Assessment of the water facilities’ impact types on the basin geosystems’ geosphere during construction and operation

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Abstract. Water resources use as a renewable natural resource on all hierarchical basin geosystems levels of within the Earth biosphere, in almost all types of economic and other activities carried out by intra-basin or inter-basin water flow regulation and redistribution (surface, underground), quantitative and qualitative indicators, formed within the spatial limits of the basin system under consideration. For the water flow regulation within the considered river hydrographic seasonal or multi-year regulation network, the reservoirs are built, including the necessary complex hydrotechnical and related facilities, providing the selection of the estimated water flow (Q m³ / s) from water body with a subsequent transportation to specific water users and water consumers. For water resources use in various sectors of economic and other activities within about 10 of the basin geosystems in the Kuban, Terek and Lower Don rivers water facilities were built last century. According to the current regulatory environmental requirements at the design stage, construction and subsequent operation an urgent need to carry out the environmental impact assessment of water facilities arose. The construction objects referred to as “Facilities” and related to the water use with a systematic approach as a way to describe the processes of interconnection, interaction and the relationship between the natural, man-made components and the population developed the methodology foundations for creating and developing a class of natural-technical systems “Environment - Facility – Population” on the water resources use in the economic activity industries. The developed methodology basis for this class of natural-technical systems found practical application at the design, construction and operation stages water objects of activity, referred to as “Facilities”, with the implementation of the existing regulatory environmental requirements. In the methodology foundations development for the creation and development of this class the natural-technical systems, the concept of the dominant role of the whole was formulated, which defines the dominant effect of natural processes in the water flow formation (surface,
underground) in the zones of “Facility” influence within the considered basin geosystem. For the considered class of systems according to the study results, such basic system concepts as structure, component, element, the dominant role of the whole, including the concept of natural and technogenic components as well as the environmental acceptability are defined.

Introduction
The use of water resources in modern technological economic activity processes is carried out with the construction of new and use of the existing water facilities referred to as “activity objects” (“A.O.”), functionally performing intra-basin regulation or inter-basin redistribution of the water flow (surface, underground), the water consumption estimated selection (Qm³/s) from a water body, their transportation to particular water users and water consumers. The formation of the water flow quantitative and qualitative indicators is carried out within the spatial boundaries of the basin geosystem under consideration, located at a certain hierarchical level of the Earth’s biosphere basin geosystems. To perform the necessary functional tasks, various hydraulic structures’ types - a reservoir for regulating water flow, water intake, water transporting, water distribution, etc., which inherently make the certain changes to the natural processes of interconnection, interaction, relationship (IIR) between the natural (biotic, abiotic) components and the natural processes water runoff formation within the basin geosystem under consideration, are included in the “A.O.” composition. The introduced changes determine the types of impact on the “Natural Environment” (“N.E.”) and the vital interests of the resident “Population” (“P.”), which are characterized by the “N.E.” introduction and “N.E.” withdrawal from the environment which directly affects the processes of the ecological state (ES) formation as the dominant factor of environmental safety (ES) in the space and time where the water resources are formed [11-14].

“A.O.” impact on “N.E.” starts from the moment the construction work starts and continues with certain changes until commissioning and a further period of operation (50-100 years). In accordance with modern environmental requirements for providing ES during the construction period and further operation, it became necessary to determine the “A.O.” influence zones’ boundaries, based on the established impact types on “N.E.” in space and time of the considered basin geosystem. In the published scientific papers for the period (2005-2019) [1, 2, 4, 6, 7] the methodologies for studying the “A.O.” impact types on “N.E.” and determining the “A.O.” influence zones’ boundaries within the basin geosystems, poorly studied issues have been identified. The solutions of these problems depend on the ES level indicators. The tasks to assess the types of impact and determine the influence zones’ boundaries during the construction period were carried out using as an example the Zelenchukskaya HPP-PSP, located within the basin geosystem of the Upper Kuban on the Karachay-Cherkess Republic (KCR) territory (Figure 1.).
Figure 1. Spatial model of the basin geosystems of the Upper Kuban

