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Establishment of possibility of transferring part of machine irrigation land to gravity irrigation

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Abstract. The increasing shortage of energy resources and difficulties associated with repairing or replacing pumping equipment requires the search for alternative solutions to machine irrigation of land. This article substantiates the possibility of a phased transition of lands in the Bandykhan district from machine irrigation to gravity irrigation. To save money, the transition to gravity irrigation is planned to be carried out without reconstruction of the canal, obtaining the maximum benefit from water accumulation.

1 Introduction

Currently, much of the land in Surkhandarya province is irrigated from large machine canals - Sherabod canal with head flow $Q = 110\, m3/s$ and Amu-Zang canal with flow $Q = 120\, m3/s$. However, the increasing shortage of energy resources, difficulties associated with repairing or replacing pumping equipment, and possible limitations in electricity supply from the Nurek hydropower plant lead to the need to gradually transfer these lands from pumping irrigation to gravity irrigation. The Ministry of Water Resources of Uzbekistan, design organizations Uzgiprovodkhoz and Vodproject, Amu-Surkhan Basin Irrigation System Administration, and Tupolang-Karatag Irrigation System Administration are engaged in solving this complicated problem. Full conversion of machine irrigation lands to gravity irrigation will require large capital investments for the reconstruction of irrigation systems and the construction of necessary hydraulic structures for its implementation, which is unrealistic under current conditions. Therefore, we approached the solution to this problem step by step, considering the possibility of connecting a separate pumping station, considering the existing water situation at the site and based on the requirements of the minimum volume of reconstruction. The purpose of our work is to justify the possibility of disconnecting the Bandykhan-II pumping station, which feeds the tail part of the Khazarbag canal from the Sherabad main canal, by passing the missing water flow by gravity from the Tupolang reservoir during its filling. At that, it is necessary to coordinate the regime of the water reservoir's drawdown and filling with Khazarbag canal's operation regime so that, firstly, it would be possible to transfer some lands of

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machine irrigation to gravity irrigation without canal reconstruction and, secondly, to receive maximum return from water accumulation.

2 Methods and Materials

The following materials were used in the calculation process: linear scheme of irrigation system with hydraulic structures, general information of WUA (service area, main source of irrigation, rehabilitation, construction). Evaluate the condition and operation of hydraulic structures (water distribution unit, water measuring device). Methods for defining safety criteria of hydraulic structures, method of assessment of hydraulic structures safety level, development, and testing of hydraulic structures condition assessment system, analysis methods for research of experimental field methods were used.

The studies were conducted according to the methodology of inspection of hydraulic structures, methods for assessing hydraulic structures, methods for determining the criteria for the safe operation of hydraulic structures, calculation and evaluation of hydraulic structures (water distribution, water meter structures, etc.). and field observations [10 – 14].

In the course of the work, the following studies were carried out:

1. to study the condition of irrigation networks in the selected area.
2. to evaluate the hydraulic structures on the irrigation systems.
3. Calculate the number of necessary materials and costs for repairing hydraulic structures.
4. Determination of the order of repair of hydraulic structures.
5. Priority construction and repair of hydraulic structures.
6. Environmental impact assessment of hydraulic engineering works.
7. Rehabilitation of hydraulic structures, justification of the results achieved during construction (rehabilitation).
8. Comparison of conditions before and after construction, summarizing the results.
9. Making calculations based on regulatory documents.

The main objectives of the survey of hydrotechnical constructions on irrigation systems are:

assessment of the condition and safety of hydrotechnical constructions and their complexes, the forecast of their changes over time;

identification of deviations from project decisions, damage, defects, and changes in the physical and mechanical properties of materials;

cause of accident constructions;

identification of dangerous changes in the processes occurring in the construction system – the foundation (filtration, displacement, precipitation, stress level);

analysis and assessment of hydrotechnical constructions for emergency prevention measures;

assessment of compliance by the operating organization with the requirements of regulatory legal acts on the operation of hydrotechnical constructions;

development of recommendations to improve the safety of hydrotechnical structures.

The general issues of construction, operation, and repair of hydrotechnical structures are the equitable distribution of water between water users (farmers) and between farmers and household plots [15 – 22].

