

Progress in the implementation of sustainable small hydro in Central Asia

B. Alapfy, Technical University of Munich, Germany; D.S. Hayes and J. De Keyser, BOKU University, Austria
K. Jorde, KJ Consult, Austria; B. Karimov, TIAME National Research University, Uzbekistan
I. Kopecki, SJE – Ecohydraulic Engineering GmbH, Germany
P. Verhelst, Research Institute for Nature and Forest, Belgium

The European Union (EU), through its Horizon 2020 funding programme, is supporting the 'Hydro4U' innovation project. This initiative aims to develop and optimize sustainable technologies, planning methods, and assessment tools for small-scale hydropower, with the primary goal of enhancing their application in Central Asia. Following our project presentation report in this journal [Jorde et al., 2022¹], this paper provides an overview of the main findings and achievements from the past two years, and outlines our strategy for successfully completing the project within the next 1.5 years.

Over a five-year period, 13 partners, including scientific institutions, consultants, industry representatives, and NGOs from both the EU and Central Asia, have been collaborating to create a lasting impact in the region. The project addresses common challenges related to hydropower development, considering technical, ecological, economic, and social factors.

Key activities of the project include evaluating the potential for small hydropower in Central Asia, and analysing energy generation within the context of the Water-Energy-Food-Climate (WEFC) Nexus. The main focus is on developing two types of modular and sustainable small hydropower technologies: one designed for low heads and another for medium heads.

To facilitate the replication of the developed technologies and tools, additional planning activities, referred to as bankable feasibility studies, will support the demonstrations. These activities are part of a comprehensive replication strategy.

1. Climate change impact on Central Asia's hydrology

One key research focus within the Hydro4U project has been the impact of climate change on the region's hydrology. A comprehensive study by Siegfried *et al.* [2024²] examines the hydrological effects of 21st century climate change on 221 high-mountain catchments in Central Asia. The study utilizes a stochastic soil moisture water balance model to project changes in runoff and evaporation across three future periods: 2011 to 2040, 2041 to 2070, and 2071 to 2100, compared with the baseline period of 1979 to 2011.

Using a new dataset and bias-corrected outputs from four general circulation models under different climate scenarios, the research predicts an increase in median precipitation ranging from 5.5 to 10.1 per cent, along with a rise in median temperatures of between 1.9°C and 5.6°C by the end of the century. The findings indicate varied hydrological responses, with potential increases in actual evaporation of 7.3 to 17.4 per cent, and changes in discharge that could range from +1.1 to -2.7 per cent. Extreme scenarios predict glacier wastage and discharge reductions in some regions, while high-elevation areas may experience increases

as a result of enhanced glacier ablation. The study emphasizes the complex impacts of climate change on water resources, which are vital for agriculture and livelihoods, highlighting the need for sustainable water management strategies in the region.

Given the significant impact of future hydrological scenarios on the mid- to long-term viability of small hydro projects, it was determined that scenario analysis during the design stage of these projects is essential. As such, semi-distributed conceptual rainfall-runoff models have been implemented for both the two demonstration sites and the three planning sites to study climate impacts. Glacier contributions were calculated and included as source terms in the rainfall-runoff simulations. Monthly discharge observations from nearby gauges were used for model calibration and validation.

To simulate past and future flow duration curves, the hydrological models were run with daily time steps. Past periods with available gauging data were arbitrarily defined as baseline simulation periods against which climate impacts are evaluated using the calibrated hydrological model. Three CMIP6 climate models and four global socio-economic pathway scenario combinations were assessed for their hydrological impacts. This hydrological analysis serves as the foundation for determining the optimal capacity of powerplants and estimating future annual generation, which significantly influences the projects economic feasibility.

A unique aspect of the Hydro4U project is that the powerplant design is not based only on historical discharge values; instead, a risk-optimized analysis has been conducted that considers various climate change-dependent hydrological future scenarios.

2. Hydropower potential decision support system

The Hydro4U project aims to ensure the long-term sustainability and development of small-scale hydropower in Central Asia by developing an online decision support system (DSS) for sustainable water resources planning. This GIS-based tool builds on the large-scale analyses and datasets established during the project, and introduces advanced functionality to help stakeholders, such as public authorities and private investors, to make informed decisions. The DSS will integrate hydrological, environmental and socio-

economic data [for example, De Keyser *et al.*, 2023³] to provide an interactive and practical resource for effective hydropower planning.

