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THE JOURNAL WAS FOUNDED IN 1940

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The scientific journal News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences has been indexed in the international abstract and citation database Scopus since 2016 and demonstrates stable bibliometric performance.

The journal is also included in the Emerging Sources Citation Index (ESCI) of the Web of Science platform (Clarivate Analytics, since 2018).

Indexing in ESCI confirms the journal's compliance with international standards of scientific peer review and editorial ethics and is considered by Clarivate Analytics as part of the evaluation process for potential inclusion in the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (AHCI).

Indexing in Scopus and Web of Science ensures high international visibility of publications, promotes citation growth, and reflects the editorial board's commitment to publishing relevant, original, and scientifically significant research in the fields of geology and technical sciences.

«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылыметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

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КАТАЛИН Стефан, PhD, ассоциированный профессор, Технический университет Дрезден (Дрезден, Германия), https://www.scopus.com/authid/detail.uri?authorId=35203904500; https://www.webofscience.com/wos/author/record/ 1309251

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НУРПЕИСОВА Маржан Байсановна, доктор технических наук, профессор Казахского национального исследовательского технического университета им. К.И. Сатпаева (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=57202218883; https://www.webofscience.com/wos/author/record/AAD-1173-2019

РАТОВ Боранбай Товбасарович, доктор технических наук, профессор, заведующий кафедрой «Геофизика и сейсмология», Казахский национальный исследовательский технический университет им. К.И. Сатпаева (Алматы, Казахстан), https://www.scopus.com/authid/detail.uri?authorId=55927684100; https://www.webofscience.com/wos/author/record/1993614

РОННИ Бериdтссон, профессор, Директор Центра современных ближневосточных исследований, Лундский университет (Лунд, Швеция), https://www.scopus.com/authid/detail.uri?authorId=7005388716; https://www.webofscience.com/wos/author/record/1324908

МИРЛАС Владимир, PhD, профессор, Восточный научно-исследовательский центр, Университет Ариэля, (Ариэль, Израиль), https://www.scopus.com/authid/detail.uri?authorId=8610969300; https://www.webofscience.com/wos/author/record/53680261

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M.Kh. Dulaty Taraz University, Taraz, Kazakhstan.
*E-mail: marjanseitovna25@gmail.com

FLOW REGULATION OF THE SYRDARYA RIVER AT SHARDARA UNDER ENERGY RELEASES

Tolesh Arailym — PhD student, M. Auezov South Kazakhstan University, Symkent, Kazakhstan, mail: es330@mail.ru, https://orcid.org/0009-0007-0029-5143;
Mamitova Aigul — PhD, M. Auezov South Kazakhstan University, Symkent, Kazakhstan, mail: a-mamitova@mail.ru, https://orcid.org/0000-0003-2334-145X;
Karlykhanov Orazkhan — Doctor technical sciences, Kazakh Research Institute of Water Management LLP, Taraz, Kazakhstan,
mail:orazkhantaraz@yandex.ru, https://orcid.org/0000-0003-2101-3305;
Tazhieva Tursynay — PhD, Associate Professor, M.Kh. Dulaty Taraz University, Taraz, Kazakhstan, mail: tch.tazhieva@dulaty.kz, https://orcid.org/0000-0002-5249-7616.
Kalmakhanova Marzhan — PhD, M.Kh. Dulaty Taraz University, Taraz, Kazakhstan, E-mail: marjanseitovna25@gmail.com, https://orcid.org/0000-0002-8635-463X.

Abstract. The Syrdarya River, as a transboundary water system, faces serious challenges in coordinated water and energy management, particularly in the area of the Shardara Reservoir located on the Kazakhstan–Uzbekistan border. Winter energy-driven releases from upstream reservoirs, including the Toktogul Reservoir in Kyrgyzstan as well as hydraulic facilities in Tajikistan and Uzbekistan, generate excessive discharges that exceed the downstream channel capacity. This results in increased flood risk and forced idle water releases into the Arnasai–Aydarkul depression, negatively affecting water availability in the Syrdarya River and the Small Aral Sea. The aim of this study is to develop a scientifically justified regime for the joint operation of the Shardara Reservoir, the Koksarai counterregulator, and the Arnasai spillway. The study is based on the analysis of long-term hydrological data for 1993–2023, materials from the State Water Cadastre of the Republic of Kazakhstan, and operational characteristics of hydraulic structures. Water balance analysis, integral flow curve construction, and scenario-based modeling of inflow regulation at flow reliability levels of 5–90% were applied. The results show that

the cumulative volume of idle discharges into the Arnasai–Aydarkul depression exceeded 47 km³ during the study period, leading to a reduction in ecological flow to the Small Aral Sea. A dispatching schedule for the joint operation of hydraulic structures was developed, accounting for seasonal variability, ice conditions, and the storage capacity of the Koksarai counterregulator. The proposed regime allows idle discharges to be eliminated in most years and limited only to extremely high-water years with up to 10% flow reliability, thereby reducing non-productive water losses, mitigating winter flood risks, and ensuring sustainable ecological flow toward the Aral Sea.