3 Results and Discussion

The self-flow system of the Khazarbag canal, suspended to the Tupolang River, irrigates 59.6 thousand ha of land. The canal is about 90 km long and has a rather complicated system of recharge and discharge, including the Tupolang-Karatag canal, and from PK 599 is called Akkapchigai. Because of the lack of water in the domestic regime of the Tupolang river, the lands located at the end part of the canal with an area of 4 thousand ha are recharged from the Sherabad canal using Bandyhan-I and Bandyhan-II pumping stations with the maximum flow rates by pumps Q = 12 m^3/s and Q = 7.5 m^3/s. From Bandyhan-I pumping station located at the ShMMK, water is supplied through the Bandyhan canal to the Kyziryk canal and Bandyhan-II pumping station. Through the pressure pipeline, 6.2 km long and 1200 mm in diameter, the water rises to a height of 25 meters and discharges into the end of the Akkapchigai canal, from where it enters the distributors P-1 and P-2. The existing scheme of land irrigation at the Akkapchigai end is shown in figure 1.

According to the project, the whole Kyzyryk steppe should be irrigated by gravity flow. It was proposed to reconstruct Akkapchigai, R-1, and R-2 canals to increase their carrying capacity. From the R-1 canal, water will be supplied to the Bandykhan and Kyzyryk canals, and the Bandykhan-I and II pumping stations should be eliminated. This irrigation scheme is shown in figure 2. Therefore, we consider the possibility of partial or full disconnection of pumping stations in coordination with the Khazarbagh canal and reservoir operation modes so that the reconstruction volume would be minimal.

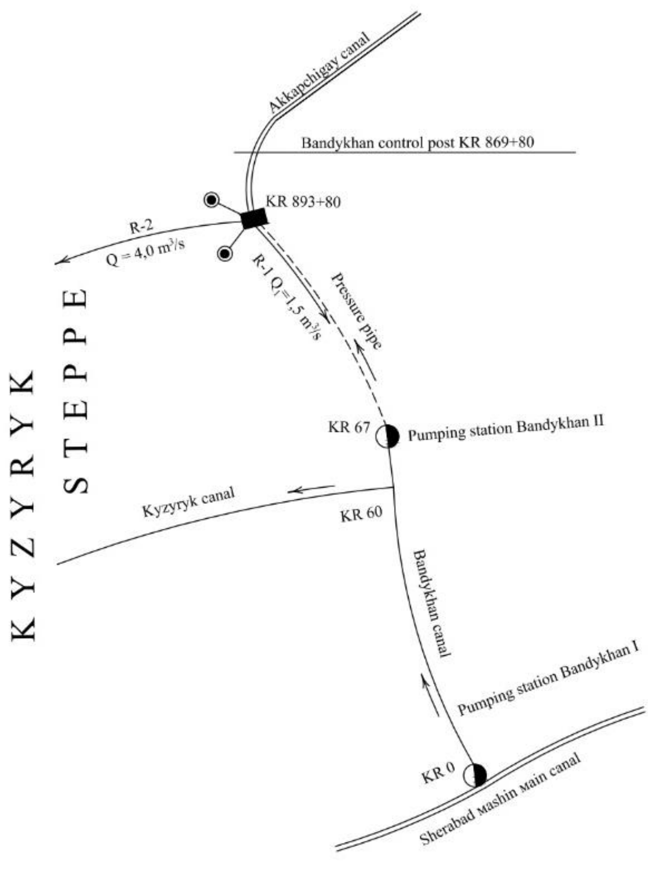

Fig. 1. Scheme of land irrigation at the end of Akkapchigai (existing position).

