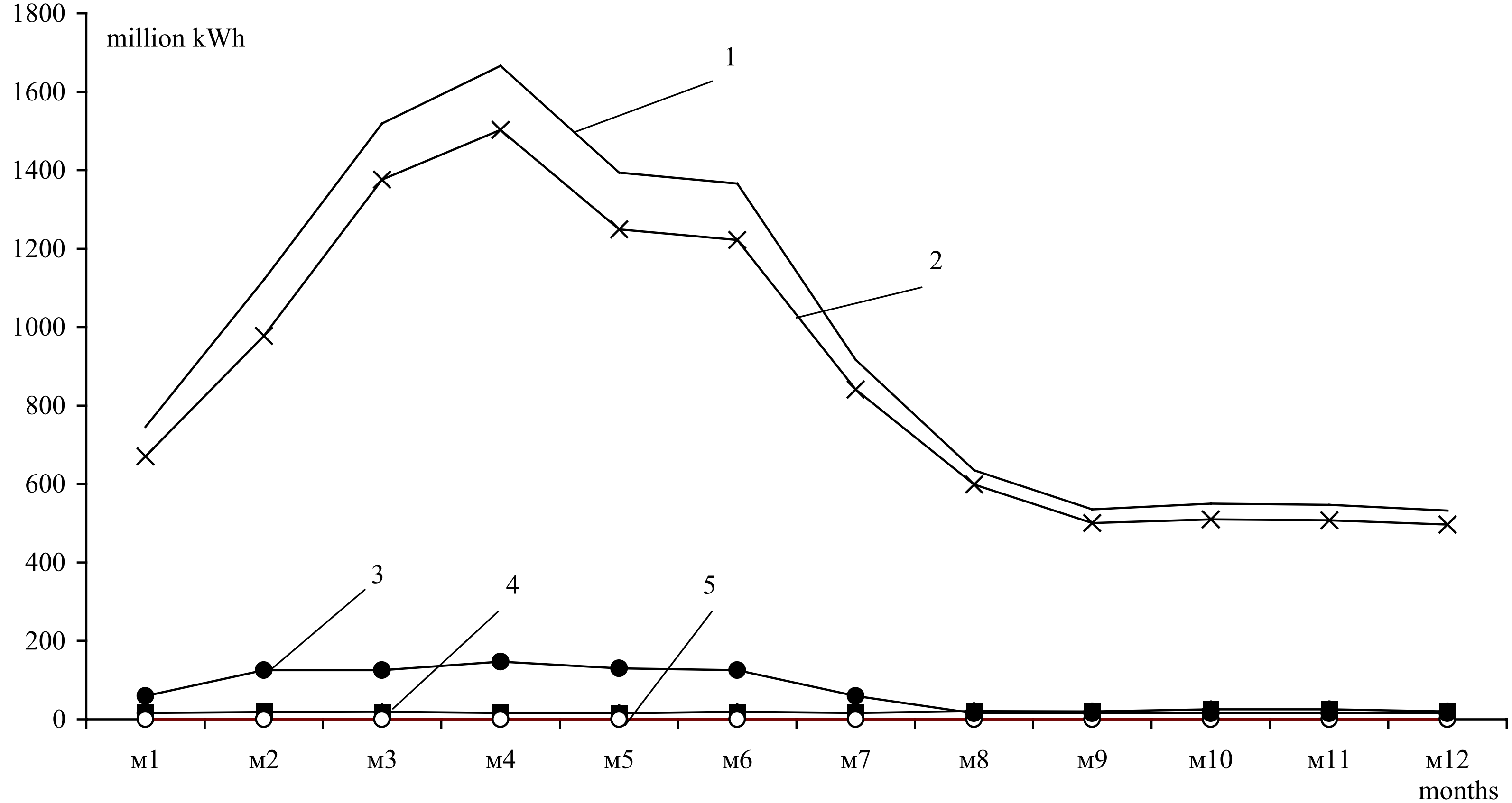


Figure 10. Energy balance of JSC Kyrgyzenergo when operating for internal consumption: 1 - internal consumption; 2 - electricity output at the Naryn Cascade HEP; 3 - electricity output at TEPP; 4 - electricity output by small-scale HEP; 5 - crossflows from UDC "Energia"

