Geoinformation systems at the selection of engineering infrastructure of pumped storage hydropower for the tuyamuyun complex

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Abstract. In this article, we also consider the results of studying the problems and prospects of using information technologies to ensure the introduction of new innovative approaches to analyze engineering infrastructure of future pumped storage hydropower. This study aims to develop a series of advanced Geographic Information System algorithms to locate prospective sites for pumped storage hydropower. It is possible and useful to use the association of outputs from various scientific researches in one GIS-database as a universal tool for modelling. This demonstrates the site searching algorithms can work efficiently in the identification of off-river pumped hydro sites, allowing high-resolution assessments of pumped hydro energy storage to be quickly conducted on a broad scale. As an example of such an approach can be considered as one interconnected system which combination results of work:
- The examples of the methodology for creating digital maps for information support, for the study of the technical parameters of hydropower and irrigation facilities at the level of Tuyamuyun hydroelectric complex.
- System of digital maps and schemes that can be used in the development of environmentally acceptable modes of operation of in engineering infrastructure of hydraulic accumulating power plants.
- The results of monitoring engineering infrastructure using geographic information systems, digital maps are shown, which allow for the design, repair and repair of hydraulic structures to take into account terrain, hydrography and other factors. Except this in work are offered several objects water systems, in which will possible introduce pumped storage power and are motivated to their technical-economic parameters.

1. Introduction
In modern conditions of development of the energy sector, there are issues of increasing the reliability and operational controllability of electric power systems (EPS), taking into account the requirements and methods for storing the produced energy.

Pumped hydro energy storage (PHES) is capable of large-scale energy time shifting and a range of ancillary services such as frequency regulation, which can facilitate high levels of photovoltaics and wind integration in electricity systems. Developments of PHES began in the 1890s and surged through the 1960s, 70s and 80s in Europe, the United States and Japan where the rapid growth of nuclear energy and coal-fired units continued. These large thermal steam plants lack sufficient operational flexibility to accommodate changing demand and required the capability of load levelling. PHES was
also regarded as a more economical alternative to oil and natural gas-fired plants for peak shaving, especially during the post-periods of energy crisis in the 1970s [1-5].

Energy storage can provide system benefits and flexibility for consumers, managers of energy companies and utilities, and can also participate in a number of market segments, especially in electricity markets, operating both as a direct energy supplier for electric power plants and for individual consumers.

As you know, the daily unevenness of the load schedule, the presence of peaks and sharp decreases in the level of energy consumption create technical problems for energy producers related to the need to ensure that production and consumption of electricity are consistent, i.e. reduced electricity production during periods of low consumption.

This leads to three groups of problems: firstly, the efficiency of using the installed capacity of power equipment, which is the most important factor affecting its payback, is reduced; secondly, the frequent operation of power equipment in variable mode dramatically increases fuel consumption at thermal plants and leads to premature wear of equipment; thirdly, the technical ability to reduce the power of generating equipment is often insufficient to compensate for the reduction in consumption, in this case, excess electric power is transferred to other regions.

In the world practice of operating large power plants, the solution to the problem of uneven energy consumption is achieved either by creating special maneuverable power equipment (peak power plants, gas turbine power plants), or by using batteries that consume excess electricity during periods of a general decrease in load in the power plants and issue it during periods of increased consumption [7-10].

Numerous foreign studies prove that the use of maneuverable power plants operating in a variable load mode leads to a significant consumption of fuel, a decrease in the efficiency of using installed capacity, a decrease in the service life of equipment, and other negative consequences.

To solve this problem, manoeuvrings sources are required to make up about 25% of the total system power. As is known in Uzbekistan, the most promising maneuvering capacities are hydroelectric power plants; however, their share in the Republic is only about 13.3% [6].

