SATBAYEV UNIVERSITY

Engineering Journal of Satbayev University

Volume 147 (2025), Issue 3, 40-47

https://doi.org/10.51301/ejsu.2025.i3.06

# Monitoring of the water and salt balance of the Bakbakty rice irrigation system under reuse of collector-drainage water for irrigation

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**Abstract.** This study presents the methodology, approach, and results of calculating the components of water and salt balances based on three years of field research on the reuse of collector-drainage water in the Tasmurun area of the Bakbakty irrigation system, under arid and low-water conditions typical for water-demanding rice fields. Balance calculations were based on data from in situ observations with active involvement of local farmers, ensuring data reliability. The water balance showed a slight negative discrepancy ranging from 0.4-0.6% in 2022 and 0.001-0.02% in 2023-2024, confirmed by groundwater level monitoring and maps. The salt balance showed a slight accumulation, with values from +0.016 to +0.29 t/ha in field No. 2 and +0.049 to +0.089 t/ha in field No. 4. Seasonal salt increases were linked to leaching regimes and the dominance of easily soluble salts, posing no threat to land reclamation status.

***Keywords:*** *water and salt balance, irrigated lands, drainage systems, collector-drainage water, salinity, water quality.*

Received: 10 January 2025
Accepted: 15 June 2025
Available online: 30 June 2025

## 1. Introduction

The review and analysis of domestic and international publications and scientific studies demonstrate increasing attention to water and salt balance research and the reclamation status of rice irrigation systems. These issues have become central in recent years as tools for actively managing irrigated areas' water-salt regime and regulating groundwater levels during both the growing and non-irrigated seasons for rice and accompanying crops. The growing scarcity of water resources necessitates the search for additional sources of irrigation water, including the reuse of collector-drainage water formed within rice irrigation systems [1-4].

For example, Y. Okuda (2020) [5] presented results of water and salt balance studies on agricultural lands subject to leaching, using shallow subsurface drainage combined with traditional drainage. Secondary salinization in arid regions was shown to raise groundwater levels. The system was implemented on farmland in Uzbekistan.At the 16th International Conference «Monitoring of Geological Processes and Ecological Condition of the Environment», Rokochynskiy et al. (2022) [6] analyzed the causes of unsatisfactory hydrological and reclamation conditions in Danube rice irrigation systems. Their study proposed improving drainage efficiency by reducing the vertical infiltration rate in the drainage zone to no more than 25 mm/day. Turchenyuk et al. (2017) [7] examined the water balance and salt distribution in arable lands, wastelands, and ponds in a typical irrigated area. A water balance model was developed to assess irrigation impacts on soil salinity across different land types. R. Singh, J.C. van Dam, and R.K. Jhorar [8] applied a calibrated SWAP agro-hydrological model to assess water and salt balances on farm fields. Soil hydraulic properties were identified as key variables and were calibrated using PEST based on measured soil moisture and salinity before and after irrigation. Kasymbetova and Ergasheva (2020) [9] evaluated the water-salt balance of floodplain areas, the aeration zone, and root zone of crops in the Shuruzak massif of the Syrdarya region, assessing the reclamation status of irrigated lands. Zaitsev V.B., Semenenko A.N. [10], and Reshetnyak N.F. [11] described the features of groundwater regimes in flooded rice fields and the effects of groundwater on the dynamics of water-soluble salts in paddy soils.

Thus, the discussion and analysis of numerous studies confirm the critical importance of water-salt balance analysis. The justification of real and forecasted parameters for the quantitative and qualitative potential of collector-drainage water reuse must be based on accurate water and salt balance data [12]. Furthermore, in irrigation practice, it is often necessary to evaluate long-term average balances and those specific to water availability levels and critical seasonal periods.

Accordingly, this study presents the methodology and results of calculating all inflow and outflow components of the water and salt balance at the field level for a rice-alfalfa crop rotation system. These findings summarize three years of field-based scientific research on implementing collector-drainage water reuse technologies in the Tasmurun section of the Bakbakty irrigation system.

## 2. Materials and methods

The field research was conducted in the Balkhash district of the Almaty region, Republic of Kazakhstan, within the Ili River basin, specifically in the Tasmurun area of the Bakbakty system of the Akdaly irrigation massif.

The irrigated lands are located within part of the ancient delta of the Ili River, whose surface was shaped by successive erosional and accumulative processes against the background of aeolian activity. The average surface slope is approximately 0.0002.

Climatically, the area belongs to the desert zone, which, combined with the shallow depth of the groundwater table, contributes to the intensive development of salt accumulation processes in the soil profile.

As a representative site for implementing the technology of collector-drainage water reuse, the irrigation (Tasmurun Main Canal) and collector-drainage network (collector K-2) of the Tasmurun section of the Bakbakty irrigation system were selected. These systems serve the irrigated lands of SPK «Miyaly Agro», PC «Dinara», and LLP «EDD».

