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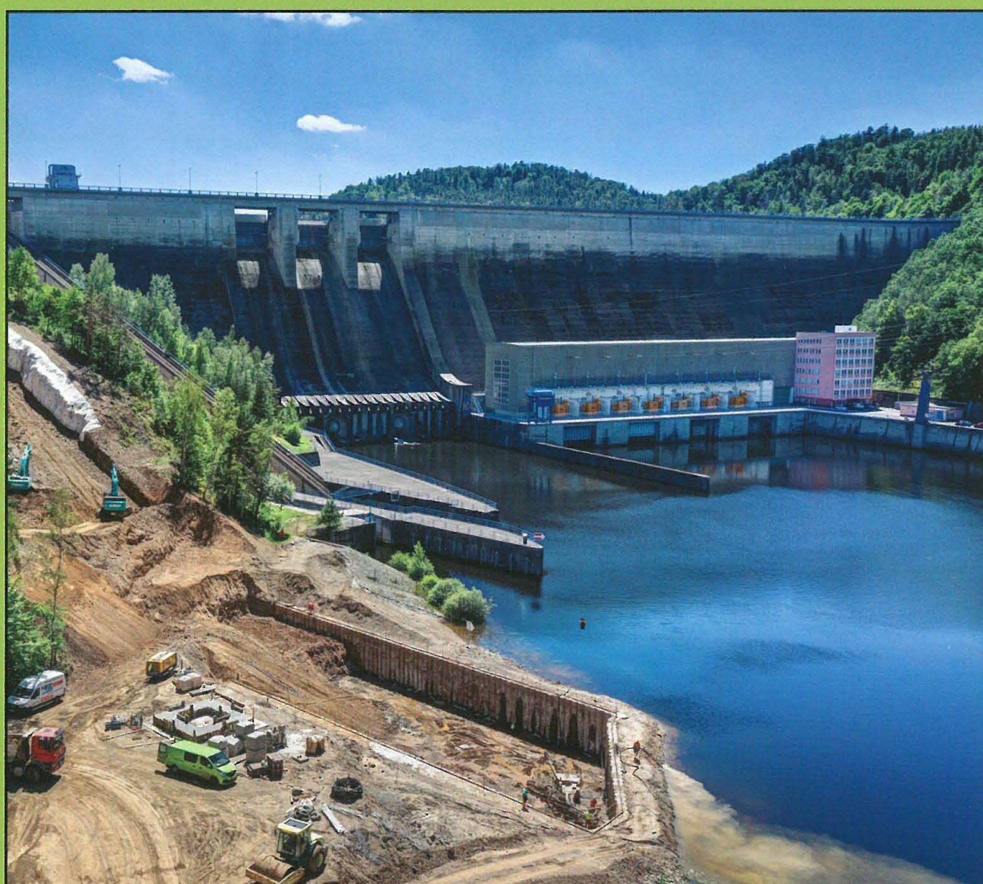

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**REGIONAL FOCUS ON CENTRAL EUROPE AND CENTRAL ASIA**

**INSTRUMENTATION AND MONITORING ~ POWERPLANT SAFETY ~ FRANCIS TURBINES**

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# EU supports small hydropower in Central Asia

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Through the innovation project 'Hydro4U', the European Union (EU) under its Horizon 2020 funding scheme is funding the development and optimization of sustainable and practical technologies, planning methods and assessment tools in the area of small-scale hydropower with the primary goal to enhance their application in Central Asia. Thirteen partners, from the EU and from Central Asia, scientific institutions, consultants, industry partners and NGOs are collaborating over a period of five years to generate a sustainable impact on Central Asia by finding new ways to deal with the challenges that normally arise with hydropower development, covering technical, ecological, economic and social aspects.

The Hydro4U project work includes the evaluation of the Central Asian small hydro potential, complemented with the analysis of this type of energy generation in a Water-Energy-Food-Climate (WEFC) Nexus context. The central focus of the project is the development of two types of modular and sustainable innovative small hydro technologies, a Hydroshaft SHP for low heads and a Francis Container SHP for medium heads, and their demonstration and assessment within two real-scale demonstration activities, including all associated planning and assessment work.

Innovation and sustainability will also be implemented in the planning process by integrating hydrological uncertainties caused by climate change into the planning, and by considering state-of-the-art methodologies to determine environmental flows (E-flows) in diverted river reaches and two-way fish migration throughout river reaches affected by the SHPs.