Keywords: Syrdarya River, water content, cycling, energy discharge, regime, regulation of runoff

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М.Х. Дулати атындағы Тараз университеті, Тараз, Қазақстан.
*E-mail: marjanseitovna25@gmail.com

ШАРДАРАДАҒЫ СЫРДАРИЯ ӨЗЕНІНІҢ ЭНЕРГИЯ ШЫҒАРЫНДЫЛАРЫ КЕЗІНДЕГІ АҒЫНЫН РЕТТЕУ

Төлеш Арайлым — PhD докторант, М. Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан,
E-mail: es330@mail.ru, https://orcid.org/0009-0007-0029-5143;
Мамитова Айгүл — PhD, М. Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан,
E-mail: a-mamitova@mail.ru, https://orcid.org/0000-0003-2334-145X;;
Қарлыханов Оразхан — техника ғылымдарының кандидаты, «Қазақ су шаруашылығы ғылыми-зерттеу институты» ЖШС, Тараз, Қазақстан,
E-mail: orazkhantaraz@yandex.ru, https://orcid.org/0000-0003-2101-3305;
Тәжиева Тұрсынай — PhD, қауымдастырылған профессор, М.Х. Дулати атындағы Тараз университеті, Тараз, Қазақстан,
E-mail: tch.tazhieva@dulaty.kz, https://orcid.org/0000-0002-5249-7616;
Калмаханова Маржан — PhD, М.Х. Дулати атындағы Тараз университеті, Тараз, Қазақстан,
E-mail: marjanseitovna25@gmail.com, https://orcid.org/0000-0002-8635-463X.

Аннотация. Сырдария өзені трансшекаралық су жүйесі ретінде су және энергетикалық ресурстарды үйлестіріп тиімді басқаруда күрделі мәселелерге тап болып отыр, әсіресе Қазақстан мен Өзбекстан шекарасында орналасқан Шардара су қоймасы аймағында. Қыс мезгілінде жоғары ағыс бөлігінде

орналасқан су қоймаларынан, соның ішінде Тоқтоғұл су қоймасынан (Қырғызстан), сондай-ақ Тәжікстан мен Өзбекстандағы гидротехникалық нысандардан жүзеге асырылатын энергетикалық босатулар төменгі ағыс бөлігінің өткізу қабілетінен асатын артық су шығындарын қалыптастырады. Бұл су тасқыны қаупінің артуына және судың Арнасай–Айдаркөл ойпатына мәжбүрлі холостық тасталуына әкеліп, Сырдария өзені мен Кіші Арал теңізінің сумен қамтамасыз етілуіне теріс әсер етеді. Зерттеудің мақсаты Шардара су қоймасының, Көксарай контрреттегішінің және Арнасай су тастағышының бірлескен жұмыс істеуінің ғылыми негізделген режимін әзірлеу. Зерттеу 1993–2023 жылдар аралығындағы көпжылдық гидрологиялық деректерге, Қазақстан Республикасының Мемлекеттік су кадастрының материалдарына және гидротехникалық құрылыстардың пайдалану сипаттамаларына негізделген. Зерттеу барысында су шаруашылық баланстық талдау, ағынның интегралдық қисықтарын құру және ағынды реттеудің 5–90 % қамтамасыз етілу деңгейлері үшін сценарийлік модельдеу әдістері қолданылды. Зерттеу нәтижесінде қарастырылып отырған кезеңде Арнасай–Айдаркөл ойпатына тасталған холостық су көлемі 47 км³-тан асқаны анықталды, бұл Кіші Аралға бағытталған экологиялық ағынның төмендеуіне алып келді. Маусымдық ағынның өзгергіштігін, мұздық жағдайларды және Көксарай контрреттегішінің жинақтаушы мүмкіндіктерін ескере отырып, гидроқұрылыстардың бірлескен жұмысын реттейтін диспетчерлік график әзірленді. Ұсынылған режим су шаруашылық жылдарының басым бөлігінде холостық тасталымдарды болдырмауға және оларды тек 10 %-ға дейінгі қамтамасыз етілген аса сулы жылдарда ғана шектеуге мүмкіндік береді, соның нәтижесінде су ресурстарының өндірістік емес шығындары азайып, қысқы су тасқыны қаупі төмендейді және Арал теңізі бағытындағы тұрақты экологиялық ағын қамтамасыз етіледі.

Түйінді сөздер: Сырдария Өзені, су құрамы, қозғалыс циклі, энергия шығыны, режимі, ағынды суларды реттеу

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Таразский университет имени М.Х. Дулати, Тараз, Казахстан.
*E-mail: marjanseitovna25@gmail.com

РЕГУЛИРОВАНИЕ СТОКА РЕКИ СЫРДАРЬЯ В РАЙОНЕ ШАРДАРЫ В РАМКАХ ЭНЕРГЕТИЧЕСКИХ ВЫБРОСОВ

Төлеш Арайлым — докторант PhD, Южно-Казахстанский университет имени М. Ауэзова, г. Шымкент, Республика Казахстан,
E-mail: es330@mail.ru, https://orcid.org/0009-0007-0029-5143;
Мамитова Айгуль — PhD, Южно-Казахстанский университет имени М. Ауэзова, г. Шымкент, Республика Казахстан,
E-mail: a-mamitova@mail.ru, https://orcid.org/0000-0003-2334-145X;

