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Analysis of pump stations operation mode and measures to improve them

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Abstract. This article presents the data analysis of pumping stations controlled by the Pumping Stations and Energy Departments (PS&ED) of the Republic of Karakalpakstan. Collected data was analyzed according to the number of pumping stations, the amount of water they released, water delivery capacity, annual electricity consumption, and other parameters. The results of the observations and the data compared across districts are presented in tables and graphs. In addition, further measures have been developed to ensure efficient and reliable operation of pumping stations.

1 Introduction

Most of the water management facilities operating in our country are managed by water management organizations under "The Ministry of Water Management". The water supply sources to these facilities are the Amudarya and Syrdarya transboundary rivers [1, 2]. Everyone knows there is a high demand for modern energy-saving pumping stations today. Moreover, it is no secret that most pumping stations in the Republic require major repairs. Several measures are being implemented in the Republic of Uzbekistan to ensure pumping stations' reliable and efficient operation [3]. In particular, it is an urgent issue to carry out monitoring work on the current state of pumping stations under the control of PS&ED of the Republic of Karakalpakstan and to develop the necessary plans [4, 17].

Background information: Pumping stations under the Ministry of Water Management are exploited by PS&ED under the Ministry of Water Management and Irrigation Systems Basin Departments (ISBD) of the Republic of Karakalpakstan [5].

Relevant data on pumping stations on account of PS&ED were collected, processed, and analyzed. As of January 1, 2019, Karakalpakstan has 220 pumping stations on account of PS&ED [6].

Water resources are relatively unevenly distributed throughout the territory of the Republic of Uzbekistan, and the irrigated lands have a complex (low-high) relief. More than 55 percent of irrigated lands are supplied with water using 1,687 pumping stations at the expense of the Ministry of Water Management system organizations. The annual electricity consumption of these stations is 8 billion kWh on average [7, 8]

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It is a fact that 4153 irrigation wells are used in the Ministry of Water Resources system. Also, 172 reclamation pumping stations and 3897 vertical drainage wells are used to improve the reclamation of irrigated lands.[9]

Approximately 74% of 1,687 pumping stations on account of water management organizations have been in service for more than 30 years, 20% for 20 years, and 6% for more than 10 years. This means that 94% of pumping stations have exceeded their standard service life (16-18 years) and require modernization and replacement. More than 10 percent of the total 2,887 km of pressure pipelines require an urgent replacement. As a result, many accidents are observed during operation processes, and electricity consumption remains high. In addition, 93 reclamation pumping stations and 1,530 vertical drainage wells must be reconstructed and rebuilt [10].

2 Research methods

To determine the annual price of electricity consumption by pumps, the actual head H_i, flow rate Q_i and efficiency $\eta_{\text{н},i}$ of pump units in each water transfer period are taken from the characteristics of the pumps. Power of the pumping station for each t_i period is determined by the following formula (kW) [2]:

$$N_i = \frac{9.81 \cdot \sum Q_i H_i}{\eta_{\text{н},i} \eta_{\partial в,i}} \tag{1}$$

Where, $\eta_{\partial в,i}$ is efficiencies of electric motors in different water transfer periods; $\sum Q_i$ is the sum of water flow rates of working pump units in each t_i period, $(m^3/s.)$
The amount of electricity consumed during the year (kWh) is found as follows[11]:

$$\Sigma E = (N_1 t_1 + N_2 t_2 + \ldots + N_n t_n) \cdot 24 \tag{2}$$

Where, $N_1, N_2, \ldots, N_n$ are powers of the pumping station in different water transfer periods (kW); $t_1, t_2, \ldots, t_n$ are water transfer periods of the pumping station (days).
The annual cost of electricity consumption (soum):

$$C_{EN} = (\Sigma E + 0.02 \cdot \Sigma E) S$$

Where S is the price of 1 kWh of electricity, (*soum*); $0.02 \cdot E$ is the amount of electricity the station consumes for its own needs, kWh.
Amount of water released per hectare, (m^3/ha):

$$q = \frac{\Sigma W}{\omega}$$

where ω is the area attached to pumping stations (ha); ΣW is the total amount of released water (m^3).
The cost of 1 m^3 water pumping $(soum/m^3)$ [12]:

$$C_W = \frac{E}{\Sigma W}; \tag{5}$$

Where, E is annual costs of water pumping (soum); ΣW is the amount of water released during the year (m^3).