To replicate the experiences gained and to make them available for as many locations as possible, further so-called planning activities (to be understood as bankable feasibility studies) complement the demonstrations and are embedded in a wide-ranging 'replication strategy'. Aspects of exploitation and dissemination are key within the project structure. A separate work package ensures the quality of the implementation of the project activities over the whole duration.

The two demonstration activities will show how sustainably applied small hydro can contribute to solving current and future challenges posed by the need for energy transition in the context of climate change and social development. Central Asia is a particularly chal-

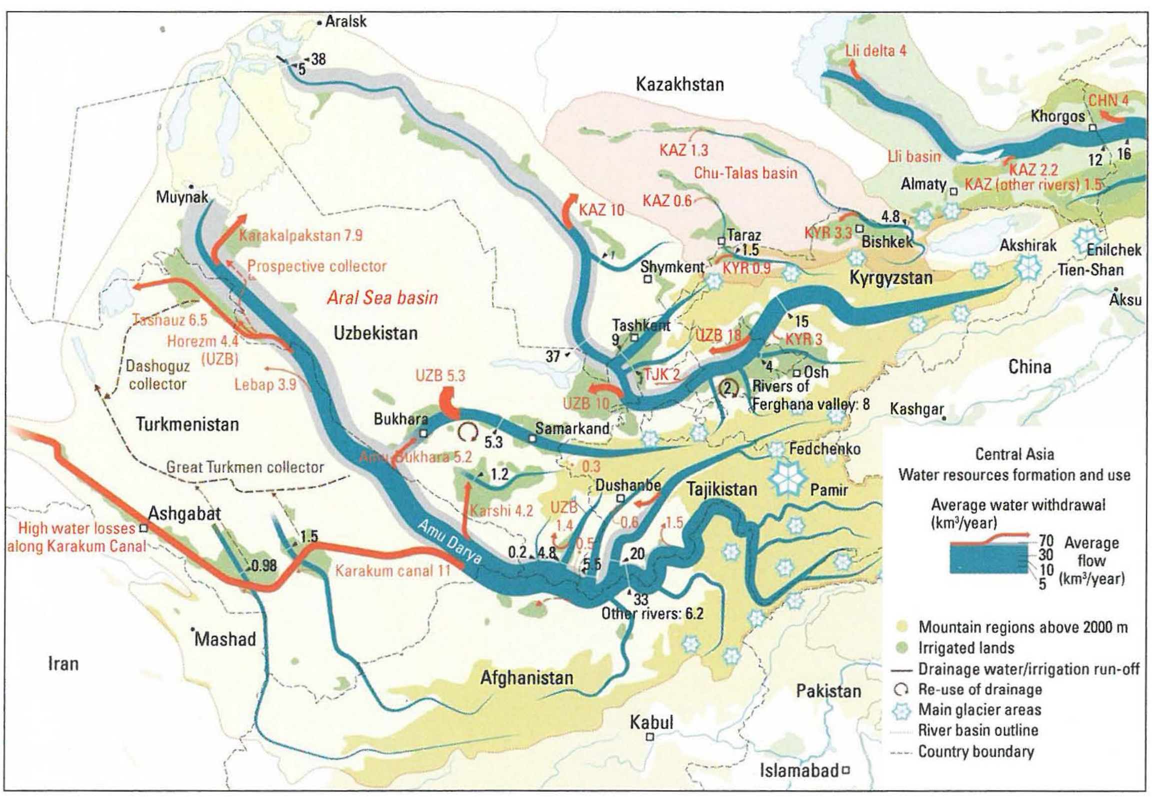



*Fig. 1. Water resource formation and use in Central Asia.*
*Source: Zoï Environment Network.*

lenging region, as there are already numerous conflicts related to water, and further studies indicate that climate change will hit this region particularly hard, with temperatures increasing significantly. It is obvious that this will have an impact on the water balance, and thus possibly exacerbate the conflicts [Siegfried *et al.*, 2012[1]].

This article presents the different facets and objectives of the Hydro4U project, and gives an overview about the current and planned activities to reach these objectives.

## 1. Topography, hydrology and small hydro potential in Central Asia

Central Asia covers an area of about 4.6 × $10^6$ $km^2$, including Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan and Afghanistan. It is a region that is rich in diverse energy resources with significant reserves of coal, oil, and gas and an equally important hydropower potential with significant development potential, also in relation to other renewables such as solar and wind [Eshchanov *et al.*, 2019[2]; Lalbajebaev *et al.*, 2022[3]].

