Technical and economic indicators of reconstructed irrigation pumping stations

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Technical and Economic Indicators of Reconstructed Irrigation Pumping Stations

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Abstract. The analysis of the reconstructed pumping stations showed that most of the reconstructed pumping stations, despite their specific features (commercial operation year, different sources of water intake, differences in the designs of hydraulic structures, connection schemes of pumping units and pressure communications), have a fairly standard set of reconstruction works: the main hydraulic structures of irrigation pumping stations are in more or less satisfactory condition, need partial restoration (replacement), and the equipment needs a complete replacement, modernization. This allows us to conclude the existing dependence of pumping stations' technical and economic indicators. The statistical analysis carried out using applied computer programs allowed us to choose the type and empirical coefficients in the analytical dependences of cost indicators on the pumping station's power and flow/head. The analysis and comparison of dependencies showed that the best convergence is observed for the formula $K = 14 \cdot N^{0.64}$. This formula can be used when selecting priority objects for reconstruction.

INTRODUCTION

One of the priority directions for improving the efficiency of the machine water supply is the reconstruction of irrigation pumping stations [1-4]. The basis of the machine water supply in our Republic is irrigation pumping stations, with the help of which more than 50% of the irrigated lands are irrigated. Since the vast majority of operated pumping stations are now physically and morally outdated, large-scale reconstruction (rehabilitation) and modernization of irrigation pumping stations are being carried out in the Republic [5-9].

When designing reconstructed irrigation pumping stations, it is necessary to consider the peculiarities of design work on reconstruction from the design of a new station [4, 7, 10]. The work on the reconstruction (technical renewal and modernization) of pumping stations requires a reliable feasibility study[11-15]. The assessment of the effectiveness of the reconstruction of pumping stations is complicated by their uniqueness, as well as the fact that they mostly work as part of the water management complex (and, of course, it is difficult to determine their economic effect and not the entire complex as a whole) [4, 6, 13].

The purpose of the research is to analyze the materials on the reconstructed pumping stations to identify the features (differences) of design work during reconstruction and select the type and empirical coefficients in the analytical dependencies of the cost indicators of the reconstructed pumping stations on its parameters. The materials of the design institute "Uzgip" on the reconstructed pumping stations of the Republic of Uzbekistan and the materials of the "Water energy Use and pumping stations" Department of the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers (TIIAME) were used for the analysis. [16-18]

Design work on the reconstruction of the pumping station is a difficult task. The choice of priority pumping stations for reconstruction is particularly difficult. When choosing, first of all, it is necessary to consider the results of the inspection of the pumping station (i.e. the technical condition), data on operational reliability indicators for past periods, etc.[16-20]. But the technical condition of pumping stations is not always in the limit (emergency) state [3,21]. Therefore, to solve this problem, it is necessary to calculate the preliminary cost indicators of the reconstruction of each station separately [22-24]. Knowing these data, it is possible to determine the economic

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efficiency of the reconstruction of a particular pumping station and, based on them, make a choice of priority objects for reconstruction.

The cost indicators for the reconstruction of pumping stations depend on the purpose of the pumping station, the type of installed main equipment, the composition and layout of structures [14, 16, 17, 20, 25, 26, 27]. The cost indicators for the reconstruction of pumping stations depend on the purpose of the pumping station, the type of installed main equipment, the composition and layout of structures. The vast majority of irrigation pumping stations (more than 70%) are equipped with pumps of the "D" type and have a semi-buried (chamber) type of building [6, 7, 17]. All the reconstructed pumping stations considered in the article are of this type.

METHODS

Employees of the TIIAME Department "Using Water Energy" T.A. Kolpaykova and K.V. Stupakov, at one time, a formula was proposed to determine the cost of new pumping stations on the integrated indicators derived based on projects 10 pumping stations [25]:

$$K = a \cdot N \tag{1}$$

Where a is the cost of 1 kW of installed power, for the calculation of which the dependence is proposed:

$$a = AQ^{\alpha} H^{\beta} \tag{2}$$

where A is some constant coefficient, Q is pumping station supply (flow rate), m^3/s; H is the design head, in m.

The empirical coefficients were determined by statistical methods:

$$a = \frac{4200}{Q^{0.26} H^{0.28}} \tag{3}$$

This formula was proposed to determine the estimated cost of one kilowatt pumping station power when drawing up prospective and design tasks. The projects under consideration were developed more or less at the same level of technology and prices of that period.

