Designing Decentralized Water and Electricity Supply System for Small Recreational Facilities in the South of Russia

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Abstract. The article tackles the issues of designing seasonal water and power supply systems for small recreational facilities in the south of Russia based on intelligent decision support systems. The paper proposes modular prefabricated shell water and power supply works (MPSW&PW) along with energy-efficient standalone water-treatment plants as the principal facilities compliant with the environmental and infrastructural requirements applied to specially protected areas and ensuring the least possible damage to the environment due to a maximum possible use of local construction materials characterized by impressive safety margins in highly seismic environments. The task of designing water and power supply systems requires the consideration of issues pertaining to the development of an intelligent GIS-based system for the selection of water intake sites that facilitate automation of data-processing systems using a priori scanning methods with a variable step and random directions. The paper duly addresses such issues and develops parameterized optimization algorithms for MPSW&PW shell facilities. It equally provides the substantiation of water-treatment plants intelligent design based on energy recovery reverse osmosis and nanofiltration plants that enhance the energy efficiency of such plants serving as the optimum solution for the decentralized water supply of small recreational facilities from renewable energy sources.

1. Substantiation of water supply systems for water and power supply of small recreational facilities in the Russian South

1.1. Design criteria for water and power supply systems of small recreational facilities

Utilization of the local waterpower potential is the optimum solution for ensuring water and power supply of remote seasonal recreational facilities compliant with the current environmental infrastructural requirements, particularly those applied to specially protected areas in the south of Russia, minimizing negative environmental impact [1,2].

The creation of decentralized water and power supply systems and reliable operation thereof require the application of biopositive shell structures made of composite materials making the maximum use of local construction materials characterized by impressive safety margins in highly seismic environments along with RES-based energy-efficient standalone water-treatment plants excluding chemical reagent treating methods.

1.2. Substantiation of modular prefabricated shell water and power supply works (MPSW&PW) for small recreational facilities

The modular prefabricated shell water and power supply works (MPSW&PW) complex consists of the following: surface water source controls; water intake facilities; pipe-lines, hydroelectric installations (turbines and pumps); water-treatment plants using recirculating or recycling water systems, energy recovery and off-line regeneration waste treatment and recycling characterized by modular design [2-4] (figure 1-3).
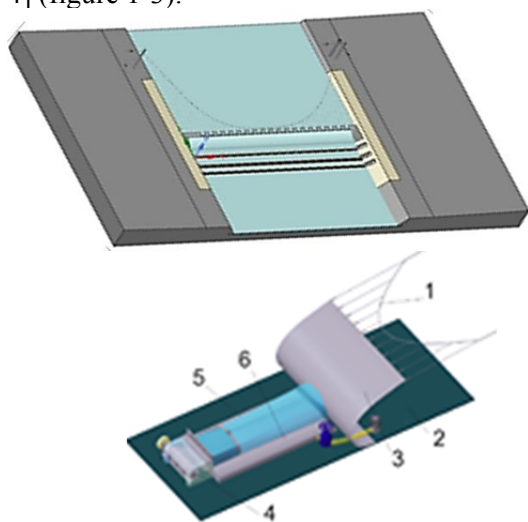

Figure 1. Water intake on the basis of a membrane-cable dam.

Figure 2. Mobile micro HPP (from 3 to 30 kW); 1 - cable system; 2 - flexible flood bed; 3 - water retaining shell; 4 - hydraulic unit; 5 - flexible sleeve.
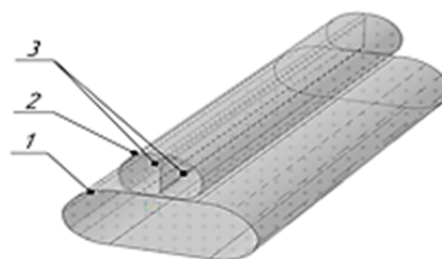

Figure 3. Pipeline-shell flexible pipeline with water-filled base: 1-inner shell; 2 – outer shell 3 – water-filled base.

An example of the mathematical modeling and the estimation were presented in the previous article [3].

Table 1. The main characteristics of the proposed facilities.