Central to the DSS is a comprehensive assessment of the sustainable hydropower potential. The intuitive and interactive interface of the DSS will allow the user to query this hydropower potential at the river segment level. The user will be able to access various geospatial information critical to project feasibility. This includes, for example, infrastructure information, such as the proximity to roads and settlements relative to the river network, which will aid in assessing accessibility and local energy demand. The tool also highlights existing and planned plants and unpowered dams with potential for hydropower development [De Keyser *et al.* in review⁴].

The DSS will also guide decision-making for environmental sustainability, by incorporating ecological and geomorphological criteria. For example, the tool identifies ecologically sensitive areas that are unsuitable for hydropower development. These areas are not only critical for hydropower development, but may also be relevant for other water-related uses to support the conservation of freshwater biodiversity. The tool also considers sediment transport, a key factor in the sustainability of hydropower. Sediment transport can significantly affect the long-term performance and viability of hydropower systems [Kondolf *et al.* 2014⁵]. By including estimates of sediment transport probabilities, the DSS provides stakeholders with information on a potential challenge that is often overlooked. The user will be able to filter river segments based on various criteria, enabling stakeholders to identify suitable locations for specific hydropower technologies.

When finalized, the DSS will be tested and validated using site-specific data collected during feasibility studies carried out as part of the Hydro4U project (see, for example, chapters 4.1 and 4.2). These studies provide critical insights into local conditions, allowing the tool to be refined for real-world applications in Central Asia. Even though the tool will not replace detailed site-specific feasibility studies, it will serve as a valuable resource for preliminary decision-making. By providing essential data and functionality, the DSS facilitates the early stages of site assessment, saving time and resources while ensuring that projects are aligned with sustainability goals.

3. Aquatic ecology and sustainable hydropower design

The high-mountain regions of Central Asia feature relatively untouched ecosystems, especially in comparison with the more developed foothill areas and valley rivers. However, these pristine environments are increasingly threatened by factors such as irrigation schemes, recreational activities, climate change [Elistratov and Mukhammadiyev, *et al.*, 2023⁶], and, importantly, new hydropower projects that aim to meet the growing demand for energy [Radovanović *et al.*, 2021⁷].

These developments present significant risks to aquatic life and their habitats, as they can disrupt local ecosystems and biodiversity [He *et al.*, 2024⁸]. Furthermore, there is a notable lack of understanding regarding fish ecology in Central Asia, which is vital for the responsible advancement of hydropower initiatives. Field surveys have revealed that many hydropower and irrigation dams in Central Asia, particularly on highland streams, were built without proper fish passages and

bypasses. This oversight has led to the complete disappearance of fish upstream of these dams in rivers such as Koksū and Aqsu in Uzbekistan, and Maylisu in Kyrgyzstan. In contrast, fish populations have been found to thrive in rivers without artificial dams. The Hydro4U project aims to address these issues by enhancing ecological knowledge, which will facilitate environmentally sustainable decision-making.

The project team has focused on studying the habitat preferences of snow trout (*Schizothorax eurystomus*), a key indicator species for river hydromorphology and instream connectivity, at the Shakhimardan demo site [Jorde *et al.*, 2022¹]. These observations have established the foundation for environmental flow assessments at project demonstration and testing sites through the use of 2D habitat modeling [for example, Hayes *et al.*, in review⁹]. Subsequent habitat studies, conducted after implementation, are designed to evaluate the ecological effectiveness of these environmental flows.

In addition, an ongoing fish-tracking study utilizes both radio and passive integrated transponder telemetry to collect vital data on the movement patterns of snow trout before and after hydropower development. These techniques facilitate a detailed assessment of the spatio-temporal movement behaviour and habitat use of snow trout in the Shakhimardan catchment, including seasonal migrations between wintering habitats and spawning grounds. Furthermore, the study evaluates the effectiveness of the fish pass in aiding upstream migration and whether the bar racks at the hydropower site guide fish to the bypass for downstream passage.