The amount of annual water transfer is determined by the following expression (m^3).

$$\Sigma W = (Q_1 t_1 + Q_2 t_2 + \ldots + Q_n t_n) \cdot 86400; \tag{6}$$

where, Q_1 $Q_2, \ldots Q_n$ are water transfers of the pumping station in different periods (m^3/s).
The cost for irrigation of one hectare of land (*soum/ha*):

$$C_{\varpi} = \frac{C}{\varpi} \tag{7}$$

where ϖ is the irrigated area (ha).
Expenditure on electricity at pumping stations about total exploitation costs, (*%*):[4]

$$K_N = \frac{K}{K_{exp}} \cdot 100$$

where, K is the sum of expenses spent on pumping station electricity, (soum); K_{exp} is total exploitation costs of the pumping station (soum).

3 Research results

3.1 The amount of water released through pumping stations of Karakalpakstan PS&ED during 2014-2019

According to the results of the analysis of the data obtained from *PS&ED* of Karakalpakstan, the volume of water released through pumping stations during 2014-2019 was the lowest (minimum) in 2014, with 2457.0 million m^3, and the highest (maximum) in 2018, with 3224.76 million m^3 (Fig. 1).

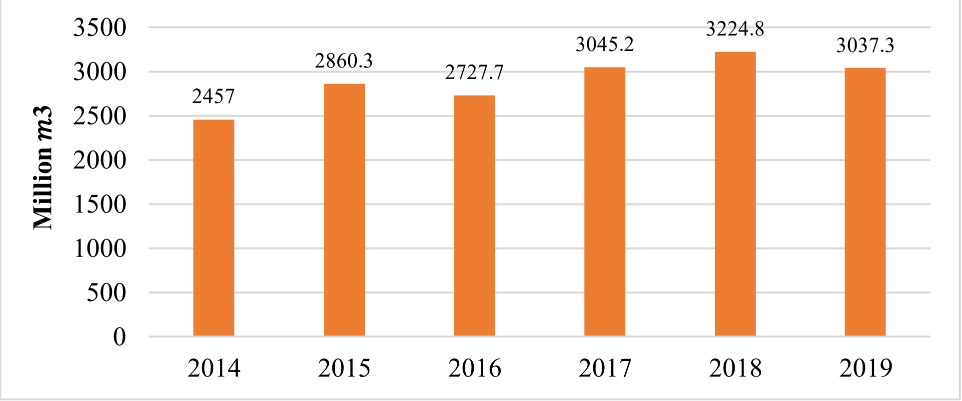

Fig. 1. Released water volume by pumping stations of PS&ED of Karakalpakstan during 2014-2019

In 2014, the total volume of water used for irrigation was 6115.74 million m^3. From this, the volume of water released through pumping stations was 2457.0 million m^3 (Table 1), which was 40.2 percent of the total volume of water used for irrigation.

In 2018, the total volume and pumping stations portion was 4615.40 and 3224.76 (69.8 percent of the total) million m^3 respectively

Table 1. The volume of water released by pumping stations of *PS&ED* of Karakalpakstan during 2014-2019

№	**Districts of pumping stations**	**Total released water (million m^3)**					
		2014	**2015**	**2016**	**2017**	**2018**	**2019**
1	Xojeli district	293.7	341.5	354.5	377.2	347.8	356.8
2	Taqiyatas district	199.2	179.3	131.1	118.3	147.2	138.2
3	Qanlikól district	215.3	324.2	261.1	287.5	274.4	330.6
4	Shomanay district	134.0	117.2	112.9	108.8	93.6	111.8
5	Qońirat district	75.5	90.0	69.0	99.6	82.4	109.0
6	Moynaq district	64.9	58.4	93.7	87.4	82.6	96.2
7	Nókis district	160.2	153.7	189.1	198.4	207.9	200.2
8	Kegeyli district	335.6	386.0	300.4	360.4	325.4	270.6
9	Bozataw district	20.5	18.3	29.1	22.2	41.2	42.5
10	Shimbay district	57.1	57.6	68.0	71.9	79.4	65.3
11	Taxtakópir district	66.6	103.3	147.4	167.7	202.8	69.4
12	Qaraózek district	194.1	258.7	183.9	227.4	215.0	246.8
13	Ámudárya district	640.4	771.8	787.3	918.4	1125.1	999.8
Total:		**2457.0**	**2860.3**	**2727.7**	**3045.2**	**3224.8**	**3037.3**

The largest part of the volume of water released during 2014-2019 through pumping stations corresponds to the Amudarya district. The lowest volume was 640.4 million m^3 in 2014, and the highest volume was 1125.1 million m^3 in 2018 (Fig. 2).