The most promising way to solve this problem is the use of pumped storage power plants (PSP), which are both a highly maneuverable peak power source and a consumer-regulator. PSPs are the main type of storage systems, currently they account for 96% of the accumulated energy in the world [15-19]. The PSP consists of hydropower plants designed to generate electricity and pump water into the upper basin, which is storage of hydraulic energy. Often the volumes of the upper and lower basins in a fixed time do not correspond, since the time of the turbine operation does not coincide with the time of the pump mode.

Therefore, the growing interest is the development of another area of hydropower in the Republic of Uzbekistan - the design and construction of pumped storage power plants (PSP) [6, 11-14].

Due to the fact that in Uzbekistan there is a large water management complex, knowledge of the specifics of the formation of operating modes of hydropower plants and pumping stations, assessment of the hydraulic, hydrological and hydrochemical status at a given time is a very important component for planning future work. A dense network of canals requires systematic hydroecological and hydrotechnical monitoring [20-25], since it depends on the quantity and quality of water how hydroelectric power stations and pumping stations will work.

2. Purposes and research tasks
According to the conclusions of scientists, the potential of the PSP in the world is significantly higher than previously thought. Australian scientists have identified hundreds of thousands of land plots suitable for accommodating pumped storage power plants. Scientists at the Australian National University, using geoinformation technologies, have identified 530,000 places around the world that could become suitable sites for accommodating pumped storage power plants with a total capacity of 22 million gigawatt hours. “There is an opinion that all over the world there is a limited number of places for gas power plants, but we found hundreds of thousands,” the researchers note [15].
It is noteworthy that this is not about natural reservoirs, but about the so-called closed-circuit projects that have minimal impact on the environment.

The research methodology is published in the scientific journal Applied Energy [5, 15-16]. The geographic information system allowed the group to develop a cartographic tool, which, it is claimed, identifies ideal sites for the deployment of PSPs, requiring the smallest amount of earthwork. Information on each identified site includes data on the upper and lower reservoir plus a hypothetical tunnel route between the reservoirs, latitude, longitude, altitude, minimum altitude difference, slope, water volume, water area, rock volume, energy storage potential, and approximate relative costs and so forth.

This work is devoted to solving the following issues [20-25]:
1. Development and application of computerized databases, geographic information systems and integrated models for assessing the various possibilities of environmentally acceptable operating modes of hydropower plants and pumping stations.
2. The potential and ongoing use of models in the planning and management of water resources.

Given the favourable conditions in the area of the hydroelectric complex, a scheme for its conversion into a hydropower complex is proposed from risk management to sustainability management, the creation of decision support systems (Fig 1). The experience of using GIS technologies will be used in the development of criteria for the safe operation of hydraulic power stations, hydroelectric power stations, pumping stations, as well as the development of hydrometric support.

![Diagram](image)

**Figure 1.** Block – Hydroecological and hydrotechnical monitoring [25]:

The peculiarities of creating a PSP in our country are the relatively small potential of watercourses and their main task is water supply to agriculture. Consideration of the tasks of building a PSP taking into account the characteristics of watercourses in Uzbekistan is the goal of this work.

When substantiating the construction of a PSP in Uzbekistan, it is necessary first of all to study the water-energy potential of the country's watercourses and their location.

The analysis shows that in many energy-economic systems of the country, that is, existing facilities, there is a potential for producing clean electricity, including through the construction of a PSP [6]. The creation of a PSP would allow improving the operating modes of the energy-water system and at the same time take into account the needs of water-management systems and the operating modes of electric power systems operating in the daily, weekly and seasonal energy storage mode in order to increase the manoeuvrability of power supply.

At the same time, there are also opportunities to reduce investment in the construction of a PSP, for example, it is the construction of only one reservoir, and instead of the second, use a large river or canal. Another economical option is to use existing reservoirs. The shortage of water resources and
their water management in Uzbekistan and the region as a whole dictates that at the current stage of hydropower development, the development of hydropower resources must be carried out on seasonal seasonal inland streams, in reservoir systems and in hydraulic structures without prejudice to the interests of irrigation and water supply. This, as calculations show, significantly reduces capital investments for the development of hydropower resources and makes it possible to more fully use the potential of the accumulated volume of water [6, 14].