Additional aspects to be investigated by the joint team of Hydro4U and OptiPass (a project funded by the DBU, the German Federal Environmental Foundation) include the acceptance and efficiency of the bypass facilities for downstream fish migration. The OptiPass laboratory investigations aim to identify general behavioural patterns of fish in zones with accelerated currents and establish threshold values for the spatial velocity gradient (SVG) that promote high rates of acceptance for bypass entrances. Laboratory findings will be validated in field conditions at the water intake of the Shakhimardan hydropower site, which is equipped with state-of-the-art fish protection facilities, such as a fine rack, a bypass for downstream migration, and a fish pass for upstream migration.

Furthermore, the project team has undertaken extensive biodiversity surveys of fish in the mountain streams of Central Asia. The data collected from these surveys are invaluable in enriching the understanding of fish distribution in the region, particularly in relation to natural environmental factors. The significance of these studies is even greater given the lack of systematic studies of fish diversity in mountain streams of Central Asia over the past 50 to 60 years. These comprehensive efforts contribute significantly to the sustainable management and conservation of aquatic biodiversity in the face of hydropower development.

4. Implementation of demonstration activities

4.1 Shakimardan: Francis Container Power Solution (FCPS)

Shakimardan FCPS is on the Koksū river within the Uzbek enclave of Shakimardan, surrounded by Kyrgyz territory. It is a diversion-type run-of-river plant with a head of approximately 90 m and a rated flow of 3.2 m³/s. The intake is connected to the powerhouse plat-

form by a 2.3 km-long buried penstock and bifurcation pipe. The powerhouse houses two identical Francis units, each located in a double-container assembly, with an additional container for the control system.

An existing intake structure, built in the 1980s and subsequently abandoned, was redesigned and upgraded to meet safety and sustainability requirements in accordance with internationally recognized standards. The pond upstream of the intake is very small and does not have sizeable storage capacity for any type of reservoir operation. To enhance flood conveyance capacity and manage potential overflow of the pond in the event of sudden load shedding, an additional spillway was created. If the two flushing gates at the intake are closed, water can flow over the new spillway into the dewatered reach.

To facilitate fish migration in both directions, the intake structure was equipped with a vertical slot fish pass for upstream migration and a bypass channel for downstream migration. To prevent downstream migrating fish from entering the penstock, an angled vertical bar fish guidance rack has been installed in front of the penstock intake. The bar spacing is 2 cm, which is necessary to protect the turbine runners; however, it is not sufficient to physically prevent small snow trout from entering the penstock. The vertical bar rack is angled relative to the flow direction to serve as a behavioural barrier, guiding downstream migrating fish along the rack toward the bypass channel. The bypass channel is a narrow concrete canal that can be accessed throughout its entire depth. Within the canal, the flow velocity gradually increases and eventually transitions to a steel pipe that flushes the fish downstream. An overview of the arrangement is given in Fig. 1.

After the condition and original design had been evaluated, it was decided that the existing penstock could be reused as it is, with adaptations only being necessary in the bifurcation and the individual manifolds leading to the two turbines. These components were connected to the turbine intake valves and completely encased in reinforced concrete.

The double-container assembly for each turbine was required because of the relatively large turbine size and the additional flywheels needed for island-mode operation. Typically, FCPS units are built within a single standard container. The draft tubes of both turbines end in a shared tailrace basin, from which the water is returned directly to the Koksui river (see Fig. 2).

Shakimardan hydro plant was finalized, tested, and commissioned in late 2024, and it has been in operation since then. Minor works still need to be completed, such as the additional fish pass that will allow snow trout to navigate the existing artificial waterfall in the dewatered reach in both directions.

The next steps at Shakimardan will include the start of a monitoring programme focusing on the plant's performance and ecological improvements. The two fish passes at the artificial waterfall in the dewatered reach and at the intake, combined with adequate releases of environmental flows, are expected to open habitats for snow trout both upstream and beyond the hydropower scheme. Since the 1980s, the artificial waterfall has formed a migration barrier for snow trout, and no fish were found upstream during the monitoring conducted before construction began.