Materials and Methods
To assess the types of impact during the construction period, a hydraulic structures’ complex (HSC) was adopted as an object of study, including the derivation channel Zelenchuki-Kuban, into which the selection from the rivers Bolshoy Zelenchuk, Marukha, and Aksaut with a total flow of 70 m³/s occurs. The functional purpose of the HSC is the intra-basin redistribution of water flow within the spatial limits of the Bolshoy Zelenchuk river in the Upper Kuban basin geosystem (Figure 1) (F_wt=779 km²), Marukha (F_wt=36 km²), Axout (F_wt=580 km²), within which the water flow is formed, respectively 1,048 million m³; 0.58 million m³; 1.2 million m³.

The composition of the Zelenchuk-Kuban derivation channel includes: open and closed channels, hydraulic tunnels, siphons and stormwater pipelines. The structure at the pressure structure station includes: water intake; earth dams, water intake facilities, fish protection devices, spillway and sludge disposal.

The created working head at hydraulic units is 234 m (Figure 2).

In assessing the impact types of the HSC Zelenchukskaya HPP-PSP on “N.E.” within the Upper Kuban basin geosystem, a systematic approach in the HSC main technogenic component IIR processes study is used, referred to as “A.O.” as a part of the NTE class “N.E. - A.O. - P.”, which is considered as a holistic, dynamic, open, stable-nonequilibrium system, where the self-organization processes between the natural and technogenic structural formations continuously proceed [14-17].

The study of the “A.O.” impact types as a part of NTE “N.E. - A.O. - P.” starts with “N.E.” introduction into the environment description, which is caused by the intra-basin redistribution of the water flow, changes in water discharge in the channels of the rivers Bolshoy Zelenchuk, Marukha, Aksaut and Kuban in the downstream of Zelenchukskaya HPP-PSP and, accordingly, the depths of water in the channels, water discharge in the river Kuban (increase to 70 m³/s), the reservoirs creation
on the rivers Bolshoy Zelenchuk (WB.Z.=1,2 million m³), Marukha (WM.=0,86 million m³), Axout (WA.=0,96 million m³), the upper and lower basins of the daily regulation with volumes, respectively W.u.b.d.r.=1,85 million m³ and W.l.b.d.r.=1,2 million m³, a change in temperature and relative humidity, surface air masses at the locations of the UBDR and LBDR reservoirs, a change in the life processes of hydro-bionts, ichthyofauna (fish species, etc.), a change in the natural channel processes on the Bolshoy Zelenchuk, Maly Zelenchuk and Kuban downstream from the Zelenchukskaya HPP-PSP, pollution by the chemical elements and their compounds in the water and air environment during the construction period, as well as the changes in the social conditions of N’s life. [14, 15].

Figure 2. The structures’ layout along the derivation channel on the Zelenchuki-Kuban route

Withdrawal “N.E.” from the surrounding is presented by the land resources for the “A.O.” placement (5,482 km²), the parent rocks during the “A.O.” construction, the estimated water flow from the rivers Bolshoy Zelenchuk, Marukha and Aksaut (W=600,0 million m³ = 48% according to the long-term average data during the flood period (April-October)) [14, 15].

The main factors affecting water bodies during the “A.O.” construction are: a variable water regime, hydraulic and morphometric characteristics of the river channels, microclimate parameters in the reservoirs’ influence zones, hydrogeological regime of the ground and underground waters.

The dominant influence factor is “A.O.” Zelenchukskaya HPP-PSP is the withdrawal of 50% of the water flow from the Bolshoy and Maly (Marukha, Aksaut rivers) Zelenchuk.

The limiting factor of the aquatic ecosystems’ vital activity on the above-mentioned rivers is the winter low-water period, when water is not taken into the derivation channel.

“N.E.” contribution to the environment of the river basin ecosystems of the Bolshoy Zelenchuk and Maly Zelenchuk rivers introduces the changes to the natural channel-forming processes associated with siltation of reservoirs and lowering of the bottom marks in the lower pools’ channels of the reservoirs’ pressure fronts.