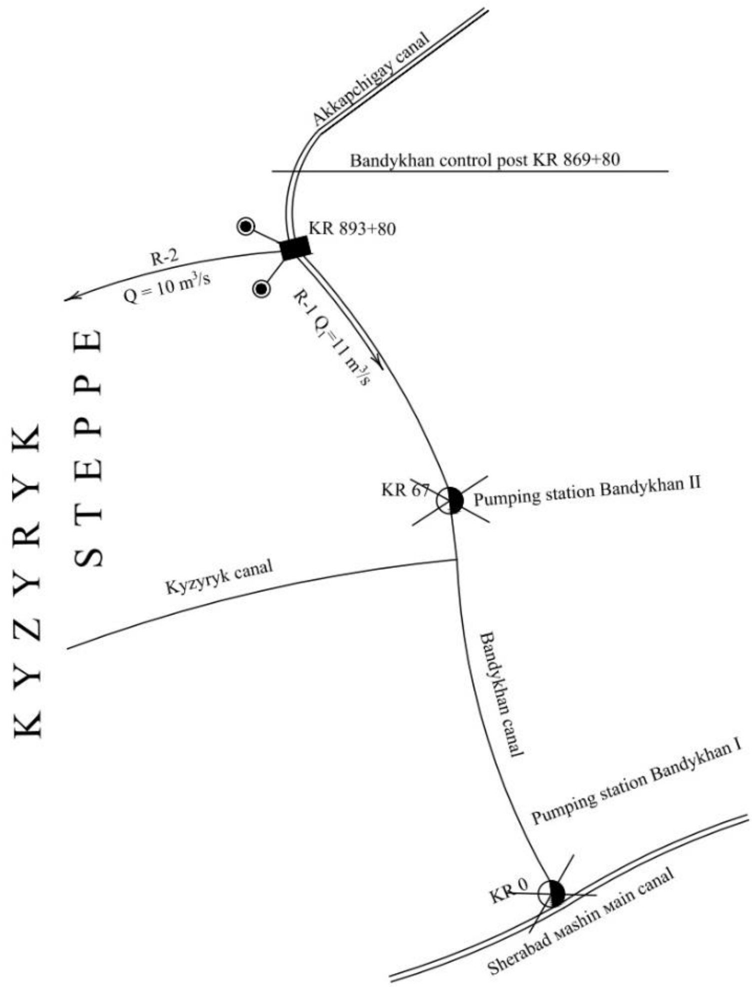

Fig. 2. Design scheme of land irrigation at the end of Akkapchigai.

The operation mode of the Khazarbag and Tupolang-Karatag canals. The Khazarbag canal takes water from the Tupolang River, whose flow rates will be regulated by the Tupolang reservoir. The linear scheme of the canal with flow capacity by sections is shown in figure 3. The Hazarbag irrigation system operation department took information on average ten-day discharges in the head of the Hazarbag and Tupolang canals and the water use plan for this irrigation system. Based on these data, graphs of average ten-day discharges of the Khazarbagh-Tupolang canals for a multiyear period were plotted (Figure 4). Canals are not operated in January, February, and the 3rd ten-day period of December. Maximum peak discharges are in the 3rd ten-day period of June and the 1st and 2nd ten-day periods of July. Comparing actual discharges in the canal with discharges according to the water use plan, it is evident that water shortage occurs in two periods: in March and the first ten-day period of April; and from the third ten-day period of July to October. At that, the water deficit in August reaches up to 20 m^3/s. The maximum actual water withdrawal in the head reached 67.6 m^3/s, i.e., currently, the canal cannot pass more than 70 m^3/s.

The operation mode of the Bandykhan-II pumping station and the possibility of its shutdown. The Bandyhan-II pumping station is located at PK67 of Bandyhan Canal and has 5 I6 NDN-25 pumps with a capacity of 1.5 m^3/s. The lifting height is about 25 m, and the pressure pipeline with a diameter of 1200 mm and a length of 6.2 km supplies water to the Akkapchigai canal (Figure 1). The pumping station Bandyhan-II was built instead of the temporary one, where 5 pumps with a total flow rate of 2.5 m^3/s were working, and water was supplied to the distributor P-1.

The actual regime of the Bandykhan-II pumping station is characterized mainly by the presence of one peak of maximum discharge, which falls at the end of July and August. Maximum discharges in this period were 1.5-2.19 m^3/s, and only in the dry year was a second peak of maximum discharge in the 3rd decade of March (Q_{max} = 1.77 m^3/s). Starting from the 3rd ten-day period of November to the 1st ten-day period of March, the pumping station does not work. During the rest ten-day period, maximum flow rates fluctuate within 0.3-1.35 m^3/s (Figure 5). Let's compare the operating modes of the canal and the pumping station. There is a shift in the supply of maximum flow rates by the canal and by the pumping station: maximum flow rates by the canal are in late June and in the first and second decades of July, and by the pumping station - in the 3rd decade of July and August months. That is, at the end of July and August, due to water accumulation in the reservoir, additional discharges can come through the canal to the Akkapchigay end without its reconstruction to compensate for discharges supplied by the pumping station during its shutdown. Values of maximum and average ten-day discharges at the Bandykhan-II pumping station for a multiyear period are given in table 1.

Table 1. Values of maximum and average discharges by decades for a multiyear period (Bandyhan-II pumping station).