### 1.1 Hydrology

In the southern part of the region, where most of the hydropower potential lies, water resources are very unevenly distributed between the humid high mountain region and the semi-arid to arid plains. The large river systems, including the Amu Darya, the Zarafshan, Syr Darya, Chu, and Talas, as well as the Ily river, emerge in the Hindukush, the Pamirs and the Gissar-Alay range, as well as the Tien Shan and are all endorheic. They are fed by many smaller mountain streams that are predominately snowmelt-fed (see Figs. 1 and 2).

The relief is the most important determinant for the regional organization of the zones of runoff formation. The rivers used to feed the Aral Sea ecosystem before the large-scale development of irrigated agriculture. Today, when the natural rivers leave the mountainous regions, the water is captured and diverted into artificial canals and storage infrastructure. These vast water supply and drainage canal systems irrigate some of the world's largest irrigation systems. Many of these systems are deteriorating and suffer from ineffective water allocation and low resource use efficiency. This situation leads to suboptimal agricultural outcomes [Siegfried *et al.*, 2022[4]] .

With climate change, the region is currently undergoing significant changes. These will likely accelerate in the future and translate into significant changes in the hydrological regimes of the region's mountain rivers. The ongoing warming will greatly impact the high mountain region, to the extent that the current nivo-glacial runoff regimes will shift more and more towards nival and pluvial regimes. These changes will greatly affect the downstream water availability. In unregulated basins, for example, late summer water availability is likely to see a significant reduction at the time of highest irrigation requirements in the irrigation oases. At the same time, it is expected that winter discharge is consistently increasing in the region as the ratio of liquid to solid precipitation increases [Siegfried *et a*l., 2012[1]].

### 1.2 Large hydropower in the region

Based on the hydrology and topography, some regions within Central Asia have an enormous hydropower potential which is already exploited, or where the further exploitation is planned. Three large hydropower cascades have so far been developed in Central Asia: the Chirchik and Naryn Cascades in the Syr Darya basin, and the Vaksh Cascade in the Amu Darya basin. With the Rogun hydro plant, the construction of large schemes is continuing in the Vaksh river basin. Interstate agreements between Tajikistan in the upstream and Uzbekistan in the downstream for the development of the Zarafshan cascade have been signed in 2022. Being mostly a border river between Tajikistan and Afghanistan, the Pyandzh river so far has not been significantly developed for hydropower, despite its tremendous potential. Hydropower plants have also been developed on many of the larger artificial canals. The small hydro potential, however, which could easily be developed by private investors, is so far somewhat under-exploited.

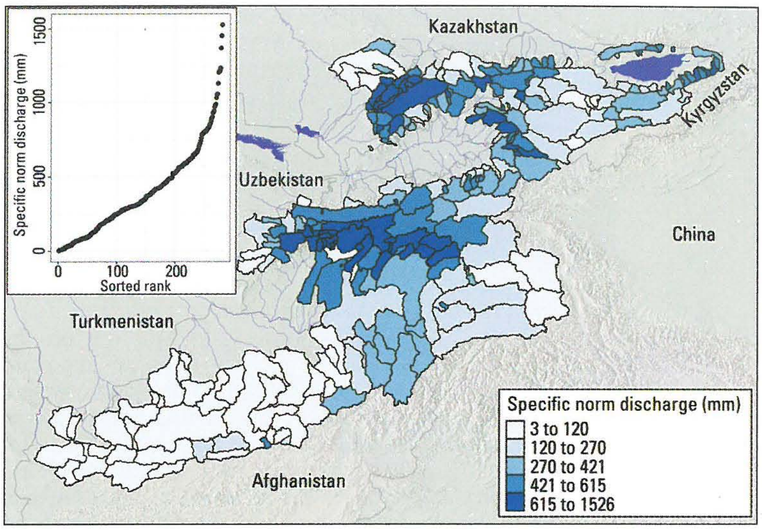



*Fig. 2. Long-term norm specific discharge of 300 mountain catchments in the Central Asian region, including Afghanistan. The catchments are coloured according to their specific long-term norm discharge. The box shows sorted specific discharge values for all mountain catchments for which data is available.*

### 1.3 GIS-based decision support tool to explore the small hydro potential

Besides bringing innovative European hydropower technologies to Central Asia, one major goal of Hydro4U is to support sustainable small-scale hydropower development beyond the lifetime of the project. Therefore, a GIS web-based tool is being developed to facilitate the decision-making process for investors, stakeholders and political decision makers. This consists of an interactive map displaying the sustainable small hydropower potential which is then intersected with a decision matrix for hydropower type-specific decision support. This web-based tool, as one final product of this research, will help hydropower actors to identify and select the best matching and sustainable technical solution for the specific location.