We needed to find an analytical relationship to determine the cost indicators of not newly designed but reconstructed pumping stations. For this purpose, 20 irrigation pumping stations of the same type were selected with different technical and operational indicators (pressure, supply, power).

As a working hypothesis, it is assumed that there is a relationship between the cost value and the pumping station's main parameters: power, pressure, and flow.

Two options were considered:

1. The relationship between capital investments during reconstruction and the capacity of the reconstructed pumping station (dependencies of the form $K = A \cdot N^{a}, K = A \cdot lnN + B,\ K = A \cdot e^{ßN}$);

2. The relationship between capital investments and parameters: pressure and flow (dependency of the form: $K = A \cdot Q^{\alpha} \cdot H^{\beta}$).

To determine the analytical dependence and coefficients type, statistical methods were used to construct the transformation and estimate the pair dependencies from experimental data. Statistical data processing was carried out using the Microsoft Excel program and "STADIA 8.0" on a computer.

RESULTS AND DISCUSSIONS

To find the relationship between capital investments during reconstruction and the capacity of the reconstructed pumping station, the following were considered:

a) Exponential dependence

$$y = ae^{bx} \tag{4}$$

where a and b are the calculated coefficients, e is the base of the natural logarithm.

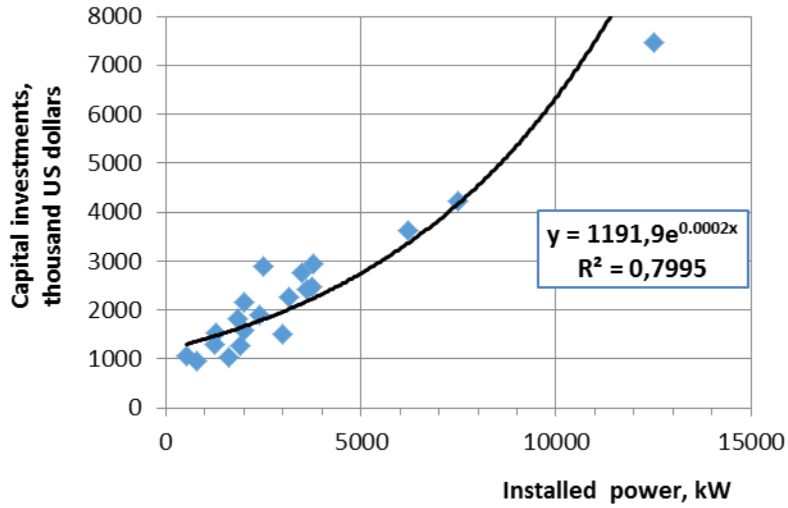

FIGURE 1. Graph, equation, and confidence value of the approximation of an exponential function

b) Logarithmic dependence

$$y = a\ln x + b \tag{5}$$

where *ln* is a function of the natural logarithm.

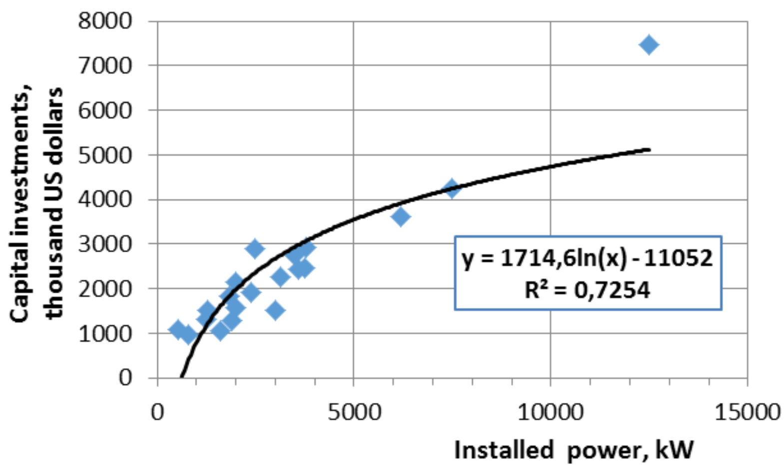

FIGURE 2. Graph, equation and confidence value of the approximation of the logarithmic function