The advantages of the FCPS became evident throughout the development and construction of the project. The turbine and generator sets, including fly-

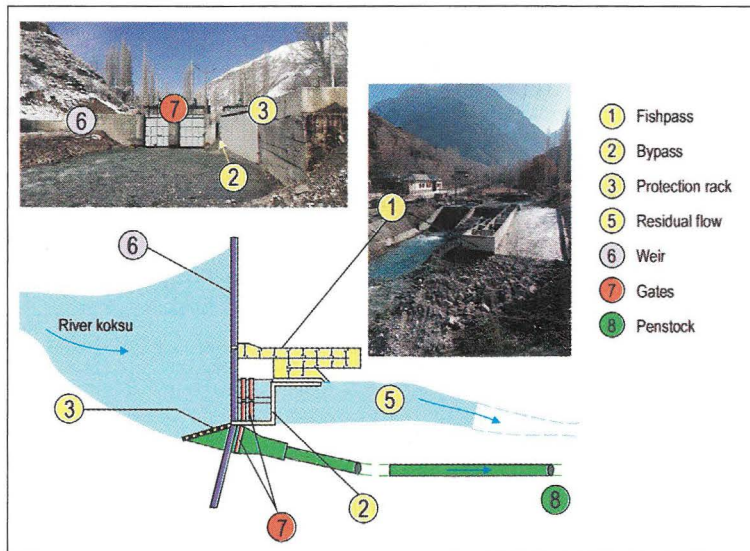


Fig. 1. Layout of the intake area of the Shakimardan hydro plant (Photos by E. Karimov, NRU TIAME).

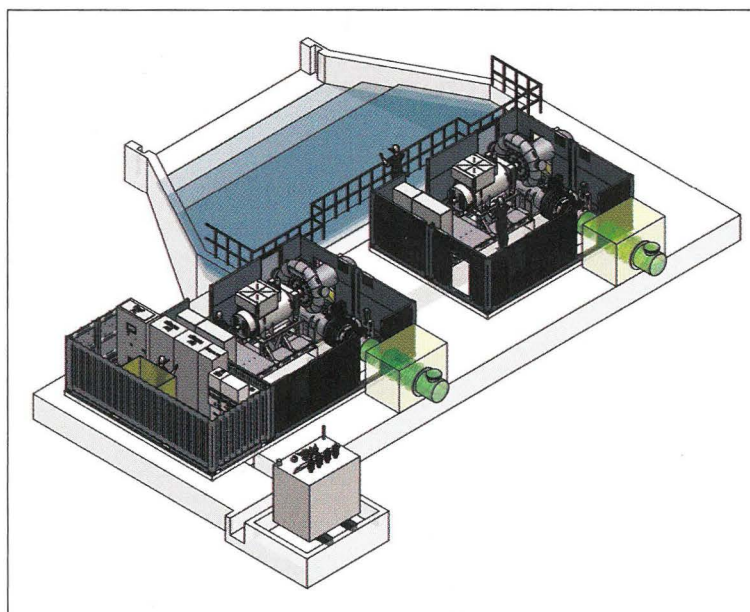
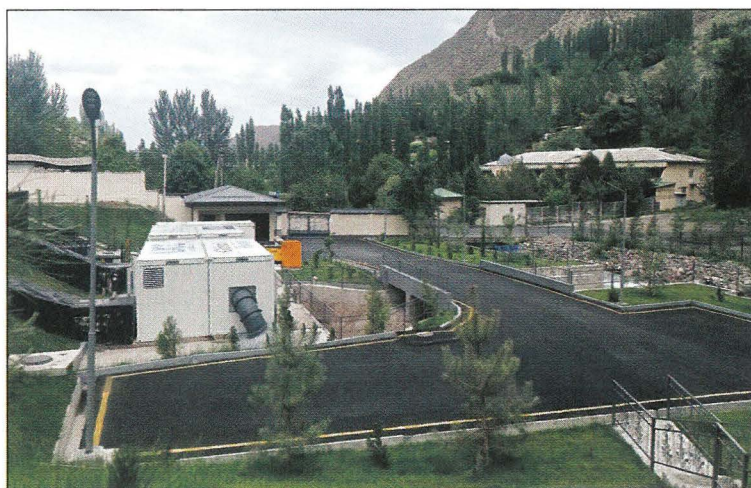


Fig. 2. Layout of the powerhouse area of Shakimardan plant; © Global Hydro Energy.