Карлыханов Оразхан — кандидат технических наук, ТОО «Казахский научно-исследовательский институт водного хозяйства», г. Тараз, Республика Казахстан, E-mail: orazkhantaraz@yandex.ru, https://orcid.org/0000-0003-2101-3305;
Тажиева Турсунай — PhD, ассоциированный профессор, Таразский университет имени М.Х. Дулати, г. Тараз, Республика Казахстан,E-mail: tch.tazhieva@dulaty.kz, https://orcid.org/0000-0002-5249-7616;
Калмаханова Маржан — PhD, Таразский университет имени М.Х. Дулати, г. Тараз, Республика Казахстан,
E-mail: marjanseitovna25@gmail.com, https://orcid.org/0000-0002-8635-463X.

Аннотация. Река Сырдарья, являясь трансграничной водной системой, сталкивается с серьёзными проблемами согласованного управления водными и энергетическими ресурсами, особенно в районе Шардаринского водохранилища на границе Казахстана и Узбекистана. Зимние энергетические сбросы из верхних водохранилищ, включая Токтогульское водохранилище (Кыргызстан), а также гидротехнические объекты в Таджикистане и Узбекистане, формируют избыточные расходы воды, превышающие пропускную способность нижнего бьефа. Это приводит к риску затоплений и вынужденным холостым сбросам воды в Арнасай–Айдаркульскую впадину, что негативно отражается на водообеспеченности реки Сырдарья и Малого Аральского моря. Целью исследования является разработка научно обоснованного режима совместной работы Шардаринского водохранилища, Коксарайского контррегулятора и Арнасайского водосброса. Исследование основано на анализе многолетних гидрологических данных за 1993–2023 гг., материалов Государственного водного кадастра Республики Казахстан и эксплуатационных характеристик гидротехнических сооружений. Применялись методы водохозяйственного балансового анализа, построения интегральных кривых стока и сценарного моделирования регулирования притока при обеспеченности стока 5–90%. Установлено, что за рассматриваемый период суммарный объём холостых сбросов воды в Арнасай–Айдаркульскую впадину превысил 47 км³, что привело к снижению экологического стока в направлении Малого Арала. Разработан диспетчерский график совместной работы гидроузлов, учитывающий сезонную изменчивость стока, ледовые условия и аккумулирующие возможности Коксарайского контррегулятора. Предложенный режим позволяет исключить холостые сбросы в большинстве водохозяйственных лет и ограничить их лишь особо многоводными годами с обеспеченностью до 10 %, снижая непроизводственные потери воды, риск зимних паводков и обеспечивая устойчивый экологический сток в направлении Аральского моря.

Ключевые слова: река Сырдарья, водность, круговорот движения, энергетический расход, режим, регулирование стока

Introduction. The favorable natural and climatic conditions of the Syrdarya River basin downstream of the Shardara Reservoir have led to the extensive

development of irrigated agriculture. At the same time, the Syrdarya River is the only natural watercourse maintaining environmental stability through its inflow into the Kazakh part of the Aral Sea (Karlikhanov et al. 2016; Dmitrievna 2016; Matsuura 2000; Tursunov 2002). The Syrdarya River, one of the largest rivers in Central Asia, flows from the Tien Shan Mountains to the Aral Sea, with approximately 1600 km located within Kazakhstan. The average long-term runoff of the Syrdarya River (~37 km³) is regulated by major reservoirs, including Toktogul (19.5 km³) in the Kyrgyz Republic, Kairakkum (4.2 km³) in Tajikistan, and Shardara (5.2 km³) in Kazakhstan, as well as numerous medium and small reservoirs whose total capacity exceeds the average annual flow (Fig. 1). These facilities, together with irrigation systems and hydropower infrastructure, form the interconnected Naryn–Syrdarya water-energy cascade.

Literature review. The lower reaches of the Syrdarya River are currently experiencing acute water shortages across all sectors of the economy, while the Aral Sea has remained an environmental disaster zone since the late 20th century (Karlikhanov et al. 2016). These problems are primarily associated with excessive and poorly justified water withdrawal for irrigation in the Syrdarya and Amudarya river basins (Dukhovny and Joop de Schutter 2018; Dukhovny et al. 1985). Despite these challenges, the lower Syrdarya plays a crucial ecological and economic role in maintaining environmental stability and water availability in the Kazakh Aral Sea region.