“A.O.” interaction with the geological environment in the upper layers of the lithosphere makes changes to the groundwater movement’s hydrogeological regime associated with the filtration processes in the pressure zones of reservoirs, diurnal regulation basins (UBDR and LBDR) and the open sections of the Zelenchuki-Kuban derivation channel.
The “A.O.” impact on the terrestrial and aquatic bio-cenosis is characterized by the changes in the stern resources. Of particular note is the “A.O.” impact on the ichthyofauna life processes (fish species, etc.) on the Bolshoy and Maly Zelenchuk rivers.

A special system element in the created NTE “N.E. - A.O. - P.”, is “P.”, which lives in the zones of influence of the “A.O.” Zelenchukskaya HPP-PSP and perceives all changes in the basin geosystem of the Upper Kuban. A comprehensive scheme of the impact of Zelenchukskaya HPP-PSP on the Upper Kuban basin geosystem is shown in Figure 3.

Results

Based on a system analysis and a systematic approach of the impact types “A.O.” Zelenchukskaya HPP-PSP to the surrounding “N.E.” the quantitative and qualitative indicators of the influence zones’ PP of the, which are determined by the PP in the basin geosystem’s spatial limits, were determined in the basin geosystem of the Upper Kuban.

It is established that the PP in space and time in the “A.O.” influence zones determined by the continuous movement of flows of substance, energy and information (SEI), which are quantitatively and qualitatively expressed by the generally accepted indicators MPC\(^1\), MPL\(^2\), MPW\(^3\), MPE\(^4\) и MPD\(^5\), which are established in the EIA procedure.

For the considered type of water resources use (water use), the PP system approach is determined by the protection object state (PO) under the VEI flows continuous movement influence emanating from the IIR processes “A.O.” with “N.E.” and living “P.” as a part of NTE “N.E. - A.O. - P.”

In the example under consideration, Zelenchukskaya HPP-PSP ES in the “A.O.” influence zones to a greater extent affects the permissible values of MPL, MPC, MPW, and MPD, which acquire practical importance in the system “protection object - source of environmental hazard - protective measures” (“PO – SHE – PM”).

Based on the concepts of ES and PP in the space and time of the influence zones “A.O.” the concept “ES criteria” is formulated for the considered water resources use.

Environmental safety criteria (ESC) determine the indicators (quantitative and qualitative) \(I_j\), \(I_i\) environmental acceptability of “A.O.” impact on the natural processes of self-regulation, without causing any negative and irreversible trends of degradation in space and time.

Based on a systematic analysis of the impact types studies results “A.O.” on “N.E.” as a part of NTE “N.E. - A.O. - P.” its zones of influence and their classification characteristics were determined: - low activity (I), active (II, V) and highly active (III, IV) (Figure 4.)

I - Inactive zone of influence within the catchment area of the upper river Kuban (11000 km\(^2\));
II - The active zone of the influence of the HSC complex on microclimate parameters (Pmc);
III - Highly active zone of influence of the HSC complex on the Bolshoy and Maly Zelenchuk (Pmpw) rivers;
IV - Strongly active zone of influence on 15 km section of the river Kuban (I\(_{HBNE}\));
V - The active zone of the influence of reservoirs and the HSC complex on the geological environment (I\(_{EERB}\))

\(^1\) MPC\(^1\) – maximum permissible concentration;
\(^2\) MPL\(^2\) – maximum permissible level; MPW\(^3\) – maximum permissible waste;
\(^4\) MPE\(^4\) – maximum permissible emission; MPD\(^5\) – maximum permissible discharge
Figure 3. Scheme of the HSC Zelenchukskaya HPP-PSP impact on the environment within the upper basin geosystem
Discussion