The completed Shakimardan powerhouse.

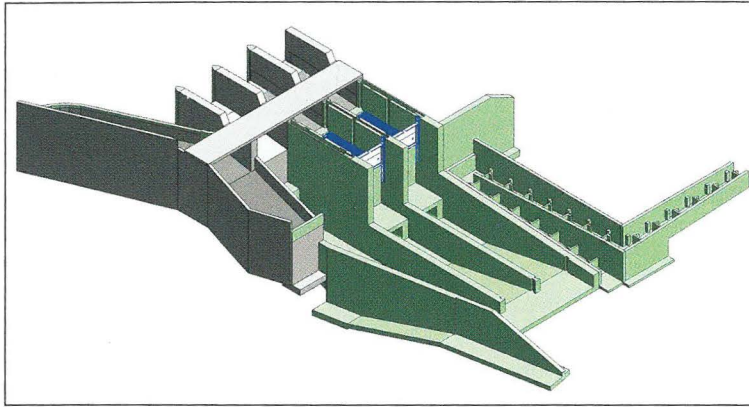


Fig. 3. 3D Model of the At-Bashy hydro plant, showing the existing spillway in grey and new structures in green.

wheels, were designed, manufactured, assembled, and tested by Global Hydro Energy GmbH in Austria. Meanwhile, the local partner, Uzbekhydroenergo JSC, was responsible for the concrete works related to the adaptation of the intake, penstock bifurcation, powerhouse platform, and tailrace basin. Shipping the ready-to-install turbine containers to the Shakimardan site faced uncertainties and delays caused by the war in Ukraine. However, once on-site, the equipment could be installed rapidly and commissioned, allowing the plant to begin operation only 3.5 years after the Hydro4U project was launched.

4.2 At-Bashy: Hydroshaft Power Solution (HSPS)

The second Hydro4U demonstration site is located in the At-Bashy district of the Kyrgyz Republic; it exploits the available head at an existing irrigation diversion weir on the At-Bashy river near the village of Ak-Muz. At this low-head site, an optimized hydroshaft solution is being applied, featuring a new turbine-generator concept developed by Global Hydro Energy, and enhancements to the hydraulic steelworks components implemented by Muhr of Germany. The local construction company, Orion LLC, has been identified as the partner for this innovative hydropower project under a build-own-operate model.

Taking into account the conditions of the existing spillway structure, and in accordance with flood safety and ecological compatibility in accordance with European standards, the hydraulic design and basic layout of the powerplant have been developed by the Technical University of Munich, Germany. The layout includes the installation of two identical shaft-type

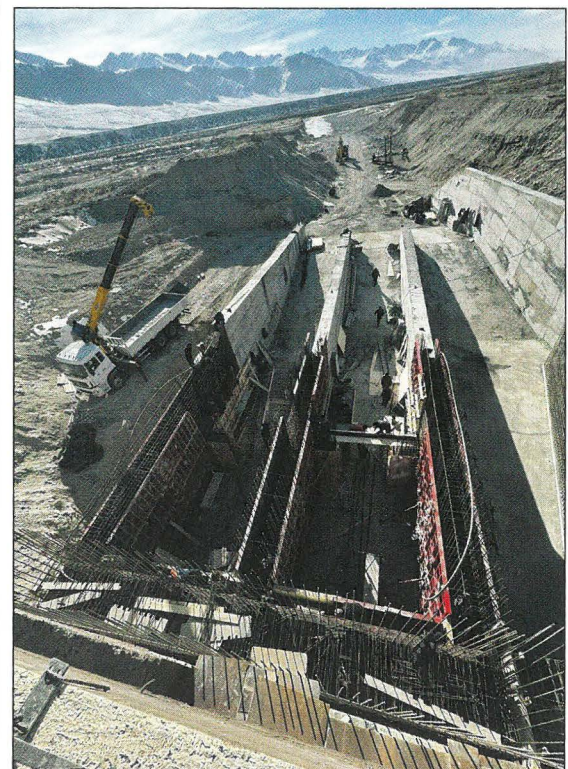
intakes directly below two of the three existing spillway gates. The headwater level is regulated by vertically adjustable, electrically operated, steel gates. To protect both the turbine from larger sediment and fish from turbine passage, the shaft intakes are covered with horizontal trash racks featuring a bar clearance of just 15 mm. An overview of the final layout is provided in Fig. 3.