c) Power dependence

$$y = ax^b \tag{6}$$

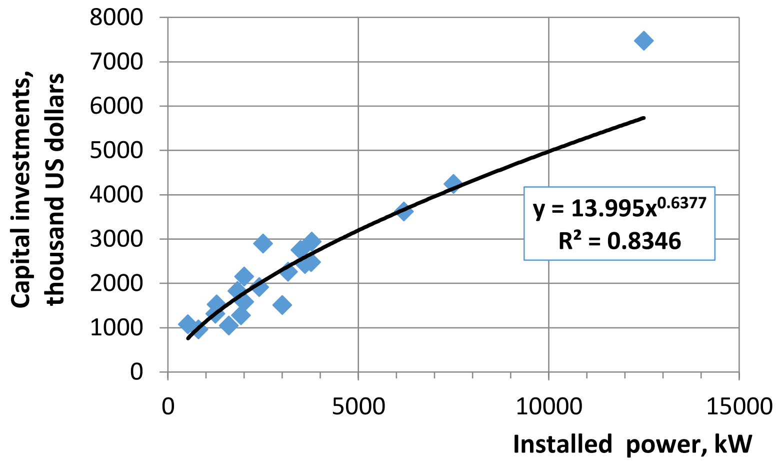

FIGURE 3. Graph, equation and confidence value of the approximation of the power function

Graphs of exponential, logarithmic and power functions obtained based on statistical data processing for 20 reconstructed pumping stations are shown in Figures 1, 2 and 3. The data and results of the statistical calculation are presented in Table 1.

TABLE 1. Data and results of statistical calculation

№	Name of the pumping station	Number of units	Power, kW	Capital investments, thousand US dollars	Calculated by the formula	Deviation in %
1	Asaka-Adyr	5	12500	7472	5863.412	-22
2	Suprotosh-1	5	3150	2258.54	2426.872	7
3	Suprotosh-2	7	3480	2750.276	2586.656	-6
4	Ukraine-1	4	2400	1910.298	2039.216	6
5	Ukraine-2	3	3000	1506.973	2252.262	33
6	Cuttackum-2	7	3780	2936.662	2727.236	-7
7	Navbahor	5	3000	3614.832	3743.335	3
8	Uzumzor-1	4	1600	1046.856	1573.131	33
9	Uzumzor-2	5	1250	1308.961	1343.23	3
10	Shredder	4	1280	1522.17	1363.774	-10
11	0-picket	7	525	1073.664	770.9567	-28
12	Buston	5	3600	2432.847	2643.392	8
13	Buston-2	5	1830	1824.598	1714.339	-6
14	Huzhamulki	5	800	958.914	1009.498	5
15	Berdali	4	2000	1579	1814.626	13
16	Pistoly	4	3760	2472.735	2717.993	9
17	Guvalak	5	2500	2892.345	2093.195	-28
18	Karabog-2	3	1915	1272.692	1764.884	28
19	Karabog-3	4	2000	2147.716	1814.626	-16
20	Yangikent	6	7500	4236.17	4228.314	0

TABLE 2. Data for statistical calculation

№	Name of the pumping station	Flow rate, m^3/s	Pressure, m	Capital investments, thousand US dollars	X_1=ln(Q)	X_1=ln(H)	Y=ln(K)
1	Asaka-Adyr	3.2	180	7472	1.163151	5.192957	8.918918
2	Suprotosh-1	3.6	67	2258.54	1.280934	4.204693	7.722474
3	Suprotosh -2	2.3	88	2750.276	0.832909	4.477337	7.919457
4	Ukraine-1	2.95	60	1910.298	1.081805	4.094345	7.555015
5	Ukraine-2	2.79	70	1506.973	1.026042	4.248495	7.317858
6	Cuttackum-2	7	35	2936.662	1.94591	3.555348	7.985029
7	Navbahor	3.3	48	3614.832	1.193922	3.871201	8.192801
8	Uzumzor-1	2.3	32	1046.856	0.832909	3.465736	6.953547
9	Uzumzor -2	1.6	37	1308.961	0.470004	3.610918	7.176989
10	Shredder	2.4	32	1522.17	0.875469	3.465736	7.327892
11	0-picket	3.5	9	1073.664	1.252763	2.197225	6.978832
12	Buston	2.3	83	2432.847	0.832909	4.418841	7.796817
13	Buston-2	3.36	54	1824.598	1.211941	3.988984	7.509115
14	Huzhamulki	2.3	24	958.914	0.832909	3.178054	6.865801
15	Berdali	3.2	39.54	1579	1.163151	3.677313	7.364547
16	Pistoly	9.4	13.4	2472.735	2.24071	2.595255	7.81308
17	Guvalak	4.85	30	2892.345	1.578979	3.401197	7.969823
18	Karabog-2	2.4	36	1272.692	0.875469	3.583519	7.14889
19	Karabog-3	3.72	40	2147.716	1.313724	3.688879	7.67216
20	Yangikent	7.5	65	4236.17	2.014903	4.174387	8.351415