In the future, the electric power industry needs to be oriented towards a more economical use of fuel resources, especially gas, towards expanding the use of renewable natural energy resources, of which the republic’s hydropower resources are traditional.

At the same time, with the increase in the increase in the cost of peak electricity and the requirements for the quality and reliability of its supply, which inevitably leads to the real implementation of multi-tariff tariffs in the energy system, the efficiency of the PSP will increase.

So, as the unevenness of the daily load schedule increases, the wholesale market for power and electricity develops, differential tariffs are introduced and the gap between them increases, an economic basis appears for buying cheaper nightly electricity and accumulating it at the PSP for use during peak periods [11-14]. At the second stage of research, it is necessary to determine the possible places for creating a PSP and the modes of their operation in the power system.

In the general case, it is advisable to place the PSP in places with concentrated elevation differences and the possibility of creating reservoirs in the upper and lower pools, near a water source and a large hydroelectric station [6].

Let us consider the options for creating a PSP in the Tuyamuyun hydroelectric complex in the Khazarasp region of the Khorezm region. Tuyamuyun's hydroelectric facility is located on the border of the middle and lower reaches of the river. Amudarya in the Tuyamuyun gorge, 450 km from the Aral Sea, at the junction of the borders of the territory of the Karakalpak Republic, Bukhara region of the Republic of Uzbekistan and Chorzhou region of the Republic of Turkmenistan.

Tuyamuyun waterworks is located in the lower reaches of the river. Amudarya is a complex multicomponent irrigation facility, including an interconnected system of reservoirs and main canals, pumping stations for water supply and the operated Tuyamuyun hydroelectric station (Table 1, Fig. 2).

The main purpose of the waterworks is [26]:

- Providing seasonal regulation of river flow Amudarya in the interests of all water consumers of the lower reaches of the river, including the Takhiatash waterworks and delta;
- Ensuring guaranteed water intake into irrigation systems, as well as a significant reduction in sediment flow during water intake into the left-bank and right-bank main canals, taking water directly from the Tuyamuyun reservoir;
- Providing the necessary water passes for the Takhiatash hydroelectric complex;
- Creation of favourable conditions for combating the phenomena of "deigish" below the site of the waterworks;
- The connection of the two banks of the river. Amudarya by road and rail crossings;
- Use of a watercourse for energy purposes.
- The hydroelectric complex is a complex, comprising more than 30 major hydraulic structures, which are divided into 2 groups:
  - River hydroelectric facility with a river reservoir;
  - A complex of structures at the bulk reservoirs Sultansanjar, Koshbulak and Kaparas, under which natural gravity flows from the channel reservoir are used.

The presence of a river reservoir and 3 bulk reservoirs as a part of the hydraulic system allows:

- Putting reservoirs into operation in stages as water consumption increases;
- Ensure the supply of water to the main canals of the required condition by turbidity by mixing turbid river water with clarified water from bulk reservoirs.

The Tuyamuyun HPP of the channel type, with a design head of 16.4 m and a flow rate of Q = 6x190 m³/s, develops a power of N = 6x25 MW.
The reservoir system consists of the Channel and three bulk Kaparas, Sultansanjar and Koshbulak. A 21 km long gravity canal connecting Sultansanjar and Koshbulak bulk reservoirs is designed for a flow rate of 200 m$^3$ / s. The maximum pressure on the channel for energy use is 10 m. The difference on the right-bank main channel (PK 169) is 6.1 m, regardless of costs - it is approximately constant. The maximum monthly average flow rate is 76 m$^3$ / s. Irrigation releases are carried out from December to September.

