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Rationale for the development of large-scale underground water storage systems in Central Kazakhstan using managed aquifer recharge

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Abstract. This paper presents a rationale for typical artificial groundwater recharge schemes, considering the physical, geographical, and hydrogeological conditions of large underground reservoirs in Central Kazakhstan. The aim of the paper is to analyze modern aquifer recharge methods and assess their effectiveness and applicability depending on reservoir characteristics, the availability of water sources, and the region's water demand. The paper examines various technological schemes for artificial groundwater recharge and measures to regulate filtration processes, assessing their technical and economic feasibility. The obtained results allow for the development of recommendations for the optimal use of the region's water resources, ensuring a sustainable water supply, and mitigating the negative impact on natural ecosystems. Furthermore, the paper emphasizes the importance of an integrated approach to water use planning that considers both geological and socioeconomic factors.

Keywords: groundwater, artificial recharge, aquifers, technological schemes, Central Kazakhstan, hydrogeology, water demand.

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1. Introduction

Rational use of groundwater is a key factor in ensuring sustainable water supply and preventing the degradation of natural ecosystems. Managed aquifer recharge (MAR) is considered an effective tool for increasing aquifer resources, regulating filtration processes, and meeting water needs in arid and semi-arid regions [1, 2].

The effectiveness of MAR is determined by a combination of physical, geographical, and hydrogeological conditions, including the geomorphological structure of the territory, the lithological composition of rocks, the filtration properties of the vadose zone, the groundwater regime, as well as climatic parameters (precipitation, temperature, evaporation), and the characteristics of the hydrographic network [3-5].

Managed aquifer recharge (MAR) and aquifer storage and recovery (ASR) are widely used in various countries worldwide, including Europe, the United States, Israel, and Australia [1]. The main applications of this technology include ensuring water supply in resource-scarce conditions, creating strategic water reserves, preventing aquifer salinization, and improving water resource management [2, 3]. Surface water, including flood runoff, can be used as recharge sources, which is especially relevant for arid areas [4].

The artificial groundwater recharge method is based on increasing the water inflow into an exploited aquifer throughout the year or during individual seasons. This is

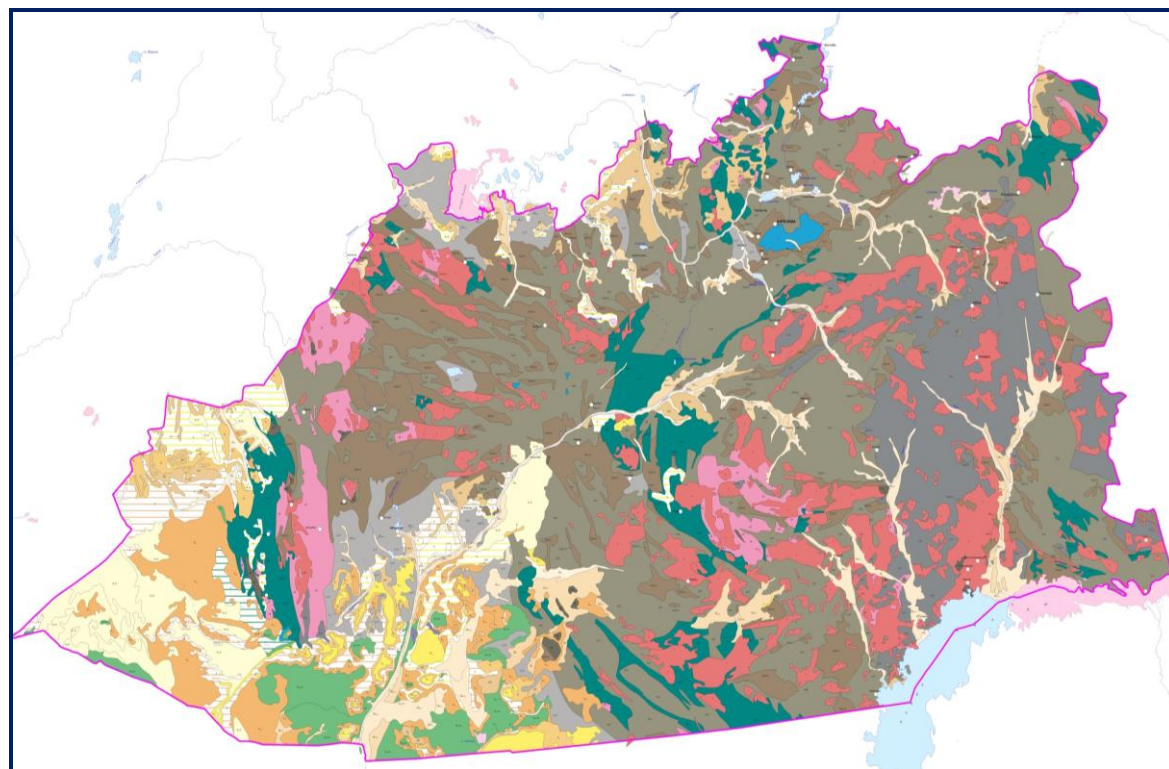
achieved through surface water infiltration through special structures (pools, canals, absorption wells, etc.) or by temporarily flooding natural depressions.