The powerplant is designed to accommodate a variable headwater level, allowing for the diversion of up to 15 m³/s over a side-overfall weir upstream of the intake for irrigation purposes. During the irrigation season (May to August), the headwater level is maintained at 0.6 m higher than during non-irrigation periods. A critical aspect of the design was to establish appropriate parameters to ensure a sufficient water column above the trashracks in winter when the river surface is expected to be completely frozen, with an ice thickness of around 0.5 m. The average gross head at the facility is approximately 8 m, and each turbine has a rated discharge of 8.5 m³/s, resulting in a total rated discharge of 17 m³/s. This configuration leads to a rated capacity of nearly 1.2 MW and an expected annual energy yield of around 6 GWh.

To enhance the ecological situation of the site, a combined fish migration facility has been planned adjacent to the powerplant. This facility will consist of a vertical slot pass and a nature-like earth channel, designed to aid fish in overcoming the 8 m head difference. Once operational, it will connect the downstream stretch, which is somewhat affected by irrigation diversion, with the relatively untouched upstream stretch, thereby expanding the habitat available for the local fish population.

Because of the deteriorating condition of the existing structures, a significant underpinning of the foundation was designed as part of the structural and detailed engineering carried out by ILF Consulting Engineers

Construction works at the At-Bashy plant. Below: Start of earthworks in September 2024. Below right: Advance by the end of November 2024.



(AT). During this design phase, ILF implemented structural optimizations and adjustments using building information modelling (BIM). This included creating a 3D structural finite element model (FEM). Various loads, such as dead load, earth pressure, and external influences (such as wind and snow), were applied to this model. As these loads induce stresses in the structure, their calculations were carried out using FEM, enabling visualization of the required reinforcement for each model element based on load outcomes.

Construction began in September 2024, and significant milestones were reached by the end of November. Because of the extreme cold conditions from December to March, construction activities were paused during the winter months. Weather permitting, it is anticipated that concrete work will be completed by the end of April this year, followed by the installation of pre-assembled mechanical and electrical equipment for the first powerplant unit before the major flows resulting from snowmelt, from June to August.

The fish pass is expected to be completed before the end of this year, with the facility becoming fully operational after that. Monitoring activities will follow, focusing on the ecological effects of the project, the functionality of mitigation measures, and the performance of the newly developed technical equipment. Construction of the second powerplant unit is already underway; however, the mechanical equipment will be procured separately by the future operator, Orion, on a commercial basis later.

5. Outlook

Despite having faced numerous challenges, the Hydro4U project consortium is on track to complete all tasks outlined in the EU grant agreement successfully. With the Shakimardan demonstration plant operational, and the At-Bashy project under construction, significant milestones have already been achieved. The team has demonstrated outstanding performance in realizing these activities within just 3.5 years, since the beginning of the grant project. This can be considered an intermediate result, showcasing that the technologies implemented can facilitate the rapid and efficient realization of sustainable small hydropower projects in Central Asia and elsewhere.

Currently, replication activities are focused on developing three additional bankable feasibility studies in three Central Asian countries: Kazakhstan, Kyrgyzstan, and Tajikistan. These studies will utilize the tools and technical solutions developed during the demonstration activities, with the aim of implementing them on a commercial basis in the future.

It is expected that at the two demonstration sites, the monitoring programme that will be conducted over the coming year will prove both economic viability and compliance with all sustainability criteria established during the planning and implementation phases. Adjustments will be made as necessary. By the end of the Hydro4U project, the aim is to demonstrate that the overall benefits of high sustainability standards, encompassing technology, river system ecology, and socioeconomic factors, can effectively be achieved using our methodologies and technical solutions. ♦

Funding acknowledgement

The Hydro4U project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101022905.