The difference on the left-bank channel at PK 170 is 3.4 m, regardless of water flow. The maximum average monthly flow rate is 267 m$^3$ / s; in the irrigation mode it works from February to September. The clarified water channel is designed to pass 500 m$^3$ / s from the Sultansanjar bulk reservoir into the Amudarya river below the Tuyamuyun hydroelectric station. The length of the channel is 9 km, the width along the bottom is 41.5 m.

| Table 1. The main parameters and data of the Tuyamuyun hydroelectric complex. |
|---------------------------------|---------------------------------|-----------------|-----------------|-----------------|
| Indicators                      | Name of reservoirs              | total           |
|                                 | channel | Caparas | Sultansanjar | Koshbulak       |
| npu mark, m                    | 130,00  | 130,00  | 130,00        | 130,00          |
| umo mark, m                    | 120,00  | 120,00  | 116,00        | 120,00          |
| full capacity, km$^3$           | 2,34    | 0,96    | 2,69          | 1,81            | 7,80            |
| useful capacity, km$^3$         | 2,07    | 0,55    | 1,63          | 1,02            | 5,27            |
| dead volume, km$^3$             | 0,27    | 0,41    | 1,06          | 0,79            | 2,53            |
| mirror area at NRL mark, km$^2$| 303     | 70,1    | 149           | 128             | 650,1           |
| mirror area at LDV mark, km$^2$| 87,0    | 43,5    | 86            | 78,5            | 295             |
| length, km                     | 102,0   | 15,0    | 24,0          | 26,0            | 169             |
| width                          | max., km| 11,0    | 9,0           | 12,0            | 11,0            |
|                               | average., km| 4,0   | 4,0           | 8,0             | 6,0             |
| depth                          | max., m | 20,0    | 36,0          | 38,0            | 41,0            |
|                               | average., m| 7,7   | 13,7          | 18,0            | 14,2            |
| depth                          | max., m | 10,0    | 26,0          | 28,0            | 31,0            |
|                               | average., m| 2,8   | 9,3           | 10,8            | 12,7            |
| shallow water area 2 m deep at the NRL km$^2$ | 93 | 6 | 10 | 7 |
| shallow water area 2 m deep with LDV km$^2$ | 59 | 4 | 2 | 9 |

The structure of this hydropower complex includes the following facilities:
1. Existing irrigation facilities and the Tuyamuyun HPP.
2. Suggested options for energy facilities:
   a) PSPP-1 and PSPP-2 between the channel reservoir and the Kaparas and Sultansanjar reservoirs.
   b) PSPP-3 on the main canal between the Sultansanjar and Koshbulak reservoirs.
Figure 2. Scheme of the Tuyamuyun hydroelectric station with the proposed PSP options

Consider the technical and economic parameters of the Tuyamuyun HPPs [6,11-14]:
1) Capital investments in $K_{PSPP}$;
2) The annual production of electricity in the turbine mode $E_{TR}$;
3) Annual energy consumption in the pump mode $E_{NR}$;
4) Annual savings in fuel resources $D_{fuel}$;
5) Fuel economy $E_{fuel}$;
6) The annual cost of the PSPP $I_{PSPP}$;
7) Benefits from the creation of the PSPP $V_{PSPP}$;
8) Pay-back period of the capital investments $T_{pbp}$;
9) Profitability of the capital investments $R$.

For this, a methodology and a special computer program were developed to determine the technical and economic parameters of the PSPP [27].

3. Results

Over the past twenty-five years, the author has developed geographic information systems based on GIS for various research purposes [10–15]. When carrying out projects, the authors used the methods and experience of leading foreign specialists from the Institute for the Study of Environmental Systems of the University of Osnabrück (Germany) and the International Technology Centers (Yokaiichi and Tsukuba, Japan), in which the author improved his skills. At that time, a large project existed at the German Institute for the study of the hydroecological situation of the Elbe River, where the focus is on the use of GIS technology (http://elise.bafg.de). Experience in the European project Intas “Restoration and management options for water and tugai ecosystems of the northern delta of the Amudarya River” project was used (project Intas Aral Sea Project Call 00-1039 Ecosystems on the Northern Amudarya Delta Region http://www.usf.uos.de/projects/aral/) The two priority areas most concerned with the issue of water conservation of the Amudarya river resources are monitoring of hydraulic structures and water quality.