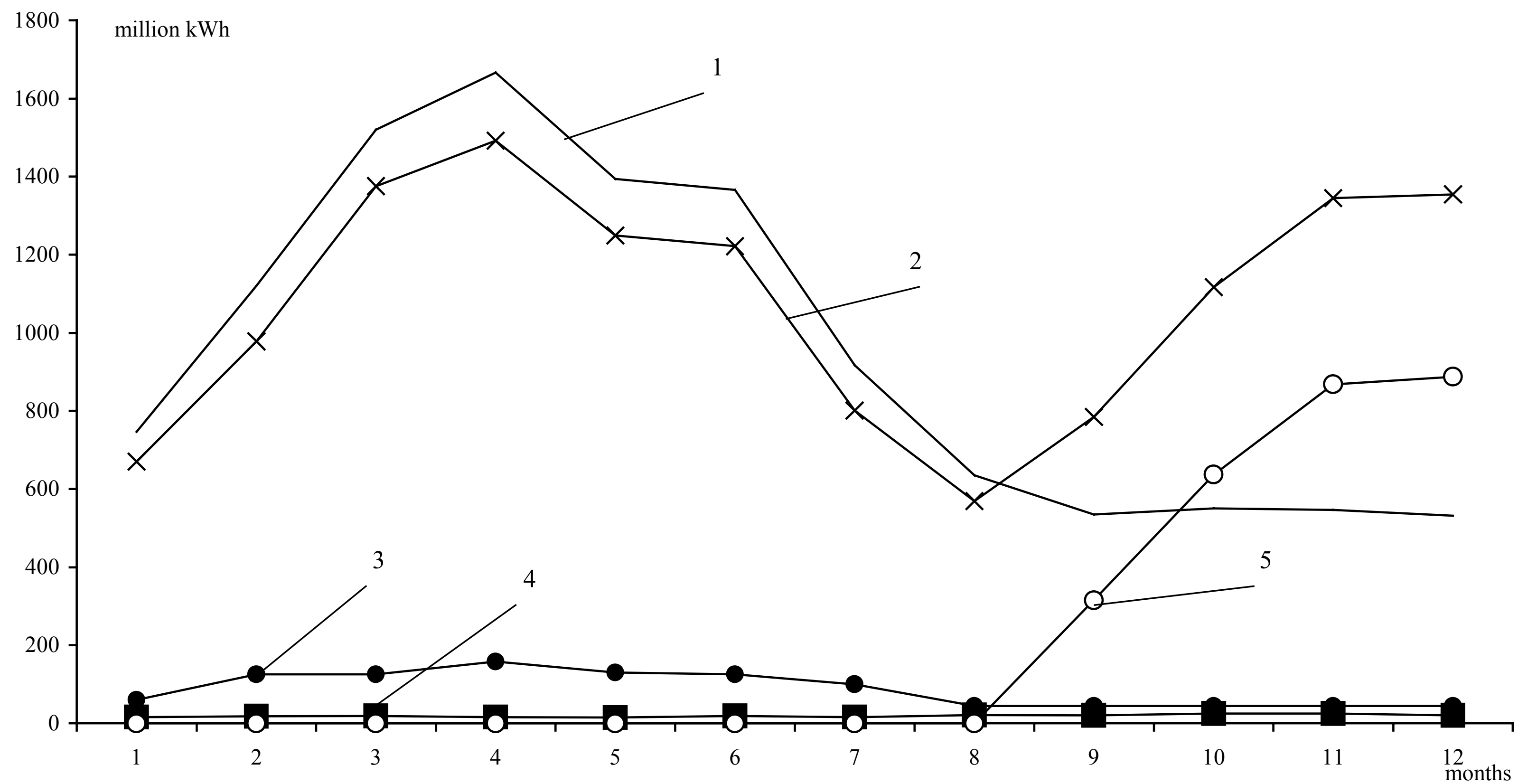
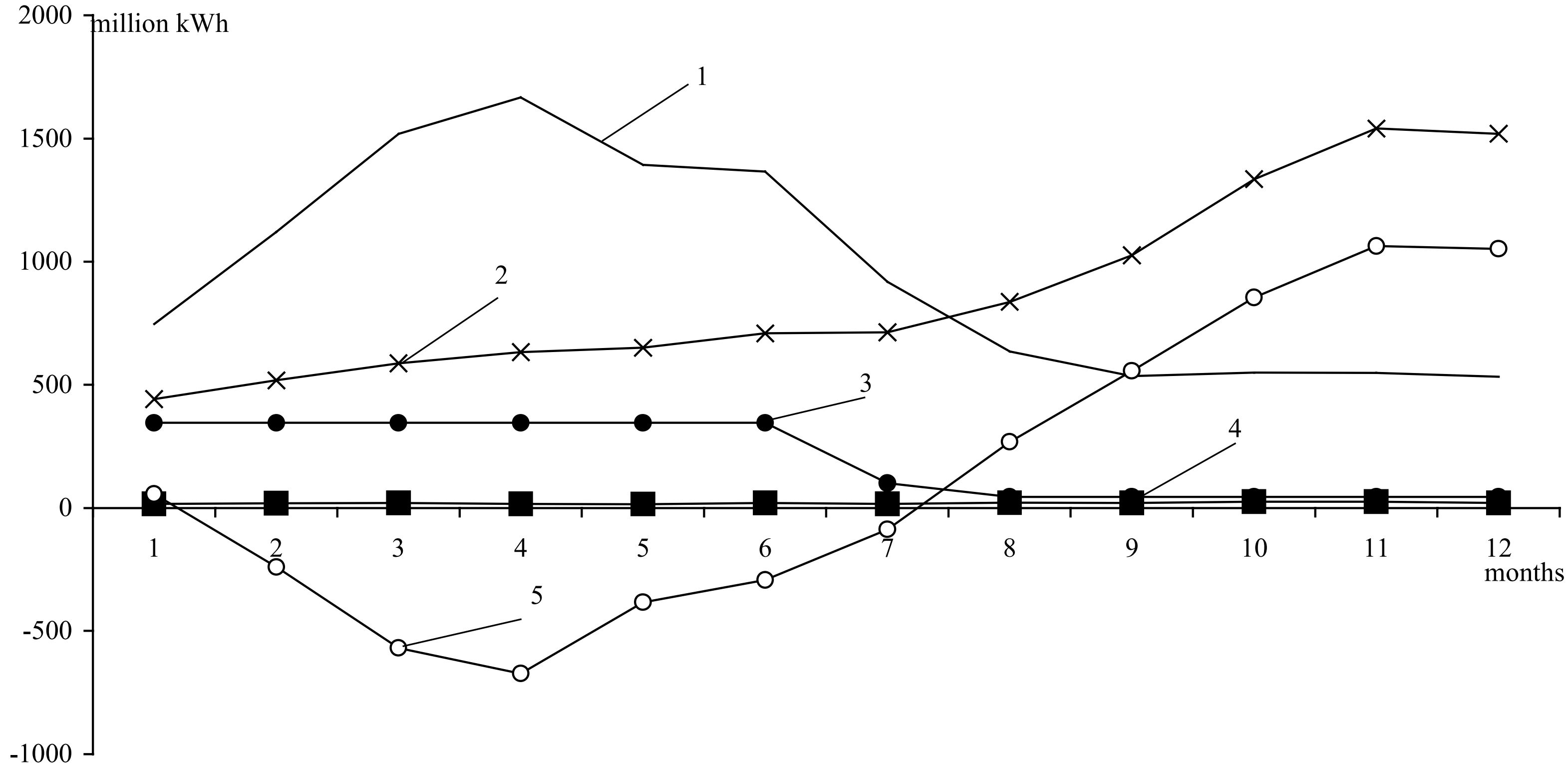