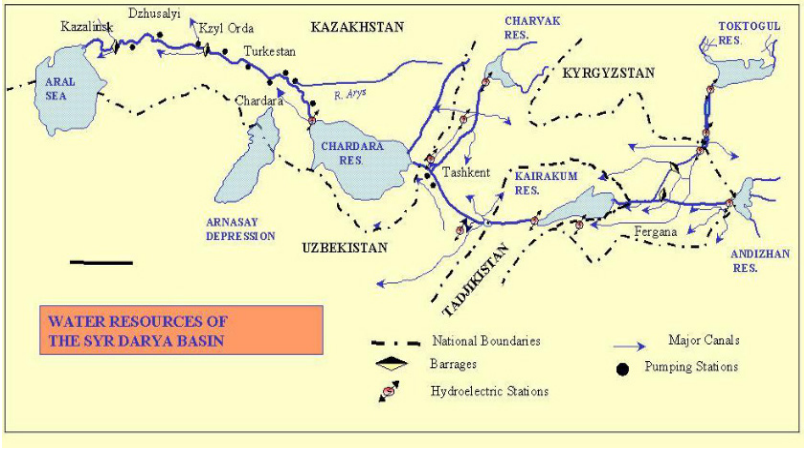

Figure 1 - Situational scheme for regulating the flow of the Syrdarya River in the zone of its formation and use (Heaven 2002).

Central Asian states increasingly disregard established water management rules by shifting reservoir operation regimes from irrigation to energy production, resulting in winter discharges reaching 60–70% of the annual flow. This shift has led to periodic overflows of the Shardara Reservoir, while discharges to the lower reaches are restricted during winter. From November to March, ice cover forms

along the Syrdarya River from the Tomenaryk site to the Aral Sea, reducing channel discharge capacity to 30–35%. Consequently, the maximum discharge capacity in the lower reaches during this period does not exceed 475 m³/s (Mashukov 1969; Vagapov 2008; Mustafaev 2005). These conditions necessitate a revision of Syrdarya River flow management principles at the Shardara Reservoir through coordinated regulation of the Shardara–Koksarai–Arnasay hydrocomplex to ensure safe year-round discharges, particularly during periods of increased winter energy releases. The Shardara Reservoir was designed primarily to regulate Syrdarya River flow for irrigation in the Turkestan and Kyzylorda regions, while also generating electricity, supplying water to more than 160 lakes and lake systems, irrigating pastures, and ensuring ecological runoff to the Kazakh part of the Aral Sea (Small Aral Sea). The 2004–2006 restoration project successfully revived the Small Aral Sea, restoring its climatic and fishery functions; however, maintaining the design level of 41 mBS remains dependent on environmental releases from the Shardara Reservoir and the Koksarai Counter-Regulator. The runoff regulation system includes the Arnasai spillway (up to 40 km³, discharge capacity 2160 m³/s), the Shardara Reservoir (5.2 km³, total discharge capacity of 2000 m³/s through the hydropower plant and Karakum canal), and the Koksarai Counter-Regulator (3 km³, discharge capacity 300 m³/s) (Figs. 2–3).

Figure 2 – Location of the Arnasay spillway as part of the Shardara reservoir.

The Arnasay spillway was constructed to divert floodwaters into the Arnasay–Aydarkul depression, historically associated with the Tuzkan–Aydarkul salt lakes that existed until 1969. As part of the Shardara Reservoir project, the spillway was completed in 1968. The Syr Darya River, as a transboundary water system, faces significant challenges in balancing hydropower generation and water resource regulation, particularly at the Shardara Reservoir located on the Kazakhstan–Uzbekistan border. During winter, increased energy releases from upstream reservoirs, including Toktogul in Kyrgyzstan and facilities in Tajikistan and

Uzbekistan, generate excess flows that exceed the downstream conveyance capacity. This results in flood risks and uncontrolled discharges into the Arnasay–Aydarkul depression, reducing water availability in the Syr Darya River and inflows to the Small Aral Sea. In this context, the development of a scientifically substantiated operational regime for the coordinated functioning of the Shardara Reservoir, the Koksarai counter-regulator, and the Arnasay spillway is highly relevant. The study is based on long-term hydrological data for 1993–2023, materials from the State Water Cadastre of the Republic of Kazakhstan, and operational characteristics of hydraulic structures. The methodology includes water balance analysis, integral flow curves, and scenario-based flow regulation modeling for exceedance probabilities of 5–90%. The results show that total uncontrolled discharges into the Arnasay–Aydarkul depression exceeded 47 km³ during the study period, negatively affecting environmental flows to the Small Aral Sea. A coordinated dispatch schedule was developed that accounts for seasonal variability, ice conditions, and the storage capacity of the Koksarai counter-regulator. This regime eliminates uncontrolled discharges and limits them to no more than 10% in extremely high-water years, while substantially reducing non-productive water losses. The proposed approach can support water management authorities in improving real-time flow regulation, mitigating winter flood risks, enhancing infrastructure reliability, and ensuring sustainable environmental flows to the Small Aral Sea.