At the level of the Upper Kuban basin geosystem, within which “A.O.” as a part of the “N.E.-A.O.-P.” NTE, its integrity is ensured by the continuously ongoing processes of self-organization and transformation in intra-system formations (hydrographic network, flora and fauna, soil cover, upper layers of the lithosphere and lithosphere surface layers, etc.) at all hierarchical levels of the basin geosystem. The “A.O.” introduction in “N.E.” complicates the inter-structural relations in the processes of self-organization between the natural and technogenic structural formations in the zones of its influence. Irreversibility in the “A.O.” interaction processes with natural environments in the influence zones leads to the emergence of new phenomena in the geological environment, in hydrographs and the channel part of the upper and lower reservoir pools, in the coastal strip of the river channels’ floodplain, in the surface layers of the air and the basin geosystem as a whole [19-21, 25].

IIR “A.O.” in regulation processes, intra-basin redistribution of water flow from the local sections of the river basin geosystems Bolshoy Zelenchuk ($F_{wt} = 779 \text{ km}^2$, $W_{atm} = 7790 \text{ km}^3$, $W_{lith} = 233.7 \text{ km}^3$), Marukh ($F_{wt} = 336 \text{ km}^2$, $W_{atm} = 3360 \text{ km}^3$, $W_{lith} = 100.8 \text{ km}^3$) and Aksaut ($F_{wt} = 509 \text{ km}^2$, $W_{atm} = 5090 \text{ km}^3$, $W_{lith} = 152.7 \text{ km}^3$) are carried out in the spatial limits basin geosystems of the Upper Kuban ($F_{wt} = 11.0 \times 10^3 \text{ km}^2$, $W_{atm} = 110.0 \times 10^3 \text{ km}^3$, $W_{lith} = 3.3 \times 10^3 \text{ km}^3$), which is an elementary part of the Earth’s biosphere, within which the global processes of moisture circulation occur under the solar energy flows’ influence (Fig. 1).

On the water flow formation within the local areas as a part of the NTE “N.E. - A.O. - P.” of the Bolshoy Zelenchuk, Marukh and Aksaut rivers basin geosystems, solar energy is consumed in the amount, respectively – $273429 \times 10^6 \text{ kw/h}$, $178659 \times 10^6 \text{ kw/h}$ on the water appropriate volumes formation (long-term average data) $-1232 \text{ million m}^3$, $290.0 \text{ million m}^3$, $446 \text{ million m}^3$, of which an average of 26% is selected ($512 \times 10^6 \text{ m}^3$) into the technological system for generating electric energy at Zelenchukskaya HPP-PSP. It should be noted that in the technological processes of the solar energy conversion ($E_{free} = 148206 \times 10^6 \text{ kw/h}$) in the targeted water flow in the volume $512 \times 10^6 \text{ m}^3$ for the electric energy generation at the HPP-PSP annually in the amount of $E_{HPP} = 400 \times 10^6 \text{ kw/h}$ is carried out with the efficiency $E_{HPP} / E_{sol} = 0.003$. In plants, this efficiency is about 0.1 [23-25].

Based on the results of the “A.O.” impact assessment systematic analysis in the zones of influence (I-V) on “N.E.” quantitative indicators I of the influence zones spatial boundaries’ ratios (I-V) to the local basin geosystems of the Bolshoy Zelenchuk, Marukha, Aksaut, UBDR, LBDR rivers, open sections of the derivation channel to the spatial boundaries of the Upper Kuban basin geosystem as a whole were determined (Table 1).

The quantitative analysis Ij (Table 1) indicates the biotic and abiotic components of the IIR natural processes dominance among themselves over the IIR processes “A.O.”, “N.E.” in the form of the introduced changes, which in a systematic review determines the ES of the considered space in the basin geosystem. So, the NTE “N.E.-A.O.-P.” ratio of the spatial boundaries ($W_{NTE(at)} = 1422.94 \text{ km}^2$), the man-made processes occur to the spatial boundaries of the Upper Kuban basin geosystem ($W_{B.G.} = 113300 \text{ km}^2$), where the natural processes occur and the runoff is formed (an average of 3000 million m$^3$ annually). So, the ratio $W_{NTE}/W_{B.G.}=0.0125 \ (1.25 \%)$ reflects the quantitative natural processes’ dominance with a probability of 98.5% to 99.003%, which is determined by P.P. and, accordingly, E.S. in the zones of “A.O.” influence.
Figure 4. The influence zones of the Zelenchukskaya HPP-PSPP hydraulic structures complex on the Upper Kuban basin geosystem environment