The beneficiaries and direct participants of the experimental studies included three farming enterprises – «Raimbek», «Bagnur», and «Alga» - affiliated with SPK «Miyaly Agro» and PC «Dinara».

The total irrigated area of the six-field rice-alfalfa crop rotation system is 890 hectares, of which the experimental area covers 607 hectares, including:

– Field 2. 173 ha (81 ha under SPK «Miyaly Agro» and KFH «Alga», and 92 ha under PC «Dinara»);

– Field 3. 187 ha under PC «Dinara»;

– Field 4. 138 ha under PC «Dinara»;

– Field 5. 109 ha under LLP «EDD».

The cropping structure for 2022-2024 was as follows: rice was cultivated on fields 2 (173 ha) and 4 (138 ha), while alfalfa was cultivated on fields 3 (187 ha) and 5 (109 ha) (Figure 1).

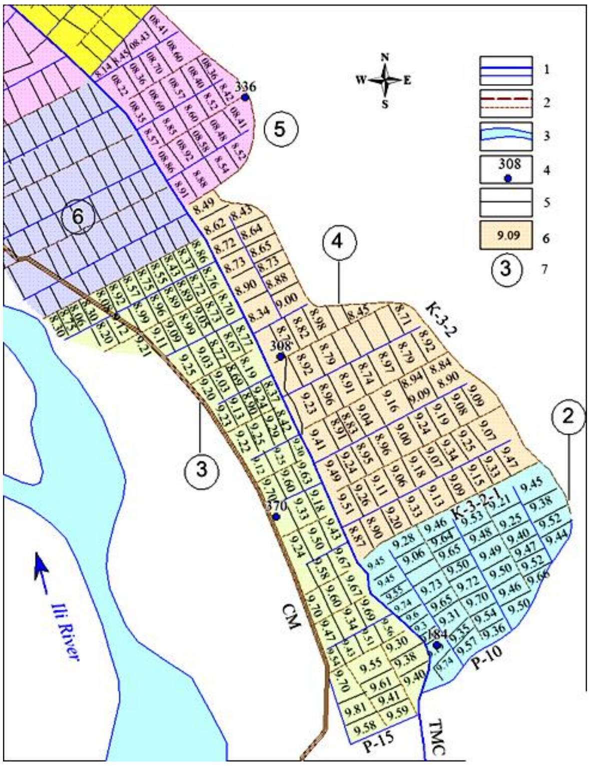



***Figure 1. Schematic map of the irrigation and collector-drainage network with land use layout for the experimental research plots (III rotation system, fields 2, 3, 4, and 5): 1 – irrigation canals; 2 – collectors; 3 – river; 4 – monitoring hydrogeological well and its inventory number; 5 – boundary of the rice check; 6 – absolute elevation of the rice check; 7 – field number***

The water and salt balance calculations were based on empirical data from stationary hydrogeological monitoring, measurements of collector-drainage water flow, meteorological observations, and agricultural and water management conditions information. These calculations were conducted separately for two experimental fields (fields 2 and 4), where rice was cultivated in 2022 under the existing irrigation regimes and technical operation conditions of the Tasmurun section of the Bakbakty massif, and in 2023-2024 using a recirculating water use system.

The water balance equation for the irrigated experimental plots is as follows [12]:

$$S_w + S_r + S_g - S_d - S_e - S_i - S_f = \pm\Delta S, \text{ million m}^3 \quad (1)$$

where:

$\pm\Delta S$ – balance discrepancy;

$S_w$ – volume of irrigation water;

$S_r$ – atmospheric precipitation;

$S_g$ – groundwater inflow into the experimental site;

$S_d$ – volume of drainage-discharge outflow;

$S_e$ – total evaporation;

$S_i$ – infiltration into the aeration zone from irrigation and mixed irrigation-drainage water;

$S_f$ – lateral filtration outflow beyond the experimental plots.

The incoming components of the water balance included: the amount of atmospheric precipitation, the volume of irrigation water supplied (including the reuse of collector-drainage water), and the inflow of groundwater to the experimental plots.

The total volume of precipitation received over the irrigated area of fields No. 2 and No. 4 (planted with rice) during the hydrological year was calculated using the formula:

$$S_a = N_a \cdot S_r, \quad (2)$$

where:

$N_a$ – total atmospheric precipitation, mm;

$S_r$ – total calculated area, ha.

The volume of irrigation water supplied was determined based on two conditions: in the first year of the experiment, the existing irrigation regimes and technical operating parameters were used; in the subsequent two years, recommended irrigation regimes and rice irrigation technologies with implementation of a recirculating water reuse system were applied.

Groundwater inflow to the field-level experimental plots of the Tasmurun irrigation system was calculated using the formula:

$$S_g = J \cdot B \cdot T \cdot 365, \quad (3)$$

where:

$J$ – average hydraulic gradient of the groundwater table for the hydrological year;

$B$ – width of the groundwater flow, m;

$T$ – transmissivity of the aquifer, m$^2$/day.