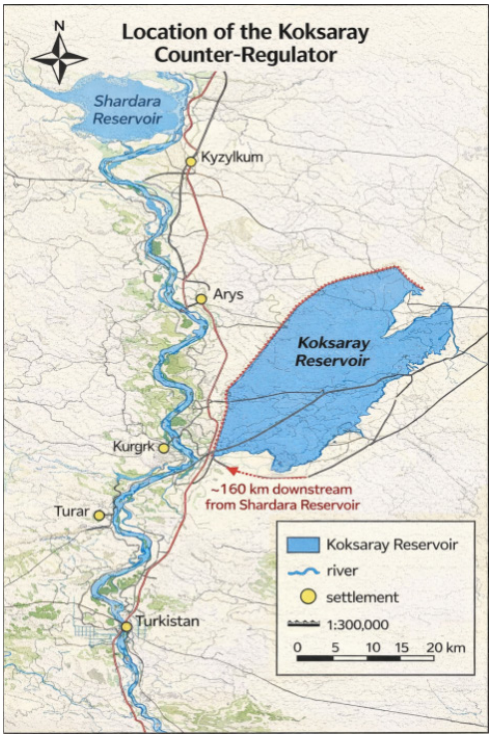

Figure 3 – Location of the Koksaray counter-regulator.

The timely commissioning of the Arnasay spillway played a critical role during the rare 1969 flood (1% exceedance probability), when more than 28 km³ of water was diverted at peak discharges of up to 4000 m³/s, preventing the failure of the Shardara Reservoir. Water discharged through the Arnasay spillway is considered non-productive, as the Arnasay–Aydarkol depression lies 15–20 m below the Shardara Reservoir and has no return flow to the Syrdarya River. At present, such discharges mainly occur in high-water years due to the limited discharge capacity of the Shardara Reservoir (maximum 2000 m³/s). Under these conditions, effective regulation of winter releases between the Shardara Reservoir, the Arnasay spillway, and the Koksaray counter-regulator remains unresolved, emphasizing the need for a scientifically substantiated flow management regime for the Shardara–Koksaray–Arnasay system.

Materials and methods. The study area covers a section of the Syrdarya River basin from the Kokbulak site (15 km upstream of the Shardara Reservoir) to the Koksaray counter-regulator (15 km downstream), including the Arnasay spillway as part of the Shardara Reservoir system. The research was conducted using generally accepted methodologies and regulatory guidelines to ensure the reliability of results. The analysis utilized data on operational indicators and flow regulation regimes of the Shardara–Koksaray–Arnasay hydraulic complex before and after the commissioning of the Koksaray counter-regulator (Karlykhanov et al. 2008; Matsuura et al. 2000; Mustafaev et al. 2005).

Results and discussion. The regulating capacity of the Shardara Reservoir system was assessed, including the bottom outlet (Q_{max} = 1200 m³/s), hydropower plant (Q_{max} = 720 m³/s), Kyzylkum gate regulator (Q_{max} = 200 m³/s), and the Arnasay spillway (Q_{max} = 2160 m³/s). Table 1 presents data on flows conveyed through these structures toward the Aral Sea during 1993–2023, a period characterized by a marked increase in energy-related discharges within the Syrdarya River basin.

Table 1 – Inflow of Syrdarya River flow into the Republic of Kazakhstan and its distribution during the period of energy releases (Ibatullin et al. 2008).

Years	Inflow to the Shardara Reservoir, km³	Discharge to the downstream reach, km³	Discharge to the Arnasay–Aydarkul system, km³	Inflow to the Small Aral Sea, km³	Discharge to the Large Aral Sea, km³
1	3	4	6	7	8
1993	21,37	21,17	2,1	9,09	-
1994	25,27	19,75	9,29	9,86	-
1995	14,18	12,94	3,43	4,53	-
1996	15,95	15,29	0,82	5,6	-
1997	14,25	13,48	1,2	4,75	-
1998	23,67	20	2,28	7,72	-
1999	18,31	16,96	3,13	6,04	-
2000	13,91	12,15	2,77	3,87	-
2001	13,31	12,26	0,43	3,56	-
2002	20,56	19,19	1,23	8,64	-

2003	26,28	20,49	5,2	9,76	-
2004	23,96	21	2,92	10,06	-
2005	22,79	22,02	2,25	11,01	-
2006	16,9	16,9	0,39	8,08	2,28
2007	18,69	17,4	0,82	7,32	3,21
2008	12,86	10,9	0,98	4,47	2,52
2009	15,36	14,9	0,19	4,9	0,32
2010	25,83	26,6	0,84	9,3	5,06
2011	13,99	13,4	0,83	4,51	3,46
2012	20,74	18,6	0,2	4,48	2,01
2013	14,38	13	1,63	4,31	2,42
2014	18,41	16,8	0,13	5,68	2,57
2015	15,43	14,8	0,34	4,83	2,45
2016	13,09	14,7	0,02	4,57	2,83
2017	23,5	23,1	2,16	8,17	6,66
2018	15,84	12,4	0,29	3,23	3,32
2019	14,78	14,2	0,55	2,3	0,83
2020	12,95	10	0,01	1,42	0,96
2021	9,8	8,44	0,1	0,91	0,18
2022	15,11	10,94	0	0,82	0
2023	13,45	11,25	0,5	2,04	0
Total	530,04	483,78	47,03	175,83	41,08

Data for 2004–2021 were obtained from the State Water Cadastre of the Republic of Kazakhstan, while data for 1991–2023 were taken from the report of the Aral–Syrdarya Basin Water Management Inspectorate.