Figure 11. Energy balance of JSC Kyrgyzenergo when operating with regard for irrigation: 1 - internal consumption; 2 - electricity output at the Naryn Cascade HEP; 3 - electricity output at TEPP; 4 - electricity output by small-scale HEP; 5 - crossflows from UDC "Energia"



1 - internal consumption; 2 - electricity output at the Naryn Cascade HEP; 3 - electricity output at TEPP; 4 - electricity output by small-scale HEP; 5 - crossflows from UDC "Energia".

Figure 12. Energy balance of JSC Kyrgyzenergo when Toktogul reservoir operates with regard for long-term control of the Naryn river

3.4.6. User manual

The program is compiled only for the energy system of JSC Kyrgyzenergo existing at the moment of design.

Since there is no interface to this program, all modifications and initial data are introduced immediately in the program itself and with the help of constraint files (files "cnstr" and constr_e).

All initial information and constraints on period selection and total water discharge for the period are introduced in the program itself - in file "two_user.gms".

File "cnstr" is a file of input of constraints on all water information (reservoir storage capacities, HEP conveying capacity, constraints or settings of the release of given discharges, etc.). All information is introduced in volumes (million m^3).

File "constr_e" is a file of introducing constraints on energy information - settings of electric power transfers, max and min loads of power plants, settings of internal consumption, etc. (million kWh).

In file "digits in" the priorities of optimization criteria are set.

Results of calculations on water and electricity information are recorded in file “river_new”.

File "two_user.lst" is a verification file of the program. It helps to find a site and to determine the type of the error in the model.

3.5. Long-period control of the Syr Darya river flow

The experience of cooperation in the usage of water and energy resources in the Syr Darya basin on the basis of intergovernmental agreements is seasonal. It considers primarily the benefits of energy resources exchange and does not solve the task of long-term balanced use of water. This can cause early drawdown of the Toktogul reservoir and huge losses both in the power and water sectors of the republics.

A situation similar to the drawdown of all effective storage of the Toktogul reservoir has arisen by the beginning of the vegetation period of 1998 following the low-water year 1997.

Apart from this, in the nongrowing season of 1999-2000 (from 24 September 1999 to 14 February 2000) supply of natural gas to the TEPP of the Kyrgyz energy system was terminated. As a result, because of extra load of the Cascade HEPs, the drawdown of water from the Toktogul reservoir increased in that period by 1.5 billion m^3 against the same period of 1998-1999. That caused additional discharge of water to the Arnasai depression from the Char Darya reservoir and aggravated the ecological situation in the lower reaches of the basin.
These factors confirm that the parties have to fulfill annual intergovernmental obligations and it is time to practice long-period control and use of water of the Toktogul reservoir.

Within the framework of this model, calculations of using this reservoir with different set initial parameters have been performed.

Results of preliminary estimations confirm that it is possible to change the regime of water drafts downstream the Toktogul Hydrosystem provided that the parties increase the compensation supplies.

The obtained output data can be used by the participants of this model under further work on interrelation of all components and elaboration of a model of long-term control and usage of water and energy resources in the Syr Darya basin.