The outgoing components of the water balance included: the volume of drainage-discharge flow, the total evaporation, the volume of water that infiltrated into the aeration zone due to irrigation and mixed irrigation-collector-drainage water, and the lateral filtration outflow of groundwater beyond the boundaries of the experimental plots.

Drainage-discharge flow was estimated based on hydrometric measurements of collector-drainage water discharge from the irrigated lands of the experimental plots at certified hydrological posts during the growing season.

The formula calculated the lateral filtration outflow of groundwater beyond the experimental area:

$$S_f = J \cdot B \cdot T \cdot 240, \tag{4}$$

where:

$J$ – hydraulic gradient derived from the post-irrigation hydroisohypse map;

$B$ – width of the subsurface flow, m;

$T$ – aquifer transmissivity, $m^2$/day;

240 – average duration of the calculation period, days.

The actual parameters were based on maps of filtration coefficients and hydrogeological cross-sections developed for the experimental sites.

The volume of moisture accumulated in the aeration zone was calculated as:

$$S_i = F_n \cdot h_{avg} \cdot W_{avg}, \tag{5}$$

where:

$F_n$ – total area of the calculated land plots with uniform groundwater depths and saturated zone thickness, before and after irrigation ($m^2$). These were determined from monitoring well data and interpolated according to the delineated calculation contours for the experimental sites.

$h_{avg}$ – average groundwater level change during the irrigation period within the calculation contours (m), obtained from constructed groundwater fluctuation graphs from 2021 to 2024 (Figure 2);

$W_{avg}$ – average volumetric water content of the aeration zone soil, expressed as a fraction. The volumetric moisture and field capacity values were taken from field and laboratory investigations.

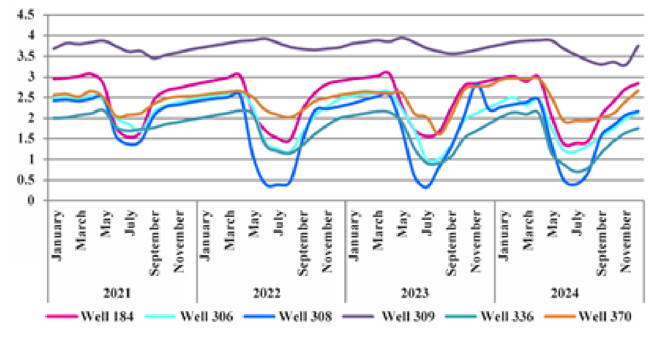



***Figure 2. Groundwater level fluctuation graphs in monitoring wells located on irrigated lands of the experimental research plots and adjacent areas during the observation period from 2021 to 2024***

The salt balance was calculated using the following equation:

$$\pm\Delta M = M_{gn} + M_w + Ma - M_{gk} - M_d - M_f, \quad \ldots\ldots(6)$$

where:

$\pm\Delta M$ – balance discrepancy;

$M_{gn}$ – salt content in groundwater of the balance layer at the beginning of the calculation period;

$M_{gk}$ – the same at the end of the calculation period;

$M_v$, $M_a$ – the volume of salts brought in with irrigation water and precipitation, respectively;

$M_d$, $M_f$ – the volume of salts carried out by the corresponding drainage and underground outflow outside the massif.

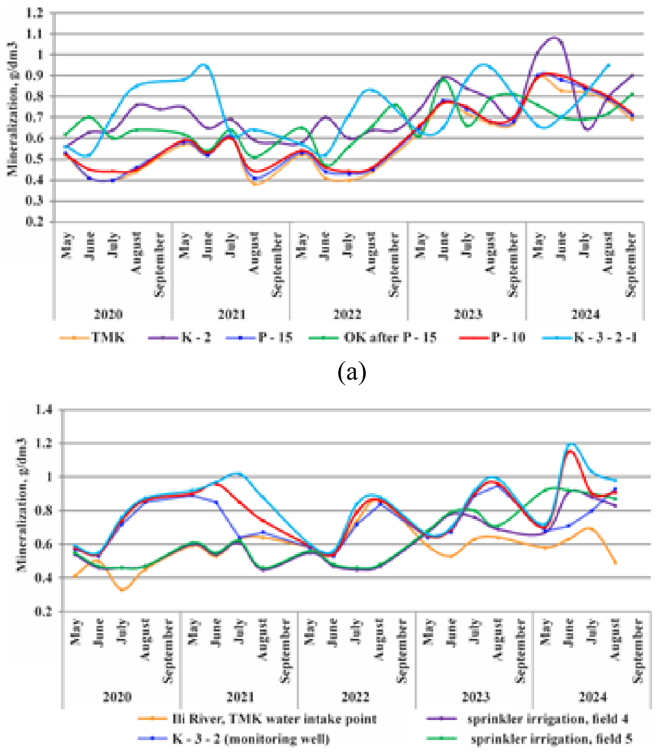
The volume of salts brought in with irrigation water, precipitation and underground inflow within the calculation contour was calculated using the equation:

$$M_v = W \cdot m, \tag{7}$$

where:

$W$ – water volume, million $m^3$;

$m$ – mineralization of irrigation water (2022) and mixed with collector-drainage water (2023-2024) (Figure 3); groundwater mineralization (Figure 4), mg/$dm^3$.