Analysis of the data in Table 1 shows that from 1993 to 2023, the volume of water inflow into the Shardara reservoir was 530.04 km3, and the volume of discharge in the lower reaches of the river was 483.78 km3, i.e. about 90% of the flow passed in the lower reaches of the river. The volume of discharge into the Arnasay-Aydarkol depression amounted to 47.03 км3. This is the so-called idle reset. According to some data, as a result of idle discharge into the Arnasay-Aydarkol depression, the Small Aral Sea received 2 times less water during this period. (Galperin et al. 2018; Arystambekova et al. 2019; Paisley 2018).

Figure 4 shows the cumulative flow curves, which demonstrate the sequential accumulation of water flow not only at the Shardara Reservoir site but also downstream to the Large Aral Sea over the period under consideration.

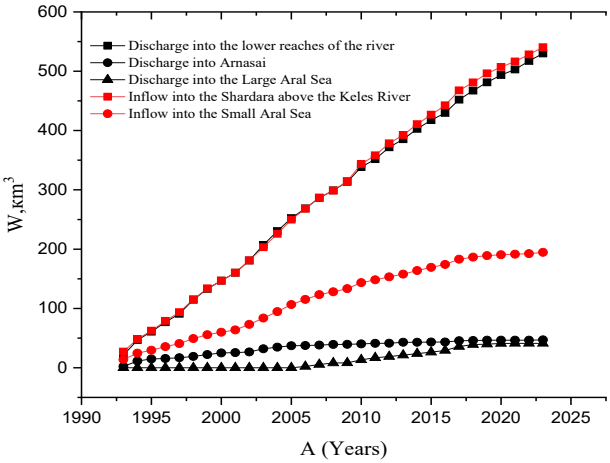

Figure 4- Integral flow curves of the Syrdarya River

Integrated flow curves for the Syrdarya River during the analyzed period indicate relatively stable inflow to and discharge from the Shardara Reservoir, reflecting its operation in line with its intended purpose. In contrast, runoff discharges to the Arnasay–Aidarkol depression and the Small and Large Aral Seas show less consistency.

A more detailed analysis of the dynamics of the Syrdarya River flow from the Shardara Reservoir to the Large Aral Sea over a 17-year period is presented in Figure 5. Here the cyclical repetition of low and high water rivers is more clearly visible. The flow inflow into the Small Aral changes synchronously in a much smaller volume than the discharge of runoff from the reservoir, which is associated with the use of water resources for economic sectors, primarily for agricultural water consumers, watering of natural water bodies and natural losses due to evaporation and filtration.

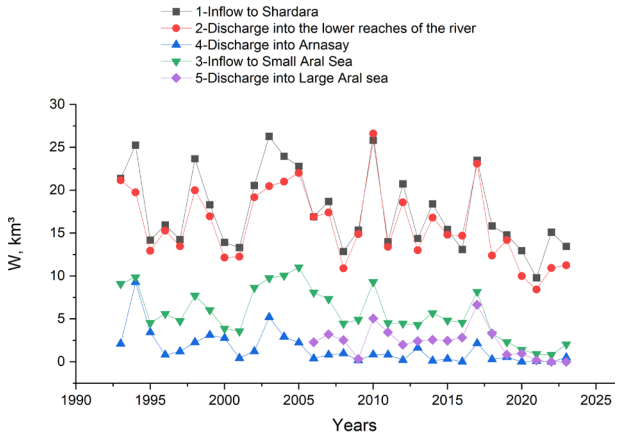

Figure 5 - Dynamics of the Syrdarya River flow from the Shardara Reservoir to the Large Aral Sea.

Over the past six years (2018–2023), inflow to the Small Aral Sea has markedly decreased due to prolonged low-water conditions in the region. Despite this, discharges into the Arnasay–Aydarkul depression have continued, which is unacceptable under conditions of ongoing degradation of the Kazakh part of the Aral Sea. To reduce the long-term pressure on the Shardara Reservoir operating in energy discharge mode, the Koksarai Counter-Regulator (3.0 km³) was commissioned in 2010, resulting in a revised flow regulation scheme within the Shardara–Koksarai–Arnasay hydrocomplex. The Shardara Reservoir is filled from October to March to the normal supported level (NSL), with an active storage volume of 4.2 km³, and is drawn down during the vegetation period to the dead volume level (DVL) of 1.5 km³. The Koksarai Counter-Regulator is filled during winter energy releases to its NSL of 3.0 km³ and is gradually emptied during the summer period starting in May. It functions as a buffer reservoir, accumulating excess winter flow of the Syrdarya River and releasing it when the river channel is free of ice. Under conditions of upstream reservoirs operating in energy mode, the need for idle discharges into the Arnasay–Aydarkul depression arises during winter energy releases, with their magnitude determined by inflow volumes to the Shardara Reservoir. Analysis of inflows to the Shardara Reservoir under different exceedance probabilities and their intra-annual distribution, accounting for discharges into the Arnasay–Aydarkul depression, reveals persistent risks associated with winter flow regulation and subsequent water shortages during the growing season. Prior to the commissioning of the Koksarai Counter-Regulator (1993–2010), more than 40 km³ of water was discharged into the Arnasay–Aydarkul depression during energy release periods, resulting in an 8 m rise in water level and an increase in volume from 16.7 km³ to 42.15 km³.