Parameters	Energy supply					
	5	10	15	25	50	100
Created water pressure, m	1-2	1-2	1-4	1-4	1-4	1-4
Flow intensity, m^2/s	0.03-0.06	0.04-0.07	0.03-0.08	0.04-0.09	0.08-0.14	0.15-0.30
Span in the water-way, m	5-10	5-20	10-20	10-30	10-40	10-40

1.3. Substantiation for the water supply schemes of small recreational facilities in the Russian South

Small recreational facilities in the south of Russia still lack proper water supply due to the shortage of water in the surface water sources and due to the salinity of artesian water treatment of which with chemical reagent treating methods is impracticable [1, 6].

The optimum solution for the surface water source water-level control in the protected areas is provided by seasonal water-treatment plants (fig. 1) based on membrane-cable dams and the installation of temporary pipelines made from composite materials installed on a water-filled or soil-reinforced base. Selecting the construction sites for the water intake facilities and pipelines is a challenging task for the decision maker (DM) limiting the application of such structures and potentially raising the design costs.

Saline artesian water for domestic purposes can be treated using reverse osmosis plants that may potentially be fully automated. Meanwhile, in the context of decentralized water and power supply,

energy consumption must be optimized to the maximum possible extent, which can be achieved through nanofiltration. The second advantage of nanofiltration as a water-treatment method consists in the full preservation of salts and minerals vital for the human body. Apart from using the renewable energy sources, another promising pathway consists in recovering the energy of the concentrate supplied under considerable pressure in the reverse osmosis plant. The existing software for nanomembrane technology estimation fails to factor in all the effects including those for an off-line operation [7].

2. Design engineering using intelligent decision support systems

To facilitate the task of designing MPSW&PW and develop the knowledge database, it is necessary to provide the knowledge database "open systems" with three access levels: expert – database editing and updating of production rules databases; Research Engineer – updating SM and empirical databases, general knowledge data-bases and background data for MMHEP standard components; designer – possibility of editing and adjusting the databases according to climatic conditions and geo-data systems.

As the intelligent ES knowledge database forms, it allows the DM to formulate preliminary requirements to justify the weight and salinity of the water-treatment facility site selection criteria and range parameters subject to the production rules that would reduce the likelihood of design errors.

It is equally important to develop an explanatory component of the intelligent ES which will increase the DM's performance and accelerate the decision-making process when designing MPSW&PW. Similar to the previous study, an MM with a systematic approach to create MPSW&PW is used. A systematic approach will integrate the simulation modeling (SM) results for MPSW&PW non-standard components through numerical methods prorated to the salience thereof into a single optimization model [8-22].

As the most part of a labor-consuming process consists in the selection of the water intake site depending on the hydraulic and hydrochemical data, the author has developed a program for GIS-based selection of the water intake site.

2.1. Water intake site selection program

The water intake site selection program (WISSP) consists of three intertwined components: extension subprogram (SP) (plug-in) for a Quantum GIS geo-data system; data-base; "Optimization" information processing SP. The extension SP has been developed to facilitate the determination of the climate and hydrology of the design area with the account of the optimized facilities' geography and topographic peculiarities. The subprogram has been created using the Python programming language. The necessary information is extracted through the analysis of multilayer vector maps in *.qgs format reflecting the peculiarities of topology and soils.

The database ensures the structuring, storage and accessibility of the input, interim and finalized data for the other components of the software package. I picked up dBASE IV data integrated in Borland Database Engine (BDE) as the database management system (DBMS). The data are physically stored in several *.dbf-format files corresponding to the group of data to be stored (site parameters, soil peculiarities, etc.).

The "Optimization" information processing program ensures access to the information stored in the database and the key optimization algorithms. The program has been created through object-oriented programming (OOP) in the Object Pascal (Delphi) programming language. The program uses the information obtained through extension SP as the input data. There are several output options: to the database, to a text file, to the computer screen [22].

When feeding the site position data, "MicroHPP" module is actuated to determine the position of the inmost depths line depending on the isoline levels and values, and to estimate the cross-section area and parameters of the hydraulic flow (of wet perimeter and hydraulic radius). Depending on the geotechnical conditions, this is followed by determining the roughness coefficients for the channel,

and subsequently for the flow rate of the estimated frequency and intake area followed by the estimation of the rate and slope.