Table 1. Generalized and local quantitative indicators in the influence zones of “A.O” Zelenchukskaya HPP-PSP.

| Influence zones | Indicators | Inactive I | Active II | Very active III | Very active IV | Active V |
|-----------------|------------|------------|-----------|-----------------|----------------|----------|
|                 |            |            |           |                 |                |          |
|                 |            | In the pool as a whole |          |                 |                |          |
|                 |            | [MPW](j) = W_{III}/W_{B.G.} |          | 0.0065(0.03%) |                |          |
|                 |            | [HBNE](j) = W_{IV}/W_{B.G.} |          | 0.0003 (0.03%) |                |          |
|                 |            | [R.F.(j)](j) = W_{V}/W_{B.G.} |          | from 0.5 ÷1.0 m |                |          |
|                 |            | [M.K.(j)]=W_{VI}/W_{B.G.} |          | 0.0057 (0.57%) |                |          |
|                 |            | According to the local elements of the basin geosystem |          |                 |                |          |
|                 |            | [B.Z.(j)]=W_{III}/W_{B.Z.} |          | 0.0079(0.079%) |                |          |
|                 |            | [M(j)]= W_{III}/W_{B.M.} |          | 0.055 (5.5%) |                |          |
|                 |            | [A(j)]= W_{III}/W_{B.A.} |          | 0.024 (2.4%) |                |          |
|                 |            | [B.Z.(j)]= W_{III}/W_{B.Z.} |          | 0.0092(0.92%) |                |          |
\[ I_{\text{М}(j)} = \frac{W_{\text{III}}}{W_{\text{B.M.}}}, \quad 0.0063(0.63\%) \]
\[ I_{\text{А}(j)} = \frac{W_{\text{III}}}{W_{\text{B.A.}}}, \quad 0.0012(0.12\%) \]
\[ I_{\text{М.З.}(j)} = \frac{W_{\text{III}}}{W_{\text{B.M.}}}, \quad 0.015 (1.5\%) \]
\[ I_{\text{К.}(V)} = \frac{W_{\text{IV}}}{W_{\text{К}}}, \quad 0.0008/0.08\% \]
\[ I_{\text{B.Z.}(V)} = \frac{W_{\text{V}}}{W_{\text{B.Z.}}}, \quad 0.00003/0.003\% \]
\[ I_{\text{NTE}} = \frac{W_{\text{NTE}}}{W_{\text{B.G.}}} = 0.125/1.25\% \]

Summary

Based on the studies’ results of the “A.O.” exposure types on “N.E.” as a part of the “N.E.-A.O.-P.” NTE created within the Upper Kuban basin geological system, the foundations of a methodology for determining the “A.O.” influence zones’ boundaries have been developed during the construction period and their classification characteristics have been depicted as: low active (I), active (II, V) and highly active (III, IV).

According to the systematic analysis results of the “A.O.” impact assessment within the established influence zones’ boundaries (I-V) on “N.E.”, the (Ij) ES quantitative component indicators were identified as an important factor in the ES assessment and maintenance. So, for example, the Zelenchukskaya HPP-PSP “A.O.” construction of Ij indicators analysis indicates the natural processes’ dominance of the natural (biotic, abiotic) components among themselves over the technogenic processes of interaction between “A.O.” and the natural components in the considered space of the Upper Kuban basin geosystem, where water resources are generated and used to generate electrical energy.

Quantitative analysis Ij in the Zelenchukskaya HPP-PSP “A.O.” influence zones (I-V) shows that natural processes of explosives dominate man-made processes with a probability of 98.5% to 99.003% and, accordingly, is provided by ES.

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