This method addresses a number of important issues, primarily in the area of domestic and drinking water supply, and also contributes to environmental improvements. Artificial recharge makes it possible to regulate the hydrogeological regime during water withdrawal, considering both the quantity and quality of water at the recharge source.

Furthermore, the accumulation of water in the aquifer and the presence of infiltration structures make it possible to shut off the water supply if necessary, for example, if its quality deteriorates (increased turbidity, contamination, odors, etc.), thereby reducing the risk of groundwater contamination.

Storing groundwater during periods of high-water levels increases the reliability of water supply, especially for alluvial horizons, and helps avoid interruptions in water supply during low-water periods.

Central Kazakhstan is characterized by a distinctly continental arid climate, complex, low-hill terrain, and a poorly developed river network (Figure 1). The region's rivers have a pronounced seasonal regime, with up to 80-90% of annual runoff occurring in the spring [6, 7]. Furthermore, the alluvial sediments of river valleys have high filtration capacity, creating productive conditions for groundwater infiltration and accumulation [6].



AQUIFERS AND AQUIFER COMPLEXES

aQ_{iv}	Aquifer of modern alluvial deposits. Sands, sandy loams, loams, pebble deposits, gravel-pebble deposits
aQ_{iv-v}	Aquifer of Upper Quaternary-modern alluvial deposits. Sands, sandy loams, loams, pebble deposits, gravel-pebble deposits
aQ_{iv}	Aquifer of Upper Quaternary alluvial deposits. Sands, sandy loams, loams, pebble deposits, gravel-pebble deposits
adQ_{iv-vQ}	Aquifer of Upper Quaternary alluvial-deltaic deposits and the overlying aeolian deposits. Sands, sandy loams, loams
aQ_{iv-iv}	Aquifer of Middle-Upper Quaternary alluvial deposits. Sands, sandy loams, gravel-pebble deposits, loams
aQ_{iv}	Aquifer of Middle Quaternary alluvial deposits. Pebble deposits, gravel-pebble deposits, sands, sandy loams, loams
aQ_{iv}	Aquifer of Lower Quaternary alluvial deposits. Sands, gravel-pebble deposits, conglomerates, sandy loams, loams
fgQ_{iv}	Aquifer of Lower Quaternary fluvioglacial deposits. Boulder-pebble and pebble deposits with a sandy-clayey matrix and sand lenses
apQ	Aquifer complexes of Quaternary deposits of various origins (apQ , IQ , dpQ , mQ , $mQ-vQ$). Boulder-pebble and gravel-pebble deposits, sands, interbeds of loams and clays, gus-rubble deposits with a sandy matrix, sandy loams, silts
N_2-Q	Aquifer complex of Pliocene-Quaternary deposits. Sands, sandstones, gravelstones with interbeds of silts, sandy loams, and clays
N_2	Aquifer complex of Pliocene deposits. Gravel-pebble deposits, less commonly boulder-pebble deposits, variably grained sands, sandy loams, loams
N_{2sr}	Aquifer of Pliocene Syrt deposits. Sands containing pebbles and loams with clay interbeds (Precaspian Depression)
N_{1-2}	Aquifer complex of Miocene-Pliocene deposits. Sands and gravel-pebble deposits interbedded with loams and sandy loams
N_1	Aquifer of Miocene deposits. Interbeds of sands and gravel-pebble deposits within sandy loams and clays; limestones, marls, gypsum, and sandstones with clay interbeds (Ustyurt and Mangyshlak)
P_2-N_1	Aquifer complex of Oligocene-Miocene deposits. Alternating sandstones, sands, gravelstones and conglomerates with clays, argillites, and siltstones
P_2	Aquifer of Oligocene deposits. Sands, sandstones, gravelstones, clays, sandy loams
P_2^2	Aquifer of Middle Eocene deposits. Variably grained sands and silty sands with clay interbeds
P_{1-2}	Aquifer complex of Palaeogene-Eocene deposits. Sands, sandstones, opokas, and siltstones with clay interbeds