(a)

(b)

***Figure 3. Dynamics of mineralization of irrigation and collector-drainage waters on irrigated lands of the experimental site and adjacent territories, a) before the start (2020-2022) and b) during the research (2023-2024), g/dm³***

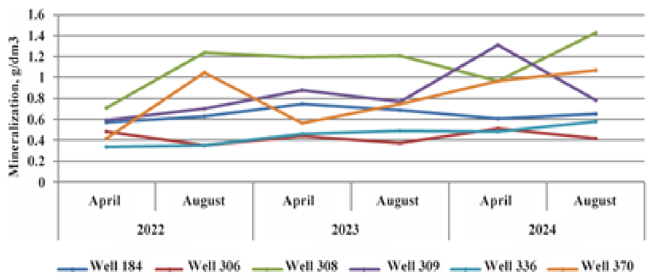



***Figure 4. Graph of the dynamics of groundwater mineralization in monitoring pits on irrigated lands of experimental sites before the beginning (2022) and during scientific research (2023-2024), g/dm³***

The salt content in groundwater of the balance layer at the beginning of the calculation period was determined by the calculation filtration blocks and by the equation:

$$M_{gn} = 0.001 \cdot F \cdot (h_y - h_{gw}) \times W_n \cdot M_{gw}, \quad (8)$$

where:

0.001 – conversion factor;

$F$ – area of the calculation contour, ha;

$h_y$ –depth of the balance layer base (10 m);

$h_{gw}$ – average weighted depth of groundwater at the beginning of the calculation period, m

$W_n$ – total moisture capacity of aquifers;

$M_{gw}$ – average weighted mineralization of groundwater within the calculation contour at the beginning of the calculation period, mg/dm$^3$ (Figure 4).

The volume of salts carried beyond the design contour by underground outflow was calculated using the equation:

$$M_f = W \cdot m, \quad (10)$$

$W$ – the volume of groundwater carried beyond the design contour by underground outflow (taken from water balance articles), million m$^3$;

$M$ – groundwater mineralization during the non-growing season, mg/dm$^3$.

The volume of salts carried beyond the design contour by collector-drainage runoff was calculated using the equation:

$$M_{drain} = W_{drain} \cdot m, \quad (11)$$

where:

$W$ – the volume of collector-drainage runoff (taken from the water balance) of groundwater carried beyond the design contour by underground outflow (taken from water balance articles), million m$^3$;

$m$ – the mineralization of collector-drainage runoff, mg/dm$^3$.

The salt content in groundwater of the balance layer at the end of the calculation period was determined based on the calculation filtration blocks and the equation:

$$M_{gk} = 0.001 \cdot F \cdot (h_y - h_{gw.e}) \cdot W_n \cdot M_{gw.e}, \quad (9)$$

where:

$h_{gw.e}$ – weighted average depth of groundwater at the end of the calculation period, m;

$W_n$ – total moisture capacity of aquifers;

$M_{gw.e}$ – weighted average mineralization of groundwater within the calculation contour at the end of the calculation period, mg/dm$^3$ (Figure 4).

Wells 184, 306 and 308 – rice; wells 336, 370 – alfalfa; well 309 – on cutting. Figure 4 shows the graph of the dynamics of groundwater mineralization in monitoring wells on irrigated lands of experimental sites before the start (2022) and during scientific and applied research (2023-2024), g/dm$^3$.

## 3. Results and discussion

Table 1 presents detailed results of the calculated inflow and outflow components of the water balance for irrigated lands at the experimental plots of the Tasmurun irrigation system.

***Table 1. Water balance of irrigated lands at the experimental plots of the Tasmurun irrigation system with the implementation of a field-level return-flow reuse system of collector-drainage water, before (2022) and during the applied scientific research period (2023-2024)***