References

1. Jorde, K., Alapfy, B., Schwedhelm, H., Siegfried, T., Habersack, H., De Keyser, J., Hayes, D.S., Purushottam, A., Schneider, M., and Anarbekov, O., "EU supports small hydropower in Central Asia", *Hydropower & Dams*, Vol. 29, No. 5; 2022.
2. Siegfried, T., Mujahid, A.U.H., Marti, B. et al., "Unveiling the future water pulse of central Asia: A comprehensive 21st century hydrological forecast from stochastic water balance modelling", *Climatic Change* Vol. 177 ; 2024.
3. De Keyser, J., Hayes, D.S., Marti, B., Siegfried, T., Seliger, C., Schwedhelm, H., Anarbekov, O. et al., "Integrating Open-Source Datasets to Analyse the Transboundary Water-Food-Energy-Climate Nexus in Central Asia", *Water* (Switzerland); Vol. 15, No.19; 2023.
4. De Keyser, J., Osuna Fuentes, P., Hayes, D.S. and Habersack, H., "A Review of Hydropower in Central Asia: Past, Present, and Future"; submitted for publication (under review).
5. Kondolf, G.M., Yongxuan Gao, Annandale, G.W., Morris, G.L., Enhui Jiang, Junhua Zhang, Yongtao Cao, et al., "Sustainable Sediment Management in Reservoirs and Regulated Rivers: Experiences from Five Continents", *Earth's Future*, Vol. 2, No. 5; 2014.
6. Elistratov V.V. and Mukhammadiyev M.M., "Integrated use of the hydropower sources of Uzbekistan in the context of climate change", *Applied Solar Energy*, Vol. 59, No. 1; 2023.
7. Radovanović, M., Filipović, S., and Panić, A., "Sustainable energy transition in Central Asia: status and challenges", *Energy, Sustainability and Society*, Vol. 11, No. 49; 2021.
8. He, F., Zarfl, C., Tockner, K., Olden, J.D., Campos, Z., Muniz, F., and Jähnig, S.C., "Hydropower impacts on riverine biodiversity", *Nature Reviews - Earth and Environment*, Vol. 1, No. 18; 2024.
9. Hayes, D.S., Hägele, T., Kopecki, I., Zeiringer, B., Karimov, E., Karimov, B., Coeck, J., Verhelst, P., De Keyser, J., Omonov, O., and Schneider, M., "Environmental flows assessment integrating snow trout habitat requirements in the Shakhimardan basin, Central Asia"; under review.

Bertalan Alapfy received his Dipl-Ing degree in 2017, specializing in Hydraulic Engineering, and his MSc in 2019 in Management at the Technical University of Munich (TUM), Germany. He worked with ILF Consulting Engineers (Bangkok) on hydropower projects in Southeast Asia before partly joining TUM again as a Research Engineer. He is the coordinator of the Horizon 2020 project Hydro4U and, within that role, is responsible for the technical optimization of the shaft powerplant concept and its implementation in Kyrgyzstan. Besides his academic activities, he has been working as an independent consultant on numerous hydropower projects since 2019 with his company Alapfy Engineering & Consulting GmbH.

Department of Hydraulic Engineering, TUM,
D-80333 Munich, Germany.

Dr Daniel Hayes is a freshwater ecologist at BOKU University in Vienna, Austria, with expertise in ecohydrology, multiple stressors, biodiversity, and ecosystem restoration. He earned his PhD from the University of Lisbon, Portugal, and BOKU University in 2021, specializing in environmental water management. He has published 33 SCI-indexed articles, many of which focus on the ecological effects of and solutions for hydropower operations. As chair of the 'Early Careers on Ecohydraulics Network' (ECoENet) and Board Member of the interdisciplinary 'Hydropeaking Research Network' (HyPeak), he is at the forefront of global efforts in sustainable river management.

University of Natural Resources and Life Sciences,
Gregor-Mendel-Straße 33/DG, 1180 Vienna, Austria.



B. Alapfy



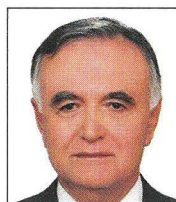
D. Hayes



J. De Keyser



K. Jorde



B. Karimov



I. Kopecki



P. Verhelst

Jan De Keyser graduated in Water Management and Environmental Engineering from the University of Natural Resources and Applied Life Sciences Vienna (BOKU). He subsequently completed a complementary Master's degree in Legal and Business Aspects of Technology at the Johannes Kepler University in Linz, Austria. Currently, he works as a Scientific Assistant, focusing on hydropower-related projects in Central Asia, while pursuing his PhD at the Institute of Hydraulic Engineering and River Research.