Months	Decades	Q_{max}, m^3/s	Q_{cf}, $m^3/sec.$	Months	Decades	Q_{max}, m^3/s	Q_{cf}, $m^3/sec.$
	1	dry	dry		1	0.54	0.39
I	2	-	-	VII	2	0.54	0.38
	3	-	-		3	1.9	0.84
	1	-	-		1	2.19	1.17
II	2	-	-	VIII	2	1.5	0.96
	3	-	-		3	2.0	0.96
	1	-	-		1	1.02	0.59
III	2	0.463	0.015	IX	2	0.57	0.22
	3	0.54	0.186		3	0.73	0.26
	1	1.77	0.43		1	0.84	0.26
IV	2	0.66	0.29	X	2	1.38	0.57
	3	0.43	0.15		3	1.0	0.44
	1	0.48	0.18		1	1.35	0.35
V	2	0.3	0.27	XI	2	0.75	0.23
	3	0.35	0.22		3	0.84	0.05
	1	0.63	0.27		1	сухо	сухо
VI	2	0.48	0.33	XII	2	-	-
	3	0.42	0.3		3	-	-

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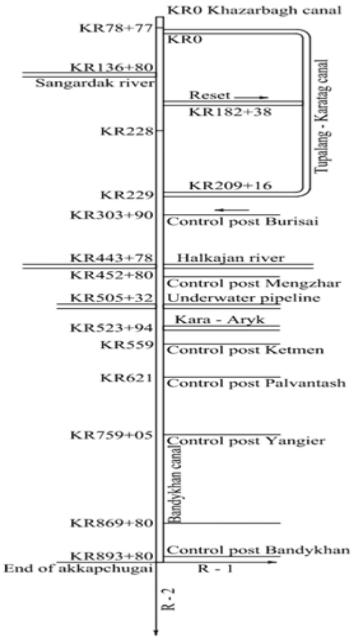
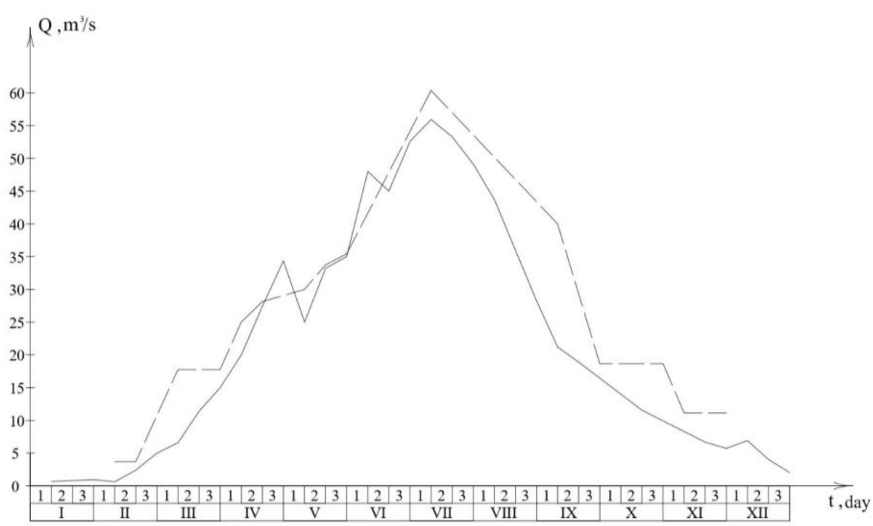


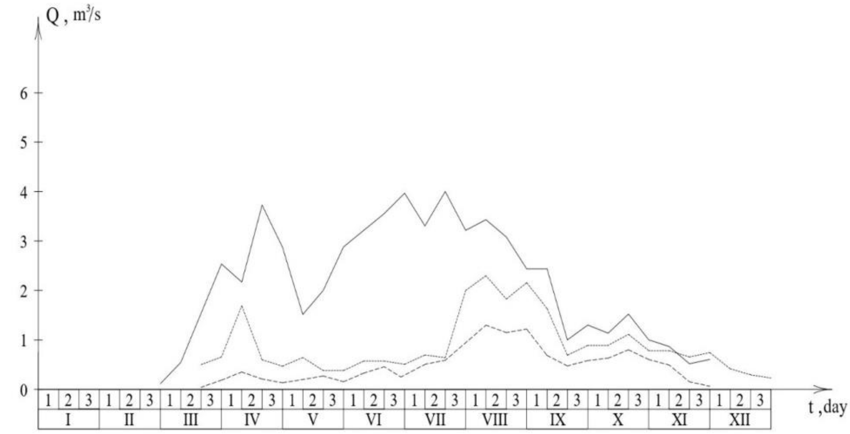
KR by site	Maximum possible flow rates by sections, m^3/s
KR 0 … KR 136+80	110
KR 136+80 … KR 146	80
Tupolang-Karatag c-l.	
KR 182+38 discharge	40
from	
Tupolang-Karatag c-la.	
to HazarbagKR	16
182+38 … KR 228	24
KR 228 … KR 289	15
KR 289 … KR 452+80	54
KR 452+80 … KR 505+32	32
KR 505+32 … KR 523+94	27
KR 523+94 … KR 559	25
KR 559 … KR 621	16
KR 621 … KR 739+05	12.5
KR 739+05 … KR 869+80	8.5