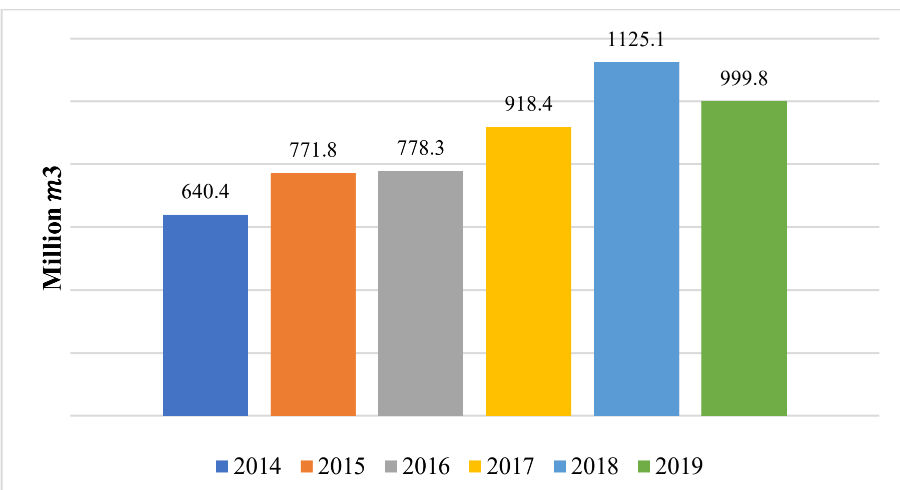

Fig. 2. Amount of water released by pumping stations in Amudarya district in 2014-2019

Table 2. The amount of electricity consumed by pumping stations at the expense of *PS&ED* of Karakalpakstan in 2014-2019

№	Districts of pumping stations	Total consumed electricity (million kWh)					
		2014	2015	2016	2017	2018	2019
1	Xojeli district	8.31	12.31	12.23	11.89	12.66	12.76
2	Taqiyatas district	5.68	7.19	5.11	4.09	5.58	5.40
3	Qanlikól district	7.01	9.25	7.66	9.18	9.23	9.10
4	Shomanay district	5.07	2.89	3.25	3.52	3.35	3.56
5	Qońirat district	2.88	2.75	3.06	3.29	2.66	3.77
6	Moynaq district	2.36	2.32	1.64	2.78	2.79	3.36
7	Nókis district	6.09	5.45	5.48	6.32	6.94	5.79
8	Kegeyli district	14.98	14.97	10.05	11.63	11.21	9.71
9	Bozataw district	0.79	0.82	1.65	0.79	1.86	1.81
10	Shimbay district	2.19	2.78	2.10	2.25	2.81	2.27
11	Taxtakópir district	2.84	4.79	6.78	5.48	6.43	3.41
12	Qaraózek district	9.93	10.53	6.41	7.19	6.61	7.34
13	Ámudárya district	23.15	28.51	30.89	29.19	32.59	31.27
	Total:	**91.27**	**104.54**	**96.32**	**97.59**	**104.70**	**99.53**

Amudarya district accounted for most of the electricity used by pumping stations between 2014 and 2019. The minimum quantity of electricity utilized in 2014 with 23.15 million kWh. In 2018, 32.59 million kWh of electricity consumption was recorded, which is the maximum value in years (Fig. 3).