The tab "Hydrology, river network, water-resource region code to be inserted, name of waterworks and tributaries" helps to confirm the data for the selected site in the context when hydrological data are available (figure 5).

The data to be fed include the distance from the river bed to the selected site, post type, class, group, subgroup, type and kind of the site along with the collection edge level, minimum and maximum depths, channel cross section area, channel surface width at the maximum and minimum rate, head, estimated frequency water flow rate, suspended sediment and bed-load discharge, minimum and maximum water temperature and wet perimeter [22-24].

2.2. Designing and optimizing the parameters of a derivational pipeline (PIPELINE) and membrane *cabling dam*

Let's take a look at the estimation procedure for a derivational pipeline optimization.

In determining the initial cross-section parameters of a single-shelled soft water pipeline which has support on a horizontal plane over all its length, we take into account only the internal hydrostatic pressure. The shape of its cross section is described by two Euler elastics - the upper and lower module elliptic integrals which are located in the following range. (Figure 3).

When defining shaping and stress-strain of the flexible derivative conduit, the following assumptions are considered: the shell is mounted on a hard, horizontal base which is inextensible, weightless and gets filled with incompressible fluid. Let's consider the design scheme for a water-filled soft shell (Figure 4).

Consider the basic elements of water retaining structures. For membrane-cable dams these elements include: drooping; anchor support; cable-stayed systems; water retaining shells and jacket; aprons (Figure 5) [9,10].
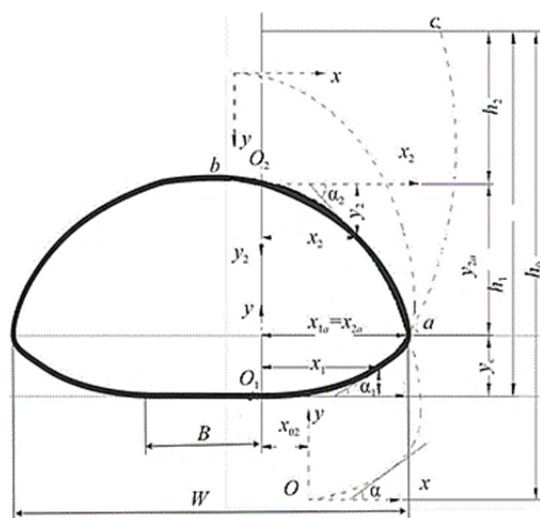

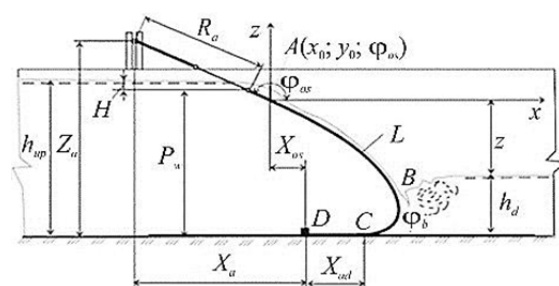**Figure 4.** Design scheme for a water-filled soft shell.

Figure 5. Design scheme for a membrane cabling dam (figure 1,2): 1 – drooping; 2 – bank anchor support; 3 – cable system; 4 – water-retaining shell; 5 – flexible apron.

We introduce the following denotations: W, B – the width of the shell and the adhesion of the shell to the base; p_b - the pressure at the base of the shell; L – the perimeter of the shell; the relative adhesion of the shell to the base and the width can be determined using the following formula: $b = B/L$; $w = W/L$

Tension per unit length in the shell is to be estimated, N/m [22-26]:

$$N(\varphi, L) = \rho \cdot g \cdot \sin^2(\varphi) \cdot L^2 / 16 \cdot \left[K(\varphi) - E(\varphi) \right]^2$$

where $K(\varphi); E(\varphi)$ – 1st and 2nd order elliptic integrals;

Pipeline base relative pressure is to be calculated:

$$p_b' = p_b / (\rho g L)$$

Relative adhesion of the shell is to be determined:

$$w(p_b') = (0{,}5 p_b' k^2 \left\{ 1 + k^2 \pi / 32 - \left[k^4 (3\pi - 10) \right] / 64 \right\} + b$$

where b is the relative adhesion of the shell.