Fig. 3. Linear diagram of the Khazarbagh channel.



__ __ __ __ __ - average expenses per week;____________ - planning costs

Fig. 4. Graph of changes in average daily and planned discharges in the head of Khazarbag and Tupolang-Karatag canals for a multiyear period



_________________ - channel costs;_ __ __ __ __ __- average flow rates of the Bandyhan-II pumping station; _ _ _ _ _ _ _ _ _ _ - maximum flow rates of the Bandyhan-II pumping station.

Fig. 5. Graph of changes in average flow rates over a multiyear period at the end of the Akkapchigai channel, average and maximum flow rates of pumping station № 2.

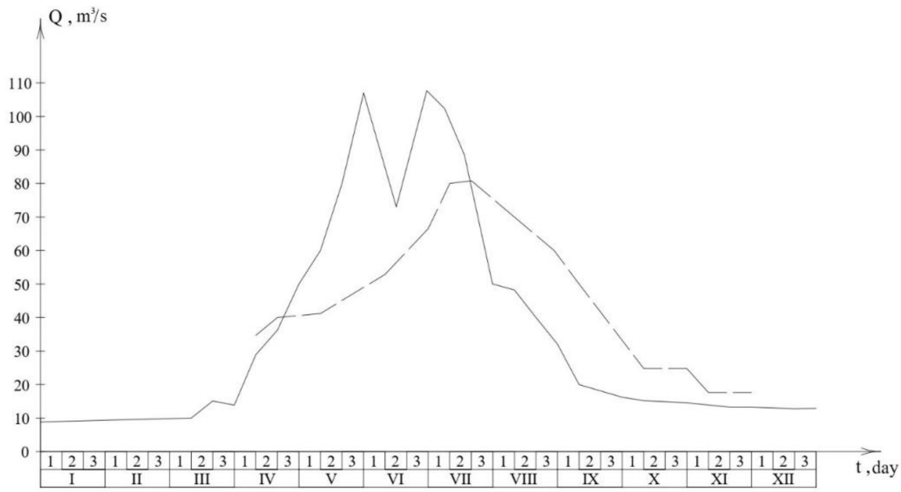
Consider the possibility of disconnecting the Bandykhan - II pumping station under partial filling of the Tupolang reservoir to 30 million m^3, 40 and 60 million m^3 of water. Comparing the water use plan to the Tupolang River irrigation system and the minimum discharges along the Tupolang River for the multiyear period of Fig. 6, it is seen that in March and the 1st decade of April, the necessary water intake into the irrigation system of the Tupolang River is not provided by own water resources of the Tupolang River. At this time, the average flow rate of the pumping station is 0.02-0.43 m^3/s. According to the tentative calculations, with a sowing area in the non-vegetation period of 35 thousand ha, given hydromodule 0.37 l/s-ha and irrigation system efficiency of 0.55, the required discharge in March is 24 m^3/sec and in April - 36 m^3/sec. Minimum discharges in the river fluctuate between 16 and 25 m^3/s; thus, the water deficit varies from 7 to 11 m^3/s. The average water discharge from the reservoir during its winter filling covers the existing deficit from 10.03 to 10.04 already at the reservoir volume of 30 million m^3 of water. The results of the calculations are given in tables 2 and 3.

Table 2. Water deficit in March-April on the Tupolang River irrigation system.

Indicators	March		April
	2nd decade	3rd decade	1st decade
Planned flow into the system, m^3/s	24	24	36
Minimum flow rates of the river, m^3/s	17.8	15.9	25
Water deficit, m^3/s	6.7	8.1	11

Table 3. The remainder of the water deficit during the winter filling of the reservoir.