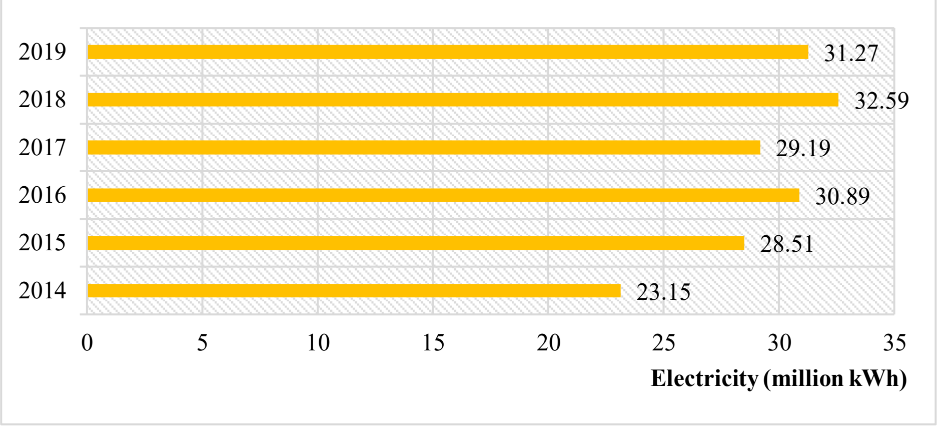

Fig. 3. Amount of electricity consumed by pumping stations in Amudarya district in 2014-2019

3.2 Electricity consumption of all pumping stations at expense of PS&ED of Karakalpakstan in 2014-2019

The results of the analysis of the data obtained from PS&ED of Karakalpakstan show that the lowest amount of annual electricity consumption of pumping stations in 2014 was 91.27 million kWh. Still, in 2015 and 2018, electricity was consumed relatively higher than in other years, which were 104.5 and 104.7 million kWh respectively (Fig. 4). This amount can be explained with pumped water volume were higher in those years. For example, in 2018, pumping stations released water 23.8 percent more than in 2014

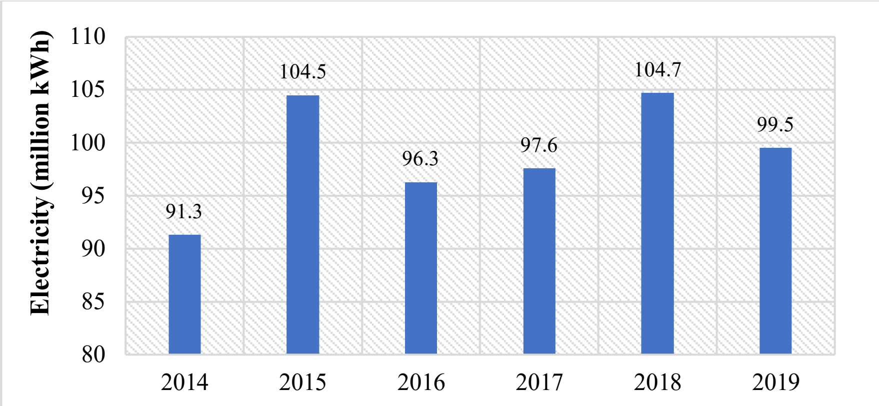

Fig. 4. Electricity consumption of all pumping stations at expense of PS&ED of Karakalpakstan in 2014-2019

Also, the pumping stations at the expense of PS&ED of Karakalpakstan have been in service for a long time (more than 30 years), or the pumping stations have passed the normative service life (16-18 years). Their modernization and replacement are required, especially the replacement of pressure pipes need an urgent replacement. Because of these old, outdated parts, the station still consumes high electricity.
Therefore, it is necessary to modernize all pumping stations step-by-step, including replacing outdated pumps, electric motors, and transformers and their control systems with energy-efficient equipment. Moreover, introducing alternative energy sources like solar batteries, wind turbines for supplying energy to pumps, and replacing high-resistant pressure pipes with more efficient and smooth ones are good solutions for electricity saving.

3.3 Amount of water released per hectare by pumping stations

The volume of water released through pumping stations per hectare of the irrigated area was given in Figure 5 with a thousand m^3/ha.

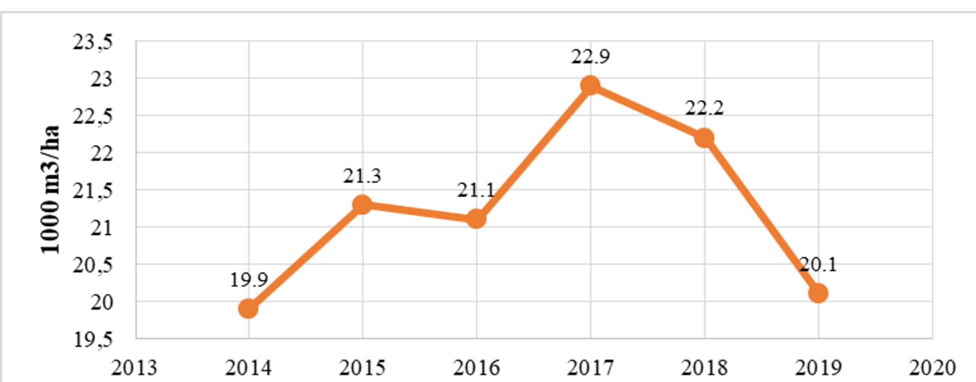

Fig. 5. Volume of water released to 1 hectare of irrigated area through pumping stations