K_2	Aquifer complex of Upper Cretaceous deposits. Fine- and medium-grained sands alternating with clays, siltstones, and sandstones
K_1A_2-Sn	Aquifer complex of Upper Turonian-Senonian deposits. Fine- and medium-grained sands with interbeds of clays and siltstones
$K_{1-2}A_1-S$	Aquifer complex of Albian-Cenomanian deposits. Variably grained sands and sandstones interbedded with clays and silts
$K_{1-2}K_2-S$	Aquifer complex of Lower Cretaceous-Cenomanian deposits. Variably grained sands and sandstones, locally clayey, interbedded with clays and silts (Precaspian Depression)
K_2	Aquifer complex of Lower Cretaceous deposits. Variably grained sands with interbeds of clays, silts, and sandstones
J	Aquifer complex of Jurassic deposits. Sands, sandstones, gravelstones, argillites, brown coal
T	Aquifer complex of Triassic deposits. Conglomerates and sandstones interbedded with clays, shales, and argillites
C_2-P	Water-bearing fracture zone of terrigenous Middle Carboniferous-Permian rocks. Sandstones, siltstones, argillites, conglomerates, gravelstones
$C-P$	Water-bearing fracture zone of sedimentary-volcanogenic Carboniferous-Permian rocks. Sandstones, siltstones, conglomerates, tuffaceous sandstones, tuffs, lavas, and tuffs
D_3Im-C_1	Aquifer complex predominantly composed of Famennian-Lower Carboniferous fractured and karstified carbonate rocks. Limestones, dolomites
D_2-C_1	Water-bearing fracture zone of terrigenous Upper Devonian-Lower Carboniferous rocks. Sandstones, shales, siltstones, gravelstones
$S-D$	Water-bearing fracture zone of volcanicogenic-sedimentary Silurian-Devonian rocks. Porphyries, tuff breccias, tuffs, sandstones, siltstones, clayey-siltaceous shales
$C-O_2$	Aquifer complex predominantly composed of Cambrian-Middle Ordovician fractured and karstified carbonate rocks (Maly Karatau Basin). Limestones, dolomites
$C-O_1$	Water-bearing fracture zone of volcanicogenic-sedimentary Cambrian-Ordovician rocks. Lavas, tuffs, sandstones, siltstones, tuffaceous sandstones, jaspers, shales
PZ	Water-bearing fracture zone of undivided Palaeozoic rocks. Sandstones, siltstones, shales, tuffs, conglomerates, tuffaceous sandstones, gneisses, amphibolites
pC	Water-bearing fracture zone of metamorphosed Precambrian rocks. Shales, quartzites, jaspillites, gneisses
Y	Water-bearing fracture zone of predominantly granitoid intrusive rocks of various ages. Granites, granodiorites

LOCAL AQUIFERS AND AQUIFER COMPLEXES

Local Upper Pliocene-Lower Quaternary ($N_2^1-Q_1$), Upper Neogene-Quaternary (N_2-Q_1), Quaternary (aQ_{iv} , aQ_{iv-iv} , aQ_{iv} , dpQ , IQ , dpQ), Neogene (N_1 , N_1-2), Upper Palaeogene-Lower Neogene (P_2-N_1), Palaeogene (P_2 , P_2^1 , P_2^2 , P_2^3), and Cretaceous (K_{1-2} , K_2) aquifers and aquifer complexes. Interbeds and lenses of sands, gravelstones, and sandstones within clays and siltstones; marls, dolomites, and argillites.

The color and geological index correspond to the age of the water-bearing rocks.

LOCAL AQUIFERS AND AQUIFER COMPLEXES

HYDROLOGICAL

- Seas, lakes
- Rivers
- Intermittent river section
- Freshwater and brackish lakes
- Saline lakes

HYDRAULIC STRUCTURES

- Reservoirs

OTHER SYMBOLS

- Administrative region boundaries
- Cities
- Astana – capital of the Republic of Kazakhstan

Figure 1. Hydrogeological map of Central Kazakhstan

The choice of technological schemes for artificial replenishment of groundwater reserves is determined by the presence and characteristics of aquifers, the availability of replenishment sources, the current and future needs of the region for water supply, as well as the economic efficiency of the implemented measures [1, 4, 5].

The use of zoning of the territory according to the conditions of artificial replenishment of groundwater reserves

allows us to take into account the spatial heterogeneity of hydrogeological conditions and justify the choice of the most effective solutions for groundwater resource management.

The aim of this study is to substantiate large-scale underground water storage systems in Central Kazakhstan by assessing hydrogeological conditions, zoning the territory for managed aquifer recharge, and selecting appropriate recharge schemes.

2. Materials and methods

The territory of Central Kazakhstan is a mountainous and folded region within which unconfined fissure waters with shallow circulation are widespread. They are confined to the fractured zone of volcanogenic-sedimentary complexes of pre-Paleozoic and Paleozoic rocks [8].

Fracture-karst waters of Devonian-Carboniferous carbonate rocks are also widespread, forming numerous brachyanticline and synclinal structures [8, 9]. Each of such structure represents a unique groundwater deposit, containing significant volumes of water resources [2, 3]. Majority of Central Kazakhstan is represented by a mountainous, folded region dominated by shallowly circulating, unconfined fissure waters confined to the open fracture zone of volcanogenic-sedimentary complexes of pre-Paleozoic and Paleozoic rocks, including effusive, intrusive, terrigenous-sedimentary, and metamorphic formations. Good rock exposure facilitates active water exchange and the formation of fresh, slightly brackish, and brackish waters.