Indicators	March		April	March		April	March		April
	2	3	1	2	3	1	2	3	1
Volume of water accumulation in winter, mln. m^3	30			40			60		
Average water flow from the reservoir, m^3/s	11.5			15.4			23		
Remaining deficit, m^3/s	- 0.5			-			-		



________________ - minimum costs r. Tupolang.
__ __ __ __ __ __ __ - planned expenditures into the irrigation network.

Fig. 6. Graph of changes in minimum discharge of the Tupolang River over a multiyear period and planned discharges into the irrigation network.

According to the data of the Sherabad Main Canal Administration for the long-term period, the pumping station Bandykhan-II on average delivers 0.02-0.4 m^3 /s (Table 1, Figure 5), and only in the low-water year, the maximum flow rate in the 3rd decade of March was 1.8 m^3/s. The use of water from the reservoir, accumulated in the winter, allows even in low-water years not to switch on the pumping station in spring. Considering the average ten-day discharges of the pumping station from 10.03 to 10.04 (during the deficit period), the required volume from the reservoir when the pumping station is turned off will be 0.5 mln m^3.

In the summer months till the 3rd ten-day period of June, discharges of Tupolang river exceed water intake into the irrigation system, and discharge of Bandykhan-II pumping station varies within 0.1-0.6 m^3/sec (Table 1). Such insignificant flow rates can be additionally passed to the Khazarbagh canal end, and it is not necessary to recharge it with a pumping station during this period.

Starting from the 3rd ten-day period of July, the planned water withdrawal exceeds the river discharge. The pumping station operates with the maximum discharge Q = 1-2 m^3/s, covering the water deficit at the Akkapchigai end at the expense of water to increase water availability of lands in the Akkapchigai end, which will allow abandoning pumping station operation in this period. The necessary volume of water from the reservoir to replenish the average daily discharge of the pumping station in August-October is 5 million m^3. According to the canal operation regime, flow rates are less than maximum peak flows by 7-47 m^3/s. Thus, additional flow to the Akkapchigay's end of 1-2 m^3/s, compensating for the work of the pumping station, can be passed without its reconstruction.

In a high-water year, in addition, by September, 30 million m3/s was accumulated in the reservoir for the first time, which allowed to increase in water discharge at the end of Akkapchigai in August-September by 1-2 m^3/sec compared with the previous years. Despite this, the Bandykhan-II pumping station operated until October with flow rates of 0.1-0.6 m^3/s. However, flow rates at the end of Akkapchigai and without recharge of the pumping station exceeded the planned water intake. Having considered the actual operation modes of the Hazarbag canal of Bandyhan-II pumping station, the flow rate dynamics of

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Tupolang river for many years period and the possibility of water accumulation in the reservoir up to 30 million m^3, 40 and 60 million m^3, we recommend the following:

1. It is necessary to fill the reservoir twice - in winter and summer, and not once a year, as it was until now;
2. At double filling of the reservoir, the pumping station Bandykhan-II should be switched off because, during the water resources deficit, the pumping station expenditure will be compensated by passing by gravity to the Akkapchigai end of the accumulated water from the reservoir. During the rest of the time, water resources of the Tupolang river provide planned water intake to the irrigation system taking into account the pumping station's discharges.
3. When the pumping station is turned off, there is no need to reconstruct the Khazarbagh canal since the maximum compensating flow is 1-2 m^3/s and occurs in the spring and autumn months when the canal does not work with a full load.

The operation mode of the Bandyhan-I pumping station. Let's consider the possibility of changing the operation mode of the Bandykhan-I pump station in connection with the operation mode of the Khazarbag canal during the filling of the Tupolang reservoir during the construction period to establish the possibility of partial transfer of the Kyzyryk massif to gravity irrigation. The pumping station Bandyhan-I is located on KR 52 of the Sherabad main canal; the height of the lift is 40 m, and the forced flow $Q_{force.}$=15 m^3/sec. The station is equipped with 8 NDN-25 pumps with a total flow of 12 m^3/sec. From the pumping station, water flows into the Bandyhan canal with a length of 6.7 km and slope i=0.0001, designed for passing the normal flow $Q_{norm.}$=11 m^3/sec. The main part of the flow rate falls on the Kyziryesky canal, departing from the Bandykhan canal at KR 60. The line diagram of the Bandykhan canal is shown in Fig.7.