The analysis of the obtained dependencies (Fig.1-3) shows that the power function has the greatest confidence in the approximation. Therefore, we will accept it as the desired dependency:

$$Y = 13.99x^{0.637} \tag{7}$$

Then the expression of the analytical dependence of the cost of capital investments will take the final form:

$$K = 14N^{0.64} \tag{8}$$

Moreover, the empirical coefficient K varies in the range from 9 (pumping station "Ukraine-2") to 19 (pumping station "0 - picket").

The error can reach 33 % (pumping station Ukraine-2). This is explained by the small number of units (3 pcs.), and, accordingly, their lower cost and the cost of dismantling and installing them at the same installed capacity than with a larger number of units.

The 2nd case.

It is assumed that there is a relationship between capital investments and parameters: pressure and flow of the type:

$$K = A \cdot Q^{\alpha} \cdot H^{\beta} \tag{9}$$

After the logarithm of expression (9), we get:

$$Ln(K) = Ln(A) + \alpha \cdot Ln(Q) + \beta \cdot Ln(H) \tag{10}$$

Let's introduce the notation: $Y = ln(K)$; $a = ln(A)$; $X_1 = ln(Q)$; $X_2 = ln(H)$.

Then equation (11) will take the following form:

$$Y = a + \alpha \cdot X_1 + \beta \cdot X_2 \quad (11)$$

To find the values of the coefficients in equation (11), we use the methods of linear multiple regression analysis. Since in this case there are two factors (X_1 and X_2). The task of multiple regression analysis is to construct such a plane equation in a three-dimensional (for our case) space, the deviations of the data from which would be minimal.

To calculate the values of the coefficients, it is necessary to find the partial derivatives for all the unknowns a, α and β and equate them to zero in the expression obtained from the minimum squared deviation condition:

$$\sum_{i=1}^{n}\left(y_i - \hat{y}_i)\right)^2 = \sum_{i=1}^{n}\left[y_i - (a + \alpha * X_1 + \beta * X_2)\right]^2 \quad (12)$$

$\hat{y}_i$ is calculated, predicted, aligned values of the studied characteristic.

The program" STADIA 8.0" was used to find the coefficients. The calculation results are shown in Fig. 4 and Table 3: a=4.52, α= 0.7592, β= 0.5843.

TABLE 3. Results of statistical calculation

№	**Name of the pumping station**	**Capital investments, thousand US dollars**	**Calculated by the formula**	**Deviation in %**
1	Asaka-Adyr	7472	4526,472	39
2	Suprotosh-1	2258.54	2790,623	-19
3	Suprotosh -2	2750.276	2325,417	15
4	Ukraine-1	1910.298	2249,988	-15
5	Ukraine-2	1506.973	2358,326	-36
6	Cuttackum-2	2936.662	3174,109	-7
7	Navbahor	3614.832	2152,674	40
8	Uzumzor-1	1046.856	1293,266	-19
9	Uzumzor -2	1308.961	1067,766	18
10	Shredder	1522.17	1335,781	12
11	0-picket	1073.664	852,5899	21
12	Buston	2432.847	2247,845	8
13	Buston-2	1824.598	2336,652	-22
14	Huzhamulki	958.914	1094,519	-12
15	Berdali	1579	1879,244	-16
16	Pistoly	2472.735	2275,547	8
17	Guvalak	2892.345	2196,251	24
18	Karabog-2	1272.692	1430,223	-11
19	Karabog-3	2147.716	2121,267	1
20	Yangikent	4236.17	4789,874	-12
	Arithmetic mean error			17
	Root-mean-square error			20.61