Fracture-karst waters of Devonian-Carboniferous carbonate and terrigenous rocks are also widespread, forming numerous small brachyanticline, synclinal, and large complex structures. Each of such structure essentially represents a groundwater deposit with significant reserves, particularly in the southwestern part of the region – the Zhezkazgan-Ulatau, Niyaz-Yerementau, and other districts. The high degree of fracturing and karstification of carbonate rocks ensures intensive absorption of precipitation and floodwaters from rivers and streams; in the Zhezkazgan-Ulatau district, effective precipitation accounts for up to 60% of winter-spring runoff. Furthermore, these aquifers can be replenished by surface water from rivers.

A combination of climatic, topographic, geomorphological, and hydrogeological conditions, including the composition of water-bearing rocks and the presence of large hydrogeological reservoirs, creates favorable conditions for artificial groundwater recharge. This creates large underground reservoirs for multiple purposes: for municipal and industrial water supply of large population centers, as well as for agricultural needs.

Taking into account the region's physical and geographical conditions, including geomorphological, geological, hydrogeological, climatic (precipitation), and hydrological (development of the hydrographic network) factors, a zoning of Central Kazakhstan was conducted based on conditions for artificial groundwater recharge. This allows to determine patterns in the hydrogeological environment and serves as the basis for a differentiated assessment of the potential for artificial groundwater recharge. The zoning methodology is based on taking into account a complex of natural and artificial factors affecting the effectiveness of recharge and is used to identify areas with similar or different conditions for artificial recharge of groundwater reserves. The assessment of natural conditions during zoning is carried out in order to identify:

- 1) the recharge object – a natural or artificial collector;
- 2) recharge sources and methods of preliminary water treatment;
- 3) the need for artificial recharge;
- 4) the economic feasibility of artificial recharge of groundwater reserves.

The methodological basis of the study was a comprehensive hydrogeological analysis of the territory, including:

- Analysis of the geological and hydrogeological conditions of the region;
- Study of the lithological composition of water-bearing rocks;
- Filtration properties of rocks (transmissibility coefficients within 300-1000 m²/day);
- analysis of the hydrological regime of rivers.

The following criteria were taken into account in the process of zoning:

1. Availability of natural reservoirs for groundwater accumulation (alluvial valleys, fissure-karst structures);
2. Availability of replenishment sources (surface water, precipitation, flood runoff from the Nura, Kengir, Sarysu, and other rivers);
3. Water resource requirements;
4. Economic feasibility of artificial groundwater replenishment projects

The geomorphological factor was used as the main classification feature for zoning, allowing to establish the relationship between relief forms, lithological composition of rocks and groundwater occurrence conditions.

3. Results and discussion

Based on the conducted zoning of Central Kazakhstan according to the conditions of artificial replenishment of groundwater reserves, four groups of territories were identified, characterized by a set of geomorphological, geological, hydrogeological and hydrological indicators that determine the possibility of creating various types of underground reservoirs:

1. Large multi-purpose reservoirs – construction is possible:
 - a) in river valleys with high population density and developed industry;
 - b) in areas with developed carbonate aquifers.
2. Medium-sized reservoirs, primarily for agricultural purposes, located in large buried valleys.
3. Small reservoirs – associated with Paleozoic rocks of varying ages, intended for pasture irrigation.
4. Unpromising areas – territories unsuitable for the construction of groundwater reservoirs, for example, due to geomorphological conditions or the absence of aquifers.

A feasibility study was developed for each group of territories, and a standard technological scheme for artificial groundwater replenishment was proposed.

This study focuses on the justification and design of large underground reservoirs, as these facilities provide strategic water reserves for the integrated water supply of settlements, industrial facilities, and agricultural needs in the region. Large reservoirs are considered a key element of groundwater management, enabling the most efficient use of flood and surface water, regulating filtration processes, and increasing the sustainability of water supply in the arid and semi-arid climate of Central Kazakhstan. Geomorphological, hydrogeological, and hydrological characteristics of the territory, as well as the physicochemical properties of aquifers, are analyzed, enabling the substantiation of optimal technological schemes for groundwater replenishment and predicting their long-term effectiveness.

This group of areas includes the valleys of the region's largest rivers: the Nura, Sherubay-Nura, Taldy, Zharly, Kengir, Sarysu, and several other streams. The water-bearing rocks here are modern and Upper Quaternary alluvial deposits, consisting of inequigranular sands, sandy-gravel-pebble formations with interlayers of clays and loams. The thickness of the alluvial deposits is typically 15-30 m, but in some valley sections it can reach 40-50 m.

A characteristic feature of these deposits is the absence of a consistent aquiclude between the Quaternary formations of different ages, resulting in the formation of a single underground groundwater flow.

The depth of the groundwater table within the river valleys ranges from 1.5 m in floodplain areas to 6-8 m on the above-floodplain terraces.