Permanent ordinates of the pipeline surface are to be estimated:

$$y = h \left[1 - \sqrt{1 - k_1^2 \sin^2 \varphi} \right]$$

Determine the extreme coordinate or flex point for the pipeline cross section:

..;

$$x_{2a} = h_2 \left\{ \left(1 - k_2^2 / 2 \right) \left[E_1(\pi/2, k_2) - E_1(\varphi_{a2}, k_2) \right] - \left[E_2(\pi/2, k_2) - E_2(\varphi_{a2}, k_2) \right] \right\} / \sqrt{1 - k_2^2}.$$

In the invariant form, the MM of the membrane cable dam developed by the authors is expressed in the form of equations systems of the objective functions in the following form:

$$\begin{cases} h_{up} / L = f(\varphi_{os}; \varphi_b) \to \min; \\ C_c = f(N; L; B; R) \to \min; \\ N_C / B = f(R_C; f; N_C) \to \min. \end{cases} \tag{1}$$

where h_{up}/L – is the relative depth from the upstream to the shell perimeter L; N_C/B – is the ratio of the tension per unit length to overlap span; C_c – the relative cost of a membrane cable dam as compared to a concrete dam; R_C - the radius of the cabling system of the membrane-cable dam; φ_{os}, φ_b - the attachment angle and base for the open shell of the membrane-cable dam.

The perimeter of the shell is calculated, m:

$$L(\varphi_{os}, \varphi_b) = l_{AC}(\varphi_{os}, \varphi_b) + x_{fit}(\varphi_b)$$

• tension per unit length in the shell (taking into account the safety factor):

$$N_3(\varphi_{os}, \varphi_b) = k_3 \cdot N(\varphi_{os}, \varphi_b)$$

• shell cost from tension (piecewise constant approximation)

$$S_{0_{i,j}} = S(\varphi_{os.0_{i,j}}, \varphi_{b.0_{i,j}})$$

• tension per unit length in the shell (taking into account the spare coefficient):

$$N_3(\varphi_{os}, \varphi_b) = k_3 \times N(\varphi_{os}, \varphi_b)$$

• optimal value of tension per unit length in the shell (spare incl.):

$$N_{3.opt} = N_3(\varphi_{os.opt}, \varphi_{b.opt})$$

- optimal value of shell perimeter:

$$\text{L}_{opt} = \text{L}(\varphi_{os.opt}, \varphi_{b.opt})$$

- optimal value of the cost of the shell per square meter:

$$\text{S}_{opt} = \text{S}_{pul}(\varphi_{os.opt}, \varphi_{b.opt})$$

Next, data is assigned: coefficient of weight significance, α1 - coefficient of cost significance, α2. Further, the generalized target function is found based on dependence (1) [9]:

$$CF(\varphi_{os}, \varphi_b) = \alpha_1 \cdot \frac{P(\varphi_{os}, \varphi_b)}{P_{st}} + \alpha_2 \cdot \frac{S(\varphi_{os}, \varphi_b)}{S_{st}}$$

The estimation of the shell relative radius for the cross section:

$$R_a / L = \left\{ K(\varphi)\left(1 + \sin^2 \varphi\right) - 2E(\varphi) - 2\left[\left(1 - 0.5\sin^2 \varphi\right)F(\varphi, \pi/4) - E(\varphi, \pi/4)\right]\right\} / \left(1 - \cos\varphi\right)$$

where L is the shell perimeter and R_0 is the radius, respectively;

The above given estimation served as the basis for the creation of the shell pipeline and membrane-cable dam parameter optimization program that forms an integral part of MPSW&PW automated design software package [2,9].

3. Conclusion

1. The study has substantiated the need to optimize the automated design of MPSW&PW.
2. The study offers an optimization program for the selection of MPSW&PW water intake and derivational pipeline site.
3. Subsequently, dedicated software will be developed to estimate and select the nanofiltration-based water-treatment system design automation for small recreational facilities expanding the intelligent expert system (ES) database and optimizing the costs of the MPSW&PW design.

Acknowledgments

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