A series of GIS maps with different parameters of hydraulic structures of Uzbekistan were developed, a system of recommendations and practical measures aimed at using the criteria for the safe operation of hydraulic structures of the Republic of Uzbekistan was compiled (Fig 3-4).
Figure 3. Example of the use of GIS (ArcView system.) hydroecological monitoring of the Aral Sea delta. By clicking on this point located on our card, we get access to the database. Information can be obtained in two ways: 1) in the form of histograms; 2) in the form of table.

Figure 4. Using the “relief plastic” method to identify the distribution patterns of the directions of water flows and the macro-relief of the Amudarya delta. To refine the micro-relief, Google’s space images were used.

Shows the results of calculations of the technical and economic parameters of the Tuyamuyun HPPs when used as part of the Tuyamuyun hydroelectric complex(Table 2).

Table 2. Technical and economic parameters of PSPP at Tuyamuyun hydroelectric complex.

| №  | The name of indicators         | Unit of measurement | Value   |       |       |       |
|----|--------------------------------|---------------------|---------|-------|-------|-------|
|    |                                |                     | PSPP-1  | PSPP-2| PSPP-3|
| 1  | Turbine head                   | m                   | 7,87    | 6,7   | 5,8   |
| 2  | Pump head                      | m                   | 10,7    | 9,7   | 8,3   |
| 3  | Turbine consumption            | m³/sek              | 107     | 117   | 123   |
| 4  | Pump flow                      | m³/sek              | 82      | 84    | 89    |
| 5  | Turbine efficiency             | %                   | 86      | 86,3  | 85,3  |
| 6  | Pumping efficiency             | %                   | 85,5    | 85,1  | 83,7  |
| 7  | PSPP efficiency                | %                   | 73,53   | 73,4413| 71,3961|
| 8  | Number of units                | pc.                 | 2       | 2     | 2     |
| 9  | Installed power in turbine mode| kW                  | 14 209  | 13 273| 11 939|
| 10 | Installed power in pump mode   | kW                  | 20 134  | 18 785| 17 316|
| 11 | Investments in PSPP            | mln. USA dollars    | 14,209  | 13,273| 11,939|
That the obtained technical and economic parameters of the PSPP at the Tuyamuyun hydroelectric complex are the basis for the design study of the PSPP. Studies show that the capacity of the PSPP at the Tuyamuyun hydroelectric complex and its characteristics will largely depend on the capacities of the upper and lower basins, injection and discharge modes, and require optimization of technical and economic calculations taking into account the long-term development strategy of this energy system.

4. Discussion
Replacing the import of regulatory capacity with the introduction of a PSPP at the Tuyamuyun hydroelectric facility will save more than $5.6 million annually. The payback period for the use of a PSPP at the Tuyamuyun hydroelectric complex depends on the introduction of differentiated tariffs for electricity, while the difference in tariffs between the minimum cost and the average energy generation system for generating sources will provide a payback period of 6-8 years depending on the financing conditions. The results of the studies confirm the technical feasibility of creating a PSPP at the Tuyamuyun hydropower plant in the Khazarasp region of the Kharezm region.

5. Conclusion
Based on the joint use of GIS technologies and optimization models when developing environmentally applicable operating modes for hydraulic structures and hydropower facilities, the following tasks can be solved:
- Establishment of the laws and characteristics of the development of hydrological and hydro-chemical processes in the basin of the Amudarya river and the impact on hydraulic structures;
- determine the role of hydro-ecological and hydro-technical monitoring of water quality as a generalized integrated assessment of the whole complex of anthropogenic and physical-geographical factors affecting the formation of water quality;
- develop a classification that takes into account various factors: socio-demographic, economic, hydro chemical and other features affecting the engineering infrastructure of future pumped storage hydropowers;
- To propose a number of new methods of digital mapping using GIS technologies,
- develop mathematical hydraulic and hydrological models that reflect the possibility of improving the operating mode of hydraulic structures;
To sum up, we can draw the following conclusions:

|   | Turbine power generation (mln.kW*hour) |   |   |
|---|-------------------------------------|---|---|
| 12 | 31,117                              | 29,068 | 26,147 |

|   | Pump power consumption (mln.kW*hour) |   |   |
|---|-------------------------------------|---|---|
| 13 | 58,791                              | 54,853 | 50,562 |

|   | Currency savings with reduced purchases of peak electricity from neighboring power systems (mln. USA dollars) |   |   |
|---|-----------------------------------------------------------------------------------------------|---|---|
| 14 | 2,03                                               | 1,895 | 1,695 |

|   | The cost of electricity generated by the pspp during the peak period (mln. USA dollars) |   |   |
|---|-------------------------------------------------------------------------------------|---|---|
| 15 | 1,307                                               | 1,221 | 1,098 |

|   | The cost of the consumed electricity of the pspp in pump mode (mln. USA dollars) |   |   |
|---|--------------------------------------------------------------------------------|---|---|
| 16 | 1,234                                               | 1,152 | 1,062 |

|   | Annual fuel savings (t.c.f.) |   |   |
|---|-------------------------------|---|---|
| 17 | 4667,575                      | 4360,194 | 3922,081 |

|   | Cost of saved fuel (mln. USA dollars) |   |   |
|---|-------------------------------------|---|---|
| 18 | 3,280                              | 3,064 | 2,756 |

|   | The annual cost of the pspp (mln. USA dollars) |   |   |
|---|-------------------------------------|---|---|
| 19 | 0,966                              | 0,903 | 0,813 |

|   | Benefits from the establishment (mln. USA dollars) |   |   |
|---|-----------------------------------------------|---|---|
| 20 | 2,470                                                             | 2,310 | 2,022 |

|   | Economic efficiency for the year (mln. USA dollars) |   |   |
|---|---------------------------------------------------|---|---|
| 21 | 2,652                                                             | 2,480 | 2,175 |

|   | Payback period (years) |   |   |
|---|-----------------------|---|---|
| 22 | 5,753                                                             | 5,746 | 5,904 |

|   | Return on investment (%) |   |   |
|---|-------------------------|---|---|
| 23 | 0,174                                                                  | 0,174 | 0,169 |
1. The establishment of PSPPs in Uzbekistan is necessary to reduce the share of the capacity of TPPs that are used to regulate drops and peaks of electrical load.
2. Given that the main purpose of water resources is irrigation, it is necessary to develop the existing schemes of PSPPs, in particular, to construct them at local waterways.

The creation of a PSPP in the Republic of Uzbekistan is advisable for the following reasons:

- The urgent need to cover daily load schedules, the lack of peak capacities and the need for its overflows from the energy systems of neighbouring states;
- The creation of a PSPP in the Republic is necessary to reduce the share of power of TPPs used to regulate dips and peak loads.
- Saving fuel resources, reducing specific fuel consumption in electricity generation;
- The operation of the PSPP in the charge mode at night, with a decrease in power consumption, due to the generation of thermal stations, will reduce the number of short-term shutdowns, reduce wear and tear on TPP equipment and repair costs;
- Given the main purpose of water resources - for irrigation purposes, it is necessary to develop existing PSPP schemes, in particular, build them on local watercourses with regulation of part of the watercourse, in combination with solar and (or) wind energy power plants. Future work will include the development of a costing model. Cost-related information will be incorporated in the model which is now under development by for PSPP. This geology information such as rock types and structures which influence the stability and construction cost of dams; geographical distances to existing high-voltage transmission network and transport infrastructure; meteorology and hydrology conditions to determine the requirements for micro-catchments and evaporation reduction measures.

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