| Components of the balance sheet | On rice crops of experimental field No. 2 | | | | On rice crops of experimental field No. 4 | | | |
|---|---|---|---|---|---|---|---|---|
| | Year of experiment | m$^3$/ha | million m$^3$ | % | Year of experiment | m$^3$/ha | million m$^3$ | % |
| Incoming balance sheet items | | | | | | | | |
| Water supply | 2022 | 23879 | 4.131 | 92.9 | 2022 | 26082 | 3.599 | 93.3 |
| | 2023 | 22900/17518* | 3.962/3.031* | | 2023 | 22900/17518* | 3.16/2.417* | |
| | | 5382** | 0.931** | 93.5 | | 5382** | 0.743** | 93.5 |
| | 2024 | 22900/17518* | 3.962/3.031* | | 2024 | 22900/17518* | 3.16/2.417* | |
| | | 5382** | 0.931** | 91.4 | | 5382** | 0.743** | 91.0 |
| Atmospheric precipitation | 2022 | 1489 | 0.258 | 5.8 | 2022 | 1489 | 0.206 | 5.3 |
| | 2023 | 1241 | 0.214 | 4.8 | 2023 | 1241 | 0.171 | 5.1 |
| | 2024 | 1860 | 0.322 | 7.2 | 2024 | 1860 | 0.257 | 7.4 |
| Groundwater inflow | 2022 | 323.7 | 0.056 | 1.3 | 2022 | 355.1 | 0.049 | 1.4 |
| | 2023 | 358.4 | 0.062 | 1.7 | 2023 | 333.3 | 0.046 | 1.4 |
| | 2024 | 283.2 | 0.049 | 1.4 | 2024 | 384.1 | 0.053 | 1.6 |
| Total | 2022 | 25691.7 | 4.445 | 100 | 2022 | 27926.1 | 3.854 | 100 |
| | 2023 | 24499.4 | 4.238 | 100 | 2023 | 24474.3 | 3.380 | 100 |
| | 2024 | 25043.2 | 4.333 | 100 | 2024 | 25144.1 | 3.470 | 100 |
| Balance sheet expense items | | | | | | | | |
| Total evaporation | 2022 | 10930 | 1.890 | 41.7 | 2022 | 10930 | 1.5083 | 38.9 |
| | 2023 | 10930 | 1.890 | 42.5 | 2022 | 10930 | 1.5083 | 44.6 |
| | 2024 | 10930 | 1.890 | 43.6 | 2022 | 10930 | 1.5083 | 43.4 |
| Drainage and discharge flow | 2022 | 12768 | 2.209 | 50 | 2022 | 14717 | 2.031 | 63.5 |
| | 2023 | 11855 | 2.051 | 50.3 | 2023 | 11348 | 1.566 | 46.3 |
| | 2024 | 12572 | 2.175 | 49.9 | 2024 | 11877 | 1.639 | 47.1 |
| Moisture accumulation in the aeration zone | 2022 | 1601.0 | 0.277 | 6.0 | 2022 | 1754 | 0.243 | 6.2 |
| | 2023 | 1277.4 | 0.221 | 4.9 | 2023 | 1442 | 0.199 | 5.9 |
| | 2024 | 1304.6 | 0.179 | 4 | 2024 | 1601 | 0.221 | 6.3 |
| Groundwater outflow | 2022 | 514.4. | 0.0894 | 2.3 | 2022 | 710.1 | 0.098 | 2.4 |
| | 2023 | 549.1 | 0.095 | 2.3 | 2023 | 797.1 | 0.11 | 3.2 |
| | 2024 | 595.4 | 0.103 | 2.5 | 2024 | 797.1 | 0.11 | 3.2 |
| Total | 2022 | 25809 | 4.465 | 100 | 2022 | 28111.1 | 3.879 | 100 |
| | 2023 | 246112.5 | 4.258 | 100 | 2023 | 24490.3 | 3.383 | 100 |
| | 2024 | 25127.0 | 4.347 | 100 | 2024 | 25205.1 | 3.478 | 100 |
| Balance (discrepancy) of the balance | 2022 | -117.3(0.4%) | -0.020 | – | 2022 | -190(0.6%) | - 0.025 | – |
| | 2023 | - 116.5(0.5%)) | -0.020 | – | 2023 | -19.8 (0.001%) | - 0.003 | – |
| | 2024 | - 83.8 (0.3%) | - 0.014 | – | 2024 | -58.1(0.2%) | - 0.008 | – |

Assessment of Precipitation and Irrigation Contributions to the Water Balance of Rice Fields in the Tasmurun Irrigation System under Conditions of Water Scarcity (2022-2024)

According to data from the Bakanas Regional Meteorological Station, the total volume of atmospheric precipitation on the irrigated lands of fields No. 2 and No. 4 amounted to 257.6 and 205.5 thousand m³ in 2022, 214.7 and 171.3 thousand m³ in 2023 and 321.8 and 256.7 thousand m³ in 2024, respectively. These values indicate prevailing arid and water-deficient climatic conditions, as precipitation contributed only 4.5-7.4% to the total inflow components of the water balance.

In 2022, the volume of irrigation water supplied by the state municipal enterprise for water management «Balkhashirrigation» for rice cultivation in fields No. 2 and No. 4 amounted to 4.13 and 3.59 million m³, respectively. The net irrigation norm at the field level was 23.87 and 26.08 m³/ha.