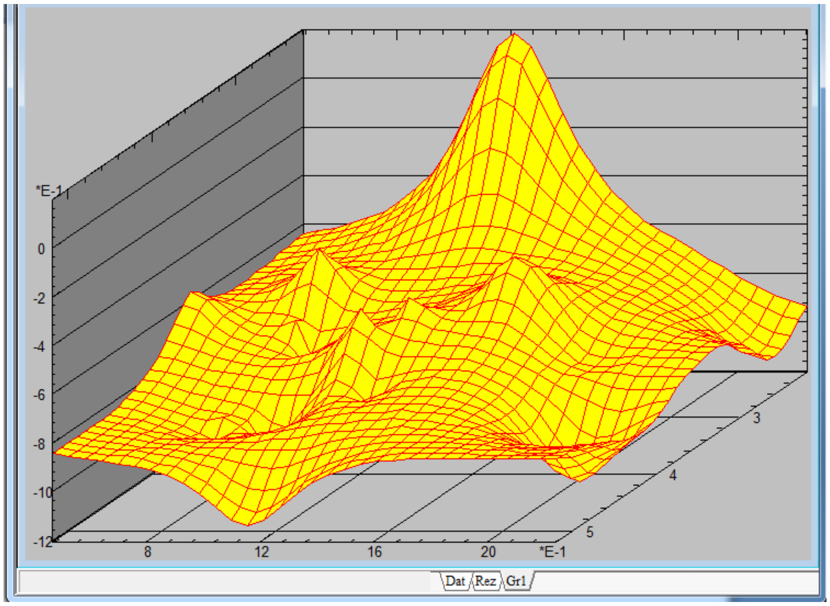

FIGURE 4. Results of statistical processing according to the program " STADIA 8.0"

Equation (12) takes the form:

$$Y = 4.52 + 0.7592\, X_1 + 0.5843 X_2 \tag{13}$$

Equation (14) is reduced to the original form, taking into account the obtained values *a=4.52*, *α= 0.7592*, *β= 0.5843*:

$$\ln(K) = \ln(4.52) + 0.7592 \ln(Q) + 0.5843 \ln(H),$$

$$K = 92 Q^{0.76} H^{0.58} \tag{14}$$

Comparing the obtained dependencies (8) and (14), we see that the formula (8) shows the best correlation and convergence. This dependence can be recommended during the preliminary feasibility study of the reconstruction of pumping stations (choosing priority objects for reconstruction).

For this equation (8), the correlation coefficient estimating the closeness of the relationship between X and Y was also determined R_{xy}= 0.834. This indicates a good correlation relationship. However, the correlation coefficient, like any statistical value, characterizes the closeness of the relationship only approximately. Therefore, the numerical coefficient must be evaluated in terms of its significance. It is necessary to calculate the standard (quadratic) error S_r and the criterion of the significance of the correlation coefficient, and then compare it with the tabular one. The standard (quadratic) error S_r is calculated using the following formula:

$$S_r = \sqrt{\frac{1-R_{xy}^2}{n-2}} \tag{15}$$

Where R_{xy} is the correlation coefficient; n is the number of pairs of values for which the correlation coefficient is calculated;

For our case, we have:

$$S_r = \sqrt{\frac{1-0.834^2}{20-2}} = 0.1305$$

The criterion of the materiality of the correlation coefficient is calculated by the formula:

$$t_r = R_{xy}/S_r$$

$$t_r = 0.834/0.1305= 6.40$$

Comparison of the actual and theoretical (tabular) values of the materiality criteria of the correlation coefficient t with the number of degrees of freedom $v = n$-2 makes it possible to assess the materiality of R_{xy} at a particular level of significance. The tabular value of the Student's coefficient (for a = 0.05 and v =18) is equal to: t_{table} = 3.9216

Comparing t_r and t_{table}, we conclude that the correlation is significant ($t_r > t_{table}$). The chosen equation is adequate to the theoretical equation.

CONCLUSIONS

The vast majority of the Republic of Uzbekistan irrigation pumping stations are equipped with pumps of the "D" type and have a semi-buried (chamber) type of building. Such pumping stations are typified, and, generally, a standard volume of work is provided for during reconstruction.

As a result of the statistical analysis of the material for 20 pumping stations, analytical dependencies are proposed to determine the cost indicators of the reconstructed pumping stations. Analysis and comparison of the dependencies of the types $K = A \cdot N^a$, $K = A \cdot lnN + B$, $K = Ae^{ßN}$, $K = A \cdot Q^a \cdot H^ß$ showed that the best convergence is observed for the formula $K = 14 \cdot N^{0.64.}$ Deviations of the calculated values calculated according to the proposed formulas reach from 33 to -28 %. This formula can be proposed when choosing priority objects for reconstruction and their feasibility study.

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