The computation of the hydro potential is done using a multistage procedure. The theoretical line potential, which is based on the hydrological conditions, is gradually broken down towards a sustainable potential, as regards environmental parameters and constraints. This procedure makes it possible to incorporate all kinds of sectors relevant for a sustainable perspective. After the line potential has been computed, technical aspects of small-scale hydro plants, such as certain ranges of head or discharge are being considered. Furthermore, already existing and currently operating plants were identified and are being integrated in the hydropower potential map. Less suitable locations from an environmental point of view are being considered by taking ecological as well as geomorphological constraints into account. Moreover, forward-looking climate change modelling approaches are being included as well, to ensure the availability of the determined potential in the future.

For a holistic approach, socio-economic aspects, such as current water uses (for example, water supply for domestic, agricultural and industrial use) as well as those which will be required in the future, need to be taken into account. All those socio-economic aspects are also addressed within Hydro4U, when studying the Water-Energy-Food Nexus in the project region.

As previously mentioned, when working on the hydropower potential in Central Asia, an important issue to deal with is the complex irrigation system which greatly influences the natural flow regime. Especially in the arid region of Central Asia, the influence of these canals cannot be neglected. The exploitation of small hydropower at irrigation canals would have almost no environmental impact. Local partners are necessary to collect information on discharge within the first order canal system.

Such a complex and holistic approach to determine the hydropower potential has not been done previously in this region. By demonstrating the remaining sustainable hydropower potential, this study will certainly contribute to enhancing the development of small hydropower in Central Asia.

## 2. SHP technology development and demonstration

Two innovative types of small hydropower will be further developed within this project.

### 2.1 Hydroshaft power solution

The Hydroshaft concept is a low-head solution that has been developed at the Technical University of Munich (TUM) and implemented at two experimental prototypes and two further mini-hydro projects (> 500 kW) in Germany so far.

The general design is based on a completely submerged Kaplan turbine in a shaft coupled to a permanent magnetic generator (see Fig. 3). The intake is parallel to the riverbed, forcing the water to enter the shaft vertically. It is equipped with a horizontal rack system with narrow bar spacing, which includes a submerged trashrack cleaning system. The rack system protects fish from being sucked into the turbines, and prevents bedload material from entering the shaft. The Hydroshaft concept includes a vertically adjustable sliding gate at the downstream end, which can be raised and lowered to regulate the headwater level. To clean the rack system, the cleaner pushes material deposited on the intake towards the downstream end, while the sliding gate is lifted and the material is flushed downstream. The gate is equipped with adjustable openings, providing a permanent fish-downstream migration corridor. This overall design of the Hydroshaft concept therefore provides downstream fish migration, as well as sediment connectivity. In addition, as most of the structures are submerged, it is hardly visible within the riverbed and flood safe.

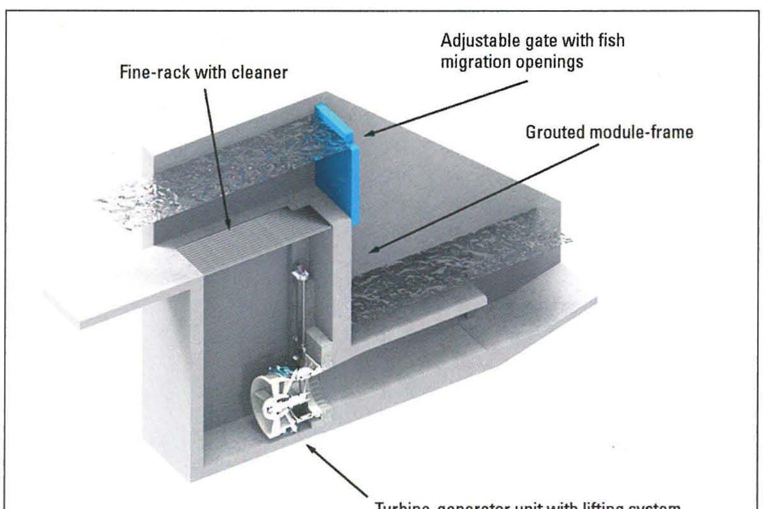



*Fig. 3. Schematic image of the Hydroshaft Power Solution, developed by Global Hydro Energy.*

The technical functionality and advantages regarding ecological consistency and fish protection have already been proven. However, both reference projects were very expensive to implement. The amount of the total costs and the cost drivers (such as elaborate planning, complex construction work, individual machine components and associated unpredictable scheduling) added to the difficulty of project implementation. Therefore, the necessity to reduce