Hydraulic Engineering and River Research, University of Natural Resources and Life Sciences, Gregor-Mendel-Straße 33/DG, 1180 Vienna, Austria.

Dr Klaus Jorde is a Civil Engineer with 35 years of experience in all aspects of hydropower development, having worked in more than 30 countries worldwide. He received his Dipl-Ing (1987) and Dr-Ing (1996) degrees from the University of Stuttgart, Germany. From 2001 to 2008, he was Professor at the University of Idaho, USA. Since 2012 he has worked as an independent consultant and for larger hydropower projects as an associated freelancer for other consulting firms in international teams. He has been the Manager of the Swiss Federal Office of Energy's hydropower research programme since 2008, and represents Switzerland in the IEA Hydropower Technology Collaboration Programme. In 2021, he became the Executive Committee Secretary of IEA Hydro. He operates his own small hydropower plant in Southern Germany.

KJ Consult, Ferdinand-Raunegger-Gasse 26, 9020 Klagenfurt, Austria.

Prof Bakhtiyor Karimov is a Professor in the Department of Ecology and Water Resources Management of the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Uzbekistan, where he has been a faculty member since 2015. From 1991 to 2014, he worked as the Head of the Hydroecology and Hydrobiology Laboratory at the Uzbekistan Academy of Sciences. His research interests lie in the areas of Aquatic Ecology, Agroecology, Limnology, and

Ecotoxicology of Arid and Desert Land in the Aral Sea Basin. He has published more than 250 scientific publications, including articles in the world's peer-reviewed leading scientific journals such as Nature, Science AAAS, Environment International, Ecology Letters, Inland Waters.

Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, National Research University (TIAME NRU), 39 Kori Niyozov str., Tashkent 100000, Uzbekistan.

Dr-Ing. Ianina Kopecki received her Diploma in Civil Engineering from the St. Petersburg State Polytechnical University, Russia, her Master's Degree at WAREM, and her doctorate from the University of Stuttgart, Germany. She has more than 20 years of experience in hydrodynamic modelling, ranging from 2D/3D laboratory simulations to 1D/2D low water and flood simulations. She is an expert in photogrammetry and the Structure-from-Motion (SfM) technique, DEM creation, and GIS. As a team leader at SJE, she is involved in many applied and scientific projects dealing with ecological aspects of hydropower development. She is also the lead developer of the habitat model CASiMiR.

sje - Ecohydraulic Engineering GmbH, Dilleniusstraße 13, D-71522 Backnang, Germany.

Pieterjan Verhelst obtained a PhD in Biology at the university of Ghent, Belgium, on the topic of European eel (*Anguilla anguilla*) movement behaviour in various aquatic environments, through acoustic telemetry. He currently works at the Aquatic Management team of the Research Institute for Nature and Forest in Belgium, where he studies fish ecology, both fundamental and applied, to provide knowledge and solutions for adequate management both nationally and internationally. The main topics relate to fish movement, habitat use and habitat restoration. Various techniques are used, such as different kinds of telemetry (acoustic, PIT, radio and archival), mark-recapture and fishing.

Research Institute for Nature and Forest, Havenlaan 88, bus 73, 1000 Brussels, Belgium.

WORLD ATLAS DIGITAL EDITION

Access the digital edition of our World Atlas

The *World Atlas of Hydropower & Dams* is the most respected and referenced annual report on the current status and investment plans in the hydropower and dams sectors. The *World Atlas 2024* provides original, comprehensive, up-to-date research on more than 180 countries, including priorities and plans for future schemes. There are also statistics on hydro potential, dams under construction and planned, pumped storage, and the role played by hydro in each country's energy mix. Research for the country reports is conducted directly with power authorities, electricity regulators, water authorities, regional organizations and ICOLD national committees.

Order an access link to this unique reference source by applying to: subs@hydropower-dams.com or visit: www.hydropower-dams.com