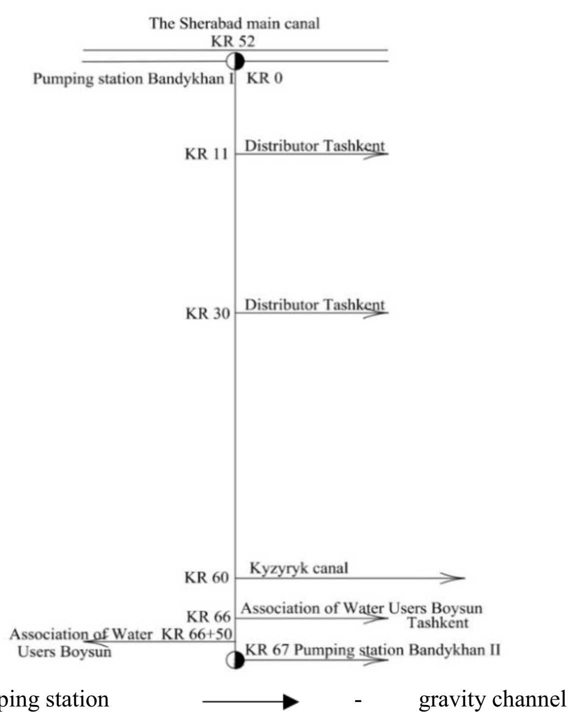


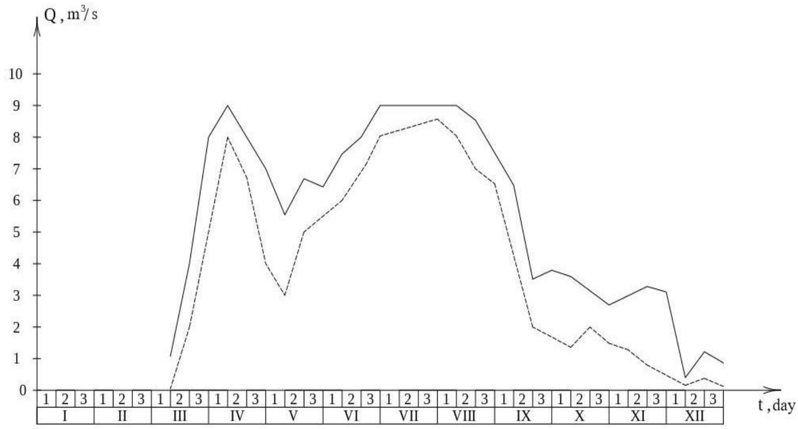
Fig.7. Linear diagram of the Bandyhan channel

Maximum discharges occur in the third ten-day period of March and the first and second ten-day periods of April (the first peak), and the second peak discharges occur from late June to mid-August; the maximum average ten-day discharges are $Q_{max.}$= 9 m^3/s. Discharge dynamics in an annual section is shown in Fig. 8, and values of maximum and average ten-day discharges are given in table 4.

Table 4. Values of maximum and average ten-day flow rates at Bandyhan pumping station-I.

Months	Decades	Q_{max}, m^3/s	Q_{cf}, m^3/sec.
I	1	dry	dry
	2	-	-
	3	-	-
II	1	-	-
	2	-	-
	3	-	-
III	1	1.35	0.02
	2	3.75	1.97
	3	7.9	5.5
IV	1	8.85	8.07
	2	7.95	6.86
	3	7.2	3.99
V	1	5.55	3.28
	2	6.75	5.52
	3	6.59	5.95
VI	1	7.5	6.57
	2	8.1	7.21
	3	9.0	8.21
VII	1	9.0	8.3
	2	9.0	8.57
	3	9.0	8.84
VIII	1	9.0	8.33
	2	8.85	6.86
	3	7.9	6.63
IX	1	6.6	4.0
	2	3.45	2.1
	3	3.6	1.84
X	1	3.45	1.8
	2	3.15	2.18
	3	2.86	1.72
XI	1	3.0	1.65
	2	3.3	1.05
	3	3.0	0.7
XII	1	0.75	0.18
	2	1.5	0.33
	3	1.0	0.17

If we compare average ten-day discharges at the Bandykhan-I pumping station with discharges at the Akkapchigai canal end, where water comes by gravity from the Tupolang reservoir, then taking into account maximum discharges at the canal end of 8.5 m^3/s, it would be possible to pass discharge compensating the pumping station operation in March, May and from September to November. This takes into account the flow capacity of the canal, which does not work with a full load in spring and autumn.



____________ - maximum ten-day costs; __ __ __ __ __ - average ten-day expenses.

Fig. 8. Graph of maximum and average flow rates by decades for the Bandyhan-I pumping station.