The results of the analysis show that the amount of water released to 1 hectare of irrigated area through the pumping stations is at a high level and corresponds to an average of 21.25

thousand m^3/ha during the years 2014-2019. In particular, this indicator was the highest in 2017 and 2018 and was 22.9 thousand m^3/ha and 22.2 thousand m^3/ha, respectively.
One of the reasons for the high amount of water released for 1 hectare of irrigated area may be that the amount (m^2) of irrigated areas connected to the pumping stations are incorrect, so it is necessary to review and clarify these indicators by measuring selected areas together with the responsible personnel of the relevant pumping stations [15].

3.4 The cost of pumping 1 m^3 of water through pumping stations

Figure 6 provides the number of expenses spent on pumping out 1 m^3 of water by pumping stations from 2014 to 2019.

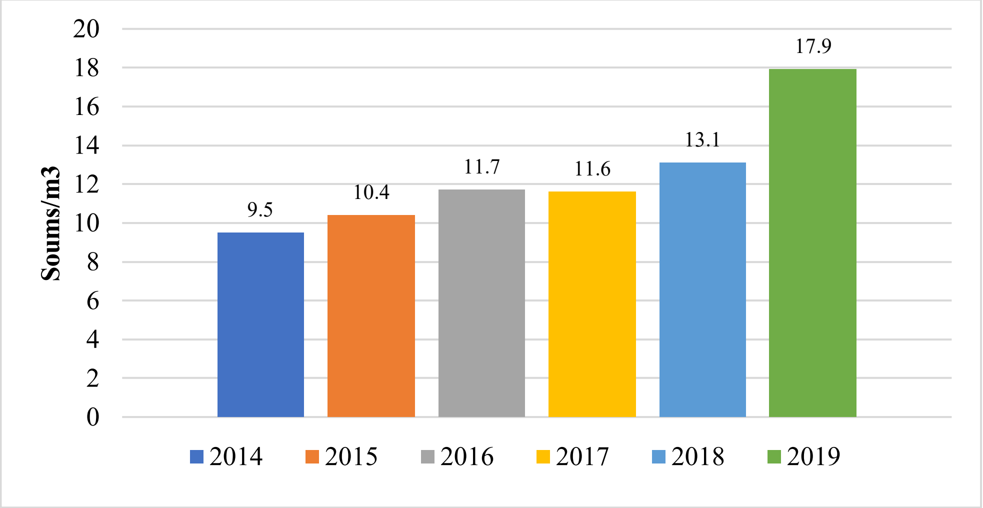

Fig. 6. Costs of pumping 1m^3 of water through pumping stations for selected period.

It is clear from the figure that the cost of pumping 1 m^3 of water through pumping stations was at the highest level in 2019 and increased by 11% compared to 2014. It should be noted here that from 2014 to 2019, this indicator has an increasing trend, which can be explained by the aging of pump units, electric motors, transformers, and pressure pipes, as well as the year-by-year increase in electricity tariffs.

3.5 The cost to irrigate 1 hectare of land through pumping stations

The cost of irrigating 1 hectare through pumping stations was 199.04 thousand soums/ha in 2014, 229.67 thousand soums/ha in 2015, 245.31 thousand soums/ha in 2016, 274.37 thousand soums/ha in 2017, 325.40 thousand soums/ha in 2018 and 413.9 thousand soums/ha in 2019 (Figure 7).