The filtration properties of alluvial deposits are characterized by high values. Transmissibility coefficients reach 300-1000 m²/day, indicating the high-water content of these rocks.

Groundwater recharge occurs primarily through the infiltration of river floodwaters. Spring floods play a decisive role in shaping the water balance of river valleys. During this period, up to 80-90% of the annual runoff passes through river systems.

These conditions create favorable conditions for the application of artificial groundwater recharge (MAR) technologies.

The most effective technological scheme for this group of regions is an open artificial groundwater recharge system using infiltration basins.

Within this scheme, surface water is directed into special infiltration structures, where it gradually seeps through the alluvial sediments into the aquifer.

Such systems are widely used worldwide and have proven their effectiveness in arid climates [1]. Large groundwater reservoirs in Central Kazakhstan are planned primarily in the valleys of the region's main rivers: the Nura, Sherubai-Nura, Taldy, Zharly, Tunduk, Kengir, Sarysu, and others. The water-bearing rocks are modern and Upper Quaternary alluvial deposits-inequigranular sands, sandy-gravel, and pebble layers interbedded with clays, loams, and sandy loams. The absence of a consistent impermeable layer forms a single underground stream with a depth of 1.5-6 m and a water-bearing rock thickness of 15-30 m; the water capacity varies from 300 to 1000 m²/day. The width of the natural stream is 3-5 km, while large valley widenings reach 10-14 km in diameter and up to 40 km in length, forming isolated deposits with high exploitable reserves. Groundwater is primarily recharged by the filtration of river flood discharges, which account for 80-90% of annual runoff.

Topographic, geomorphological, and hydrogeological conditions, including the composition of water-bearing rocks and the presence of large hydrogeological reservoirs, create favorable conditions for the development of multi-purpose reservoirs for municipal, industrial, and agricultural water supply, including irrigation. For such areas, the use of an open Type I MAR system with infiltration basins is recommended. The typical design involves gravity-fed surface water with a settling basin, infiltration basins, and horizontal water intakes (Figure 2).

In Central Kazakhstan, a promising area is the use of innovative technical solutions for groundwater regulation, which can be integrated into MAR schemes. Below are the most interesting devices and methods applicable to the region's river valleys, including the Nura, Sherubai-Nura, Taldy, Zharly, Tunduk, Kengir, and Sarysu.

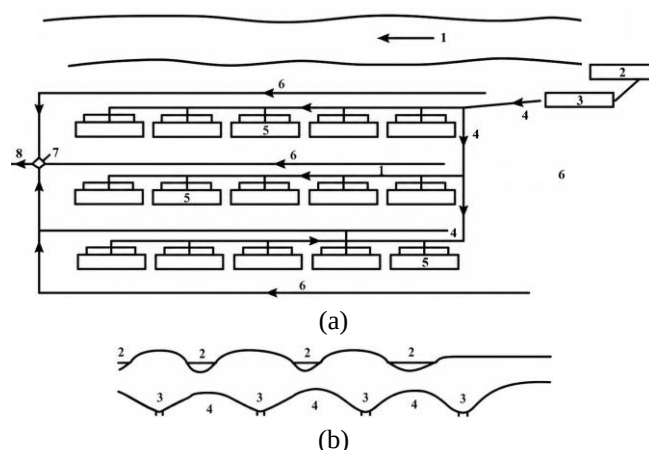


Figure 2. Scheme of the open gravity-flow MAR system, type I: a – plan view: 1 – river; 2 – river water intake; 3 – settling basin; 4 – pipelines supplying water to the infiltration basins; 5 – infiltration basins; 6 – horizontal water intakes (drainage pipes); 7 – collection well with chlorination; 8 – water conduit to the consumer; b – cross-section: 2 – infiltration basins; 3 – drainage pipes; 4 – aquifer

The groundwater accumulation regulating device (patent RU 2621359, Figure 3) pertains to water supply systems. It includes underground water intake wells or boreholes, shut-off and control pipelines, and a watertight barrage that completely seals off the aquifer in thickness and width, creating an underground reservoir.

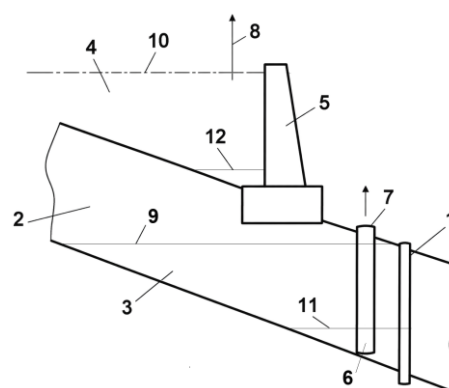


Figure 3. Device for regulating underground water accumulation

Distinctive features from the prototype include:

- the combined location of the above-ground dam and underground barrage within the same section;
- the formation of an underground screen between the piles;
- a water intake well located above the flood level;
- the possibility of mutual water transfer between the underground and above-ground reservoirs;
- reservoir volume control using pipelines;
- minimization of environmental impact.