With the implementation of recommended irrigation regimes and rice irrigation technologies, including using a return flow system to reuse collector-drainage waters, the total irrigation volume in 2023-2024 was reduced. For fields No. 2 and No. 4, the irrigation volumes were 3.962 and 3.16 million m³, respectively, with a unified net irrigation norm of 22.90 m³/ha. Of these totals, 3.03 and 2.41 million m³ were supplied from the surface water of the Ili River. At the same time, 0.931 and 0.743 million m³ originated from collector-drainage waters pumped from collector K-2 into the Tasmurun central canal. The substitution of irrigation water with drainage water accounted for approximately 23.5% across both experimental sites during 2023-2024.

The calculations confirm that irrigation is the primary forming component of the water balance, with irrigation water volumes contributing from 91.0% to 93.4% of the total inflow balance.

The value of total evapotranspiration was assumed to be 10.93 thousand m³/ha for all three years of the study, constituting more than 40% of the total outflow balance. This finding supports the widely accepted understanding that rice, being cultivated under waterlogging or partial submersion conditions, belongs to the group of hydrophytes. Hydrophytic plants exhibit high transpiration rates and possess permanently open stomatal apparatuses. As a result, the evapotranspiration of rice plants is equivalent to the rate of free evaporation from open water surfaces.

Changes in soil moisture reserves in the vadose zone and groundwater levels (Table 2) were influenced by rice crop area, infiltration water losses, and the depth of the groundwater table.

A salt balance calculation was performed to assess the direction of salt transfer processes on irrigated lands. The overall salt balance is directly related to the components of the water balance, since the movement of salts in the aeration zone occurs in the form of water-salt solutions (Table 3).

***Table 2. Moisture accumulation calculations in irrigated lands of experimental sites of the Tasmurun irrigation system before and during the field studies (2022-2024)***

| Increment, m | Year of research | Area of the calculated contour, ha | Average weighted depth of groundwater, m | | Increment, m | Volume due to increment, million m³ | Average volumetric moisture content of soils in the aeration zone, $W_{total}$ | Average volumetric moisture content of soils in the aeration zone, $W_{total}$ |
|---|---|---|---|---|---|---|---|---|
| | | | April | September | | | | |
| Field No. 2 | 2022 | 173 | 3.0 | 2.5 | +0.5 | 0.865 | 0.32 | 0.2773 |
| | 2023 | 173 | 3.0 | 2.6 | +0.4 | 0.692 | 0.32 | 0.2214 |
| | 2024 | 173 | 3.0 | 2.68 | +0.32 | 0.5597 | 0.32 | 0.1791 |
| Field No. 2 | 2022 | 138 | 3.0 | 2.45. | +0.55 | 0.7590 | 0.32 | 0.2429 |
| | 2023 | 138 | 3.0 | 2.55 | +0.45 | 0.6210 | 0.32 | 0.1987 |
| | 2024 | 138 | 3.0 | 2.5 | +0.5 | 0.690 | 0.32 | 0.2208 |

*Note: Table content should follow in your formatted manuscript with appropriate scientific units and descriptions*

***Table 3. Salt balance of irrigated lands on experimental plots (fields 2 and 4) III - its rice-alfalfa crop rotation of the Tasmurun irrigation system before the start (2022) and during scientific and applied research (2023-2024)***

| Balance sheet items | Elements of salt balance | On rice crops of experimental field No. 2 | | T/ha<br>tn | On rice crops of experimental field No. 4 | | T/ha<br>tn |
|---|---|---|---|---|---|---|---|
| | | A year of experimental research | | | A year of experimental research | | |
| | | 2022 | 2023 | 2024 | 2022 | 2023 | 2024 |
| Incoming | Salt content of the balance layer at the beginning of the calculation period before sowing rice | 1.28 | 1.36 | 1.344 | 1.395 | 2.044 | 2.53 |
| | | 221.6 | 236.15 | 232.51 | 192.51 | 282.07 | 349.31 |
| | The volume of salts brought in with irrigation and mixed drainage water | 12.178 | 16.259 | 17.862 | 14.345 | 16.717 | 17.175 |
| | | 2106.84 | 2812.81 | 3090.13 | 2481.69 | 2306.95 | 2370.15 |
| | The volume of salts brought in by atmospheric precipitation | 0.301 | 0.253 | 0.381 | 0.301 | 0.253 | 0.381 |
| | | 52.073 | 43.769 | 65.965 | 41.538 | 34.914 | 43.884 |
| | The volume of salts brought in by underground inflow | 0.226 | 0.286 | 0.269 | 0.302 | 0.366 | 0.461 |
| | | 39.098 | 49.478 | 46.537 | 41.676 | 50.508 | 63.618 |
| | Total | 13.985 | 18.158 | 19.856 | 16.343 | 19.380 | 20.547 |
| | | 2419.405 | 3142.21 | 3435.14 | 2255.33 | 2674.44 | 2841.81 |
| Outgoing | The salt content of the balance layer at the end of the calculation period after rice harvesting | 2.44 | 3.157 | 3.120 | 2.681 | 3.589 | 5.111 |
| | | 422.3 | 546.16 | 539.96 | 370.01 | 495.25 | 705.27 |
| | Removal of salts by collector-drainage runoff | 9.065 | 11.144 | 11.943 | 12.510 | 10.440 | 11.521 |
| | | 1568.0 | 1927.9 | 2066.2 | 1726.4 | 1440.7 | 1589.8 |
| | Removal of salts by filtration and discharge of runoff | 1.84 | 3.421 | 4.378 | 0.720 | 4.545 | 3.109 |
| | | 318.32 | 591.833 | 757.394 | 99.36 | 627.21 | 429.042 |
| | The volume of salts carried beyond the calculated contour by underground outflow | 0.350 | 0.399 | 0.399 | 0.497 | 0.757 | 0.717 |
| | | 60.55 | 69.013 | 69.013 | 68.596 | 104.499 | 98.946 |
| | Total | 13.695 | 18.121 | 19.840 | 16.408 | 19.331 | 20.458 |
| | | 2369.235 | 3134.933 | 3432.32 | 2264.36 | 2667.678 | 2832.204 |
| | Salt balance (mismatch), + increase, - decrease | +0.29 | +0.037 | +0.016 | -0.065 | +0.049 | +0.089 |
| | | +50.17 | +7.28 | +2.82 | -9.03 | +6.76 | +9.61 |