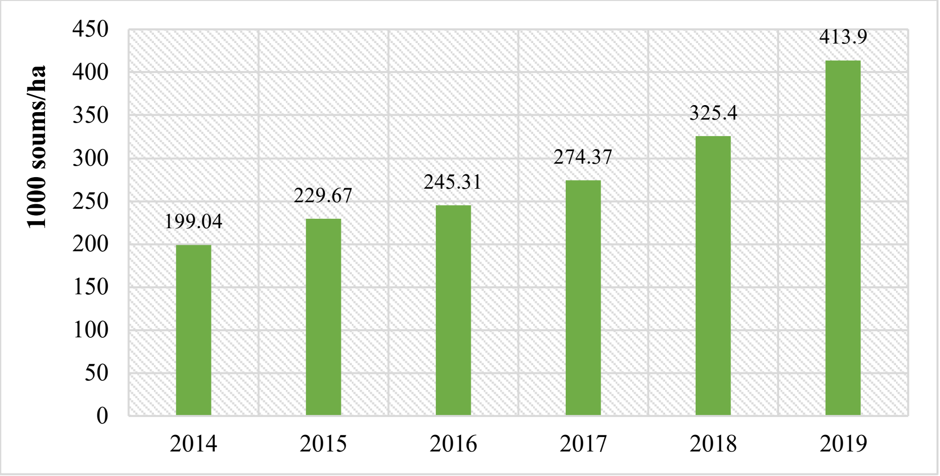

Fig. 7. Costs spent on irrigation of 1 hectare through pumping stations

The analysis results show that the cost of irrigating 1 hectare through pumping stations has increased yearly, and in 2019 compared to 2014, it increased by 52%.

3.6 Share of electricity costs in pumping stations compared to total operating costs

The diagram below shows the share of electricity costs at pumping stations concerning total exploitation costs in percent. (Figure 8).

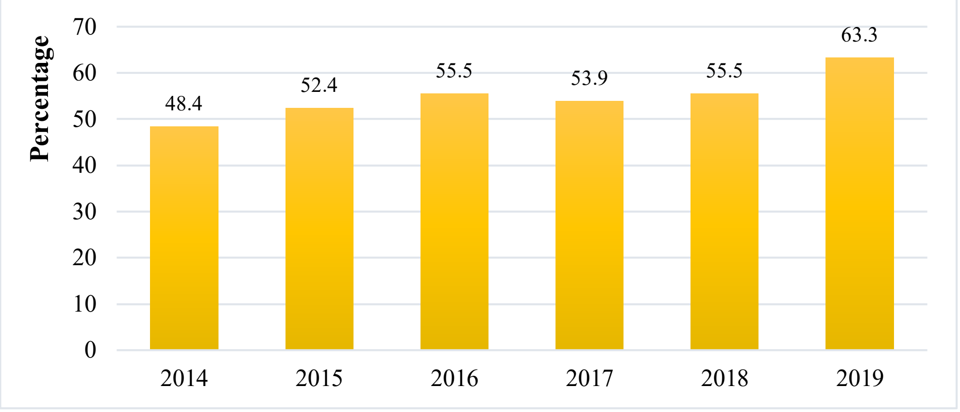

Fig. 8. Share of electricity costs at pumping stations about total operating costs

According to the analysis's findings, the annual power expenditures at pumping stations as a percentage of all operational costs were greatest in 2019 at 63.3 percent, with values of this indicator changing from 48.4 percent to 55.5 percent between 2014 and 2018.

4 Conclusions

If we look at the work done on the pumping stations in the last 5 years, no work was done on construction and reconstruction, repair, and restoration, but only funds were spent on the operating costs of the pumping stations.

To achieve economic and social efficiency, it is necessary to update and modernize the techniques and technologies used in production to rebuild and reconstruct the objects and the buildings where the object is located. Also, it is important to ensure that production objects are completely repaired every 5 years based on water consumption. Attracting qualified and experienced personnel to production, providing a comfortable environment for specialists to work, and organizing training courses to improve skills and experience is also relevant[16].

To satisfy the demand of consumers for water supply, to improve the quality of water supply, to increase the efficiency of pumping stations, and to reduce the cost of electricity, it is necessary to carry out the following works.

- modernization and reconstruction of the pumping station, renewal of all pumping station aggregates. For example, upgrading pumps and electric motors and installing solar batteries;

- to carry out complete repair work on existing equipment and technologists for systematic repair and restoration works every 5 years, to develop a repair schedule for complete repair;

- attracting mature qualified personnel to the operation process, fully studying the production technology, and identifying and eliminating deficiencies. Paying employees on time and providing favorable conditions for their work. Production implementation fully complies with technical and technological safety and fire safety rules. To study how to save electricity, apply it to production, and provide incentives for employees at the expense of saved electricity funds. Introduction to the production of new modern devices.[19], [20]

In conclusion, if the measures mentioned above are carried out in a timely and effective manner, the safe and reliable operation of pumping stations will be ensured, and their service life will be extended.

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