Baseline conditions. The assessment of Shardara Reservoir operation, including releases to Arnasay, focused on flow regulation of the Syr Darya prior to the commissioning of the Koksarai Counter-Regulator. The objective was to optimize joint operation of the Shardara Reservoir, Koksarai Counter-Regulator, and Arnasay spillway to satisfy water demand under conditions of a 17-year energy cycle characterized by increased winter inflows. Analysis of the current water management practice for joint operation of the Shardara Reservoir and Koksarai Counter-Regulator showed that the approved accumulation and release schedule for the Shardara Reservoir is based on pre-Koksarai flow conditions. This schedule does not account for interannual variability of the energy regime, timing of energy-release periods, storage capacity of the Koksarai Counter-Regulator, or discharge limitations of the Arnasay spillway. To address these limitations, a dispatch schedule was developed in tabular form (Table 2), incorporating inflow to the Kokbulak gate of the Shardara–Koksarai–Arnasay hydrocomplex under joint operation conditions. The schedule considers characteristic flow exceedance probabilities of 5%, 10%, 25%, 50%, 75%, and 90%. T The following abbreviations are used: X(31) – month and number of days, SR – Shardara Reservoir, RL SR – lower reach of the Shardara Reservoir, AAD – Arnasay–Aydarkul depression, KC – Koksarai Counter-

Regulator. A key objective of the dispatch schedule is to regulate river flow while accounting for the storage and release capacity of the Koksarai Counter-Regulator. Analysis of the interconnected operation of the Shardara–Koksarai–Arnasay system in accumulation and discharge modes enabled the development of a release regime that satisfies downstream water demand and ensures ecological flows to the Aral Sea. Boundary conditions for flow regulation include the timing of inflow, storage, and release, which form the basis for calculating dispatch parameters (Table 2). It is assumed that at the beginning of the energy period (October–November), reservoir storage is maintained at the dead volume level (DVL). The calculation procedure follows earlier methodologies (Balgerey et al. 2010), refined using subsequent studies and updated hydrological characteristics of the Syr Darya River (Vagapov and Bayalimov 2006; Karlykhanov 2014).

Procedure for applying the dispatch schedule. The reservoir volume at the beginning of each time interval (month or decade) is plotted on a control chart. Based on forecasted inflow and downstream demand, the required filling or drawdown volume is determined, yielding the projected end-of-period storage (Table 2). If filling volume equals inflow, downstream water demand is fully met. If filling volume is less than inflow, releases are adjusted with priority-based reductions in water supply, considering forecasts for subsequent periods. Increased downstream supply may be achieved by adjusting reservoir drawdown and river channel conveyance capacity. Reservoir filling and drawdown rates should not exceed 7 cm/day, and up to 10 cm/day under exceptional conditions. During winter, ice formation must be considered to minimize flood risk. If ice formation is forecast, a discharge of 1000 m^3/s should be established downstream of the hydropower complex prior to freeze-up. During ice formation until stable freeze-up, discharge upstream of the Koksarai Counter-Regulator should be maintained at 1000 m^3/s and downstream limited to 500 m^3/s. After the counter-regulator is filled, discharge along the Syr Darya should not exceed 500 m^3/s. In high-water years with reliable ice and temperature forecasts, average daily discharge from the Koksarai Counter-Regulator may be increased to 600 m^3/s, while during ice breakup it should remain limited to 500 m^3/s. If both the Shardara Reservoir and Koksarai Counter-Regulator reach full capacity and inflow exceeds allowable thresholds under ice conditions, excess water should be discharged through the Arnasay spillway until the end of the hazardous winter period. Discharges via Arnasay are also permitted during ice-free periods if downstream flow exceeds the channel capacity of 1800 m^3/s. Hydropower generation at the Shardara Reservoir is prioritized, while downstream deficits are compensated by releases from the Koksarai Counter-Regulator and excess inflow is stored in the Shardara Reservoir.

Sequence for completing the dispatch schedule. Data on the Shardara Reservoir storage at the beginning of each time step, according to the dispatch schedule, are entered into the filling and processing line (Form 1, Table 2). Inflow volumes at the Kokbulak site are recorded at the end of each period together with average discharges for the corresponding interval in Form 2 (Table 2). Comparison of inflow