The magnitude of the positive discrepancy of the salt balance in the experimental plots (fields 2 and 4) III - its rice-alfalfa crop rotation of the Tasmurun irrigation system before the start (2022) and during scientific and applied research (2023-2024) amounted to minimal values, even with the repeated use of collector-drainage waters from +0.016 to +0.29 tons/ha in rice field No. 2 and from +0.049 to +0.089 tons/ha in rice field No. 4, which indicates the predominance of insignificant accumulation of salt reserves in the zone of active salt exchange during the growing season. The leaching regime of rice and the prevalence of readily soluble salts in the chemical composition of groundwater, the increase in salts is seasonal and will not lead to a regional deterioration in the meliorative state of irrigated lands.

According to the data of the salt survey and the preliminary compiled schematic map of the degree and type of salinization of irrigated lands in the soil layer of 0-0.100 cm, the soils in all areas after the experimental studies are classified as non-saline (85% of the surveyed area) and on the lands adjacent to the collector-drainage network, a narrow strip is represented by slightly saline, the salinization type is sulfate-sodium-calcium. In the alfalfa fields, the soils are somewhat saline, and the salinization type is sulfate-hydrocarbonate-calcium. The salt content in the soil profile varies from 0.185% in the upper soil layer to 0.091% at a depth of 60 cm and below.

## 4. Conclusions

Substantiation of Forecasted Characteristics and the Potential for reuse of collector-drainage water in the Tasmurun irrigated area of the Bakbakty irrigation system

The justification for forecasted real characteristics, quantitative and qualitative potential, and the intensity of collector-drainage water reuse presented in this study is based on a comprehensive analysis of the water and salt balances in the Tasmurun section of the Bakbakty irrigation system. This system serves the irrigated lands of the agricultural enterprises SPC “Miyaly Agro,” PC “Dinara,” and LLP “EDD.” The research was conducted over three consecutive years, all characterized as arid and water-deficient, particularly affecting the water availability of moisture-sensitive rice fields.

A notable strength of the study is that the estimation of all components of the water and salt balances – both inflows and outflows – was not based on secondary literature or archival data. Instead, it was derived from field-based empirical measurements conducted directly by project stakeholders, namely local farmers. This approach ensured the reliability and validity of the baseline data used.

The recommended rice irrigation technology incorporated the reuse of collector-drainage return flow and entailed a phased water application strategy. During the initial flooding and maintenance stages (Stages I-III), irrigation relied solely on river water. During subsequent stages (Stages IV-VI), a blended water source was used, with drainage water accounting for up to 30% and river water for up to 70% of the irrigation volume. In practice, during the 2023-2024 vegetation periods, collector-drainage waters comprised up to 25% of the irrigation volume, with the remaining 75% sourced from river inflow.

Results from the water balance analysis of irrigated lands revealed a slight negative discrepancy, ranging from 0.4% to 0.6% in 2022 and from 0.001% to 0.02% in 2023-2024. These deviations correspond to an average drop in the groundwater table across the experimental sites – from 0.04 m in 2022 to 0.015 m in 2023-2024 as confirmed by stationary groundwater level monitoring and supporting cartographic materials. These results indicate that the inflow components of the water balance exhibit relative stability and are well-balanced by the outflow components.