This combination of features ensures reliable water intake throughout the year, including low-water periods, with efficient use of the underground and above-ground capacity of the mountain river valley (RU 2621359).

Device for regulating freshwater reserves (patent RU 2621268, Figure 4) is used to control underground and surface runoff in mountain river valleys with periodically drying up watercourses, increasing the reliability of water intake and providing the possibility of increasing its volume.

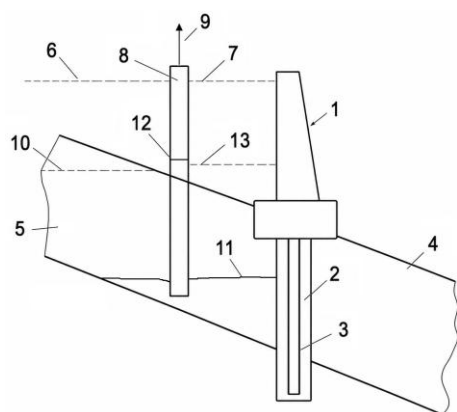


Figure 4. Device for regulating groundwater reserves

Underflow filtering water intake of combined design (patent RU 2518634, Figure 5) is designed for rivers with challenging hydrological conditions. It includes a collection gallery with a filter intake consisting of a metal grate and two rows of flexible filter mats laid along and across the channel flow. This design increases the reliability of the water intake system and allows it to be used for drinking water supply to small towns, enterprises, and as a backup supply for large population centers.

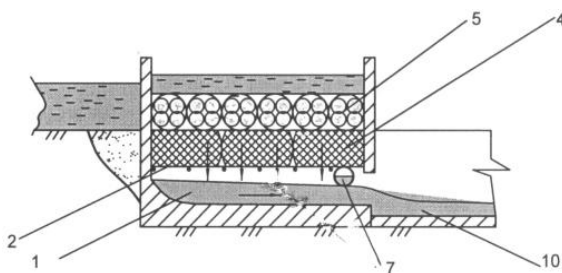


Figure 5. Underflow filtering water intake

The high-turbidity water treatment unit (patent RU 2321440, Figure 6) is a floating water treatment plant with inclined thin-layer modules, a floating filter bed, water collection channels, and a backwash collector. It ensures the effective removal of suspended solids (up to 5-10 g/l), organic and mineral impurities, and complete water disinfection without the need for additional sedimentation facilities.

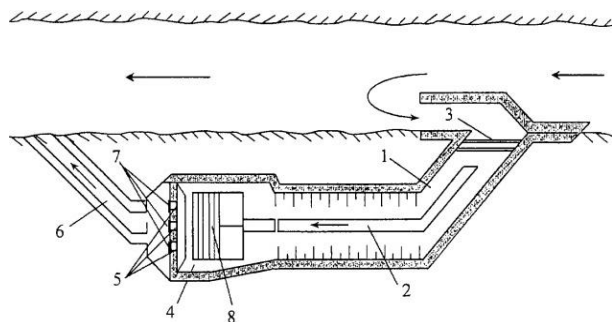


Figure 6. Device for purifying highly turbid waters

Air pumps are installed within the water intake zone, periodically pumping air to form a watertight barrage and an underground reservoir in the upstream pool. As the groundwater level drops, air supply is resumed to maintain the required reservoir capacity.

During the cold season, when groundwater flow accumulates in the unconfined aquifer, a trench is dug in the air pump area, removing the vegetation layer and snow cover. This increases the depth of soil freezing and ensures the reliable operation of the underground reservoir.

Method of regulating groundwater reserves (patent RU 2244785, Figure 7) involves creating an impermeable barrage across the river valley, which partially or completely blocks the aquifer, reduces groundwater flow beyond the barrage, and stores groundwater during high-water periods. During low-water periods, water is released according to demand. Air pumps are installed within the intake zone to control the reservoir's level, and in winter, if necessary, measures are taken to increase soil freezing to maintain water storage capacity.

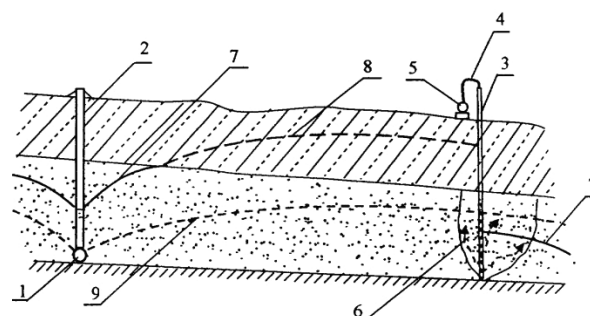


Figure 7. Device for regulating groundwater reserves

The use of such devices allows for the regulation of underground reserves, ensuring a stable water supply for settlements and industrial facilities, and creating strategic water reserves for agricultural irrigation. The process flow is adjusted depending on natural, climatic, and hydrogeological conditions.