and discharge indicates that the reservoir generally operates in filling mode, although release mode may occur depending on forecast accuracy and downstream channel capacity. The remaining storage after filling is calculated for the subsequent period and recorded in the "remaining after filling" line. Discharge to the lower reach of the Shardara Reservoir is determined from Form 1 data and entered in the discharge line. When the average discharge downstream of the Shardara Reservoir exceeds channel capacity, excess flow is diverted to the Koksarai Counter-Regulator at a rate equal to the difference between Shardara discharge and the allowable winter flow of the Syrdarya River (500 m^3/s), without exceeding the 500 m^3/s supply channel capacity. These values are recorded in the Koksarai line. Once the Koksarai Counter-Regulator reaches its full capacity of 3.0 km^3, surplus water is discharged into the Arnasay–Aydarkul depression via the Arnasay spillway, with discharges not exceeding 600 m^3/s. After the winter period, such discharges cease and releases are directed downstream, limited by the open-channel capacity of 1800 m^3/s. Under these conditions, the counter-regulator begins operating to support hydropower generation and satisfy downstream water demand. From May onward (Form 1, Table 2), discharge exceeds inflow, indicating the transition of the reservoir to release mode. Reservoir operation is initiated with minimal impact on hydropower plant performance, and discharge rates are adjusted to optimize electricity generation. Any water deficits prior to scheduled releases are compensated by the Koksarai Counter-Regulator, which is nearly depleted by the end of the hydrological year. The operation scheme of the counter-regulator предусматривает water supply to the lower reaches only at 75% and 90% flow exceedance levels; under other conditions, releases are not required due to excessive runoff.

Table 2 - Developed dispatch (operational) schedule for regulating the flow of the Syrdarya River at the Shardara Reservoir gauging section under the joint operation of the Koksarai Counter-Regulator and the Arnasay–Aydarkul Water Discharge, m^3/s at 5% flow reliability

Parameters	Months											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
Inflow to the Shardara Reservoir	515	698	1049	1146	978	881	1318	1284	1072	512	264	403
Release from the Shardara Reservoir to the downstream	500	500	500	500	500	500	700	1000	1000	1000	1000	700
Diversion to the Koksarai Counter-Regulator					397	381	381					
Diversion to the Arnasay Depression							270	284	108			
Release from the Koksarai Counter-Regulator to the downstream								373	373	373		

at 10% flow reliability

Parameters	Months											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
Inflow to the Shardara Reservoir	515	698	1049	1146	978	881	1318	1284	1072	512	264	403
Release from the Shardara Reservoir to the downstream	500	500	500	500	500	500	700	1000	1000	1000	700	700
Release from the Koksarai Counter-Regulator to the downstream	-	-	-	-	240	350	500	71	-	-	-	-
Diversion to the Arnasay Depression	-	-	-	-	-	-	116	-	-	-	-	-
Discharge from the Koksarai Counter-Regulator to the downstream reach	-	-	-	-	-	-	-	373	373	373	-	-

at 25% flow reliability

Parameters	Months											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
Inflow to the Shardara Reservoir	470	637	956	1045	984	803	1238	765	660	302	190	316
Discharge from the Shardara Reservoir to the downstream reach	470	500	500	500	500	500	700	1000	1000	1000	373	316
Discharge to the Koksarai Counter-Regulator	-	-	-	-	-	302	500	340	-	-	-	-
Discharge from the Koksarai Counter-Regulator to the downstream reach	-	-	-	-	-	-	-	373	373	78	-	-

at 50% flow reliability

Parameters	Months											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
Inflow to the Shardara Reservoir	310	718	818	1045	984	803	599	504	660	370	161	370
Discharge from the Shardara Reservoir to the downstream reach	310	500	500	500	500	489	700	1000	1000	370	373	386
Discharge to the Koksarai Counter-Regulator	0,00				170	490						
Discharge from the Koksarai Counter-Regulator to the downstream reach								82	386	187		

at 75% flow reliability

Parameters	Months											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
Inflow to the Shardara Reservoir	359	498	769	881	1071	1143	633	265	228	153	127	170
Discharge from the Shardara Reservoir to the downstream reach	310	498	500	500	500	500	520	575	594	493	482	370
Discharge to the Koksarai Counter-Regulator						276	112					
Discharge from the Koksarai Counter-Regulator to the downstream reach								370	12			

Conclusion. Analysis of project documentation, feasibility studies, hydrological data, and the regulation potential of hydraulic structures demonstrates that the operating regime of the Shardara Reservoir within the Shardara–Koksarai–Arnasay hydrocomplex has fundamentally changed due to the transition of upstream reservoirs from an irrigation to an energy regime. As a result, winter releases increased to 60–70% of the annual runoff, compared to 30–40% under the former irrigation regime. This shift has caused recurrent winter flooding in the lower reaches of the Syr Darya River, where ice cover significantly restricts channel conveyance capacity. In certain years, flooding extends upstream from the Tomenaryk station to the Koksarai Counter-Regulator. Analysis of inflows to the Shardara Reservoir since 1993 reveals persistent difficulties in regulating winter floods and ensuring sufficient summer releases due to high interannual variability and uncertainty in seasonal runoff distribution. The proposed coordinated operation scheme for the Shardara–Koksarai–Arnasay hydrocomplex, developed for different inflow scenarios at the Kokbulak boundary gauging station, provides a practical framework for operational water management organizations, accounting for hydrometeorological conditions and storage dynamics of the Koksarai Counter-Regulator. It is recommended that the Shardara Reservoir be filled from October to March to its full capacity of 5.2 km³ and drawn down from June to September to the dead volume level of 1.0 km³. The Koksarai Counter-Regulator should be filled between November and February to the normal supported level and completely emptied between July and August. Under this flow management regime, discharges into the Arnasay–Aydarkol depression are required only in exceptionally high-water years with exceedance probabilities not exceeding 10%.

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