The salt balance discrepancy on the experimental rice-alfalfa rotation fields (fields 2 and 4) of the Tasmurun irrigation system, both before (2022) and during (2023-2024) the applied research, showed only slight positive values, even with the reuse of collector-drainage waters. The excess salt accumulation ranged from +0.016 to +0.29 tons/ha on Field No. 2 and from +0.049 to +0.089 tons/ha on Field No. 4, indicating a minor salt buildup within the active salt-exchange zone over the vegetation period.

The leaching irrigation regime of rice cultivation, the predominance of highly soluble salts in the groundwater composition, and the seasonal character of salt accumulation suggest no adverse regional impact on the reclamation status of irrigated lands.

Based on soil salinity surveys and a preliminary schematic map of salinity types and severity in the 0-100 cm soil layer, most surveyed land (85%) was classified as non-saline following the experimental period. Narrow strips adjacent to the collector-drainage network showed weak salinization, predominantly sulfate-sodium-calcium type. Alfalfa fields exhibited weak salinization of the sulfate-bicarbonate-calcium type. Salt content in the soil profile ranged from 0.185% in the upper layers to 0.091% at depths of 60 cm and deeper.

## Author contributions

Conceptualization: MA, AI, VM, VR; Data curation: AI; Formal analysis: AI, VK, DU; Funding acquisition: AI, MA; Investigation: AI, VK, TR; Methodology: AI; Project administration: MA, AI, VM; Resources: AI, VK, VM; Software: AI, TR; Supervision: AI; Validation: AI; Visualization: AI, MA; Writing – original draft: AI; Writing – review & editing: VM, TR, VR. All authors have read and agreed to the published version of the manuscript.

## Funding

This research was funded by the Science Committee of the Ministry of Science and Higher Education and Science of the Republic of Kazakhstan («Groundwater resources as the main reserve of sustainable irrigated agriculture in Kazakhstan» № BR 21882211).

## Acknowledgements

The authors gratefully acknowledge the editor and the reviewers for their critical reading of the manuscript and for offering thoughtful feedback that helped refine the clarity and scientific rigor of the work.

## Conflict of interest

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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# Суару үшін коллекторлық-дренаждық суды қайта пайдаланудағы Бақбақты күріш суару жүйесінің су-тұз теңгеріміне мониторинг жүргізу


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**Аңдатпа.** Бұл зерттеуде суды қажет ететін күріш алқаптарына тән құрғақ және суы аз жағдайларда Бақбақты суару жүйесінің Тасмұрын учаскесінде коллекторлық-дренаждық суды қайта пайдалану бойынша үш жыл бойы жүргізілген далалық зерттеулердің негізінде су-тұз балансының құрамдас бөліктерін есептеу әдістемесі, тәсілі және нәтижелері берілген. Баланс есептеулері деректердің сенімділігін қамтамасыз ете отырып, жергілікті фермерлерді белсенді түрде тарта отырып, in-situ бақылау деректеріне негізделген. Су балансы 2022 жылы 0.4-0.6% және 2023-2024 жылдары 0.001-0.02% аралығындағы шағын теріс сәйкессіздікті көрсетті, бұл жер асты суларының деңгейінің мониторингі және карталарымен расталды. Тұз балансы шамалы жинақтауды көрсетті, №2 кен орнында +0.016-дан +0.29 т/га-ға дейін және №4 кен орнында +0.049-дан +0.089 т/га-ға дейін. Тұздың маусымдық көбеюі сілтілеу режиміне және құрлыққа оңай еритін тұздардың басым болуына байланысты болды, бұл қайталану қаупі жоқ.



***Негізгі сөздер:*** *су-тұз балансы, суармалы жерлер, құрғату жүйелері, коллекторлық-дренаждық сулар, тұздылық, су сапасы.*


# Мониторинг водно-солевого баланса рисовой оросительной системы Бакбакты при повторном использовании коллекторно-дренажных вод на орошение


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**Аннотация.** В данной работе представлены методология, подход и результаты расчета компонентов водно-солевого баланса на основе трехлетних полевых исследований по повторному использованию коллекторно-дренажных вод в районе Тасмурун оросительной системы Бакбакты в засушливых и маловодных условиях, характерных для водоемких рисовых полей. Расчеты баланса проводились на основе данных натурных наблюдений при активном участии местных фермеров, что обеспечило достоверность данных. Водный баланс показал небольшое отрицательное расхождение в пределах 0.4-0.6% в 2022 году и 0.001-0.02% в 2023-2024 годах, подтвержденное мониторингом уровня грунтовых вод и картами. Солевой баланс показал незначительную аккумуляцию, значения от +0.016 до +0.29 т/га на поле № 2 и от +0.049 до +0.089 т/га на поле № 4. Сезонные повышения солей были связаны с режимами промывки и доминированием легкорастворимых солей, не представляющих угрозы мелиоративному состоянию земель.

***Ключевые слова:*** *водно-солевой баланс, орошаемые земли, дренажные системы, коллекторно-дренажные воды, засоление, качество воды.*

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