For example, at the Zhartas groundwater deposit (Sherubay-Nura River valley), aquifer replenishment is achieved through the filtration of surface runoff, a reservoir, and flood discharges, while water intake capacity is increased by periodically flooding the central section of the infiltration water intake. Similarly, the water intake near Karaganda uses a 13 million m³ infiltration basin fed from the Tonarskoye Reservoir, designed for long-term flow regulation on the Sherubay-Nura River. In the Karaganda region, a 13 million m³ reservoir, functioning as an infiltration basin, is used for artificial groundwater recharge at a water intake used for municipal and industrial water supply. The reservoir is replenished by periodic water releases from the large Tonarskoye Reservoir, a long-term regulated reservoir on the Sherubay-Nura River.

In addition to river valleys, areas of carbonate structures, which are widespread in Central Kazakhstan, particularly in the southwestern part of the region, are promising for artificial groundwater recharge. Most of these structures are located near residential and industrial facilities requiring domestic and drinking water. Many structures have been explored, and their groundwater reserves have been confirmed by the State and Territorial Cadastre of Reserves. For example, the total exploitable reserves of 24 aquifers near the city of Zhezkazgan amount to 441 million m³/year, of which 145 million m³/year are approved by the State Reserves Committee.

The high filtration properties of carbonate rocks ensure efficient groundwater accumulation and flushing, making them suitable for water supply to large facilities. Geological

and hydrogeological studies allow us to accurately determine the marginal boundaries of these structures and calculate the volume of their reservoirs. Aquifer complexes of carbonate and terrigenous rocks of the Devonian-Carboniferous period are identified within the brachyanticline, synclinal, and more complex structures of the Zhezkazgan-Ulatau, Niyaz-Yerementau, and other districts [10]. The areas of aquifers vary from 60 km² (Saryopan) to 850 km² (Zhailmen), with a thickness of water-bearing deposits of 30-50 m, in places reaching 150-200 m.

Groundwater in carbonate structures occurs at depths ranging from 5-10 m at the periphery to 40-50 m in the center of the basins. Groundwater pressure can reach 4-30 m, with piezometric levels ranging from 0.6 to 18 m above the surface. The main reserves are located in the karst zone and limestone fractures, forming subartesian basins with unconfined and confined waters.

The carbonate structures of the Zhezkazgan region are of particular economic importance. Studies on the Aidos brachyanticline, cut by the Karakengir River valley, have shown high filtration of the bottom of the reaches, composed of coarse gravel, crushed rock, and pebbles. The hydraulic relationship between groundwater in alluvial deposits and the surface waters of the river is significant. The Karakengir aquifer and the fissure-karst waters of carbonate rocks provide a replenishment rate of up to $2.75 \cdot 10^6$ m³/day at the Aidos water intake site. Similar results are observed at 12 aquifers near the city of Zhezkazgan, where the total groundwater replenishment volume exceeds 30 million m³/year (≈ 1000 dm³/s).

For the creation of large underground reservoirs, it is recommended to use open, gravity-fed artificial groundwater replenishment systems (Type I) with artificial reservoirs to accumulate flood runoff and recharge groundwater. Direct withdrawal of water from reservoirs for domestic and drinking purposes is impractical due to the high content of suspended solids and the unstable sanitary and bacteriological condition of the water, which requires preliminary treatment. The most suitable for artificial groundwater replenishment are closed brachyanticline basins, such as the Eskulin, Zhanai, Aidos, Sarybulak, Mashuran, and Alaigyr structures, composed of permeable rocks capable of retaining significant volumes of water. Groundwater replenishment can be achieved by using surface water from the Zhezda, Kengir, Sarybulak, Sherubai-Nura, and other rivers.

For type II aquifers, closed process systems employing infiltration wells at depths of up to 15-20 meters and absorption wells at greater depths are rational. These systems can also be used to dilute brackish groundwater in limestone structures. The process system includes preliminary treatment and preparation of river water before injection to improve drinking water quality and reduce suspended solids and microorganisms.

4. Conclusions

In conclusion, the study emphasizes that Central Kazakhstan possesses significant and largely underutilized potential for the implementation of artificial groundwater replenishment technologies. This is due to a combination of favorable hydrogeological conditions, geomorphological features, and the region's arid and semi-arid climate. The conducted

zoning of the territory allowed us to substantiate the identification of zones of varying potential, forming a scientific and practical basis for a differentiated approach to the design and placement of artificial groundwater replenishment systems.

The most promising areas, located along the valleys of major rivers (Nura, Sherubay-Nura, Taldy, Zharly, Tunduk, Kengir, Sarysu, etc.), are characterized by thick alluvial deposits with high filtration properties. These conditions create the preconditions for the formation of significant underground reservoirs, effectively replenished by flood runoff. In turn, type II carbonate structures (Zhezkazgan-Ulatau and Niyaz-Yerementau districts) possess high potential due to their extensive fracturing and karstification, which facilitates intensive infiltration and accumulation of groundwater.

The technological schemes for artificial groundwater replenishment, both open and closed, developed as part of the study allow for the flexible adaptation of engineering solutions to specific environmental conditions. The use of infiltration basins, regulated water intake structures, and absorption wells not only increases groundwater reserves but also manages their regime. Technologies using absorption wells are particularly important for carbonate formations, where targeted dilution of brackish water by injecting fresh surface water is possible.

Furthermore, ensuring high quality of the injected water is a key condition for the effective implementation of artificial groundwater replenishment. The need for preliminary water treatment and preparation is driven by the unstable hydrochemical and sanitary-bacteriological conditions of surface water. The implementation of modern treatment facilities and water quality control systems should be considered a mandatory element of the entire process chain.

Equally important are the organizational and environmental aspects: the successful operation of artificial groundwater recharge systems requires continuous monitoring of the hydrogeological regime, control of filtration and mixing processes, and an assessment of potential aquifer contamination risks. Only by meeting these conditions can the environmental safety and long-term sustainability of water management systems be ensured.

Thus, the study results confirm that the integrated application of artificial groundwater recharge technologies, based on consideration of natural conditions, the use of modern engineering solutions, and strict adherence to environmental requirements, is one of the most promising areas for water supply development in Central Kazakhstan. The implementation of the proposed approaches will improve the reliability of water supply, ensure the rational use of water resources, and create a sustainable basis for the socio-economic development of the region in the context of increasing freshwater shortages.

Author contributions

Conceptualization: AMY, AZZ; Data curation: AMJ; Formal analysis: AMJ; Funding acquisition: AMY; Investigation: AMY; Methodology: AMY; Project administration: AMY; Resources: AZZ; Software: GET, AKA; Supervision: GET, AKA; Validation: AMY, AZZ; Visualization: GET, AKA; Writing – original draft: AMY, AMJ; Writing – review & editing: AZZ. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Орталық Қазақстанда жасанды толықтыру әдістерін қолдана отырып, ірі жер асты су қоймаларын құрудың негіздемесі

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Андатпа. Бұл мақалада Орталық Қазақстандағы ірі жер асты су қоймаларының физикалық, географиялық және гидрогеологиялық жағдайларын ескере отырып, жасанды жер асты суларын қайта толтырудың типтік схемаларының негіздемесі келтірілген. Мақаланың мақсаты - су қоймаларының сипаттамаларына, су көздерінің қолжетімділігіне және аймақтың суға деген сұранысына негізделген қазіргі заманғы сулы қабаттарды қайта толтыру әдістерін талдау және олардың тиімділігі мен қолданылуын бағалау. Мақалада жасанды жер асты суларын қайта толтырудың әртүрлі технологиялық схемалары және сүзу процестерін реттеу шаралары қарастырылады, олардың техникалық және экономикалық мүмкіндігі бағаланады. Алынған нәтижелер аймақтың су ресурстарын оңтайлы пайдалану, тұрақты сумен жабдықтауды қамтамасыз ету және табиғи экожүйелерге теріс әсерді азайту бойынша ұсыныстар әзірлеуге мүмкіндік береді. Сонымен қатар, мақалада геологиялық және әлеуметтік-экономикалық факторларды ескеретін суды пайдалануды жоспарлауға кешенді тәсілдің маңыздылығы атап өтілген.

Негізгі сөздер: жер асты сулары, жасанды қайта толтыру, сулы қабаттар, технологиялық схемалар, Орталық Қазақстан, гидрогеология, суға деген сұраныс.

Обоснование создания крупных подземных водохранилищ в Центральном Казахстане методами искусственного восполнения запасов

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Аннотация. В работе представлено обоснование типовых схем искусственного восполнения подземных вод с учётом физико-географических и гидрогеологических условий крупных подземных водохранилищ Центрального Казахстана. Цель работы заключается в анализе современных методов восполнения водоносных горизонтов, оценке их эффективности и применимости в зависимости от характеристик коллекторов, наличия источников воды и водопотребности региона. В работе рассмотрены различные технологические схемы искусственного восполнения подземных вод и мероприятия по регулированию фильтрационных процессов, с оценкой их технической и экономической целесообразности. Полученные результаты позволяют разработать рекомендации по оптимальному использованию водных ресурсов региона, обеспечению устойчивого водоснабжения и снижению негативного воздействия на природные экосистемы. Кроме того, работа подчеркивает значимость интегрированного подхода к планированию водопользования, учитывающего как геологические, так и социально-экономические факторы.

Ключевые слова: подземные воды, искусственное восполнение, водоносные горизонты, технологические схемы, Центральный Казахстан, гидрогеология, водопотребность.

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