Let's now consider the possibility of compensation for these discharges in the mentioned period at the expense of spring and autumn water accumulation in the reservoir in 30, 40, and 60 mln. m^3. Roughly, we will take canal efficiency in this period, taking into account comparatively small discharges passing through the canal, η=0.55. At that, we consider that accumulated water will be used first of all for increasing water availability of lands located in the end part of Akkapchigai and partial transfer of Kyzyryk steppe lands from machine irrigation to gravity irrigation. Having the average flow rate of the pumping station per month, the efficiency of the irrigation system, and the volume of accumulated water in the reservoir, we will determine the required volume of water to be passed through the canal by gravity instead of the water supplied by the pumping station from the ShMMK. These calculations are approximate for the time being since, in the future, it will be necessary to specify withdrawals in coordination with the water use plan and canal efficiency, which changes depending on the flow rate. The obtained data are given in Table 5. Compensation for pumping station expenses with water from the reservoir will be made in March and from September to November. In May, the own resources of the Tupolang river are enough to compensate for discharges because minimum discharges of the river at this time exceed water intake into the Tupolang river irrigation system by 37-63 m^3/s.

Table 5. Required volumes of water to compensate for the Bandyhan-I pumping station.

Indicators	Spring	Autumn		
	March	September	October	November
Average flow rate of pumping station I, m^3 /s	2.513	2.646	1.9	1.13
Required compensating flow, taking into account the efficiency of the irrigation network 0.55	4.57	4.81	3.45	2.05
Required volume of water from the reservoir under the pumping station shutdown, mln. m^3	12.24	12.46	9.24	5.31
Residual water volume for spring and autumn irrigation at W = 30 mln. m^3	17.76		2.99	
Possible irrigated area (ha) at irrigation rate «gross» 3600 mln. m^3	4933		830	
Same at W = 40 mln m^3	7711		3608	
Same at W = 60 mln m^3	13266		9164	

Thus, it follows from the table that water accumulation in the reservoir in winter and summer, already 30 mln m^3 allows compensating expenses of Bandyhan-I pumping station in March, September, October, and November at the expense of passing these expenses through Hazarbag canal to its end part. In addition, a certain volume of water remains depending on the filling stage (30, 40, and 60 million m^3), which will be used for irrigation of intermediate and winter crops in autumn, for irrigation of early crops in spring, and for watering. Roughly, considering the irrigation system's efficiency, the irrigation rate «gross» is taken 3600 m^3/ha. Following Table 5 possible irrigation area in the spring period will be 4930-13270 ha, and in autumn, from 830 to 9160 ha.

The maximum average flow rate, which in the specified period during the shutdown of the pumping station will be required to pass through the pressure pipeline and canal P-1, is about 6 m^3/s. Currently, a maximum flow of 1.5 m^3/s can pass through channel P-1. When dismantling the Bandyhan-II pumping station, the pressure pipeline should work as a siphon through which water flows by gravity. Further, it is necessary to calculate the maximum flow rate that the pipeline can pass. The water will flow from canal P-1 and the pipeline into the Bandyhan canal. For water to flow by gravity into Kyzyryk canal, the reverse slope should be replaced by a straight slope. At the creation of slope i=0.0001 from the end of Bandykhan canal to withdrawal to Kyziryk canal (length of the site 700 meters) at flow Q = 6 m^3/s dike building is not required, since channel filling, in this case, will be 1.5 meters, and the reserve in the dike will be equal to 1 meter.

4 Conclusions

Analysis of operation modes of the reservoir, Khazarbag and Tupolang-Karatag canals, pumping stations Bandyhan-II and Bandyhan-I, as well as flow mode of the Tupolang river for a multiyear period, and our approach to the problem of transferring part of the machine irrigation lands to gravity irrigation, which is necessary to consider the possibility of turning off each specific pumping station in connection with the current water situation at the site allow us to draw the following conclusions:

1. It is necessary to fill the reservoir not once a year, as at present, but twice: the first one in February, with discharging in March-April; the second one in July, with discharging in September-November. The main purpose of the reservoir in the nearest future should be to use it during the non-growing season.

2. Under double filling of the reservoir, it is recommended to switch off the Bandyhan-II pumping station because its average flow in March-April 0.02-0.4 m^3/s, in the vegetation period 0.1-0.6 m^3/s, in September-October 0.3-1.2 m^3/s can be compensated by water supply by gravity from Tupolang reservoir without reconstruction of Khazarbag canal.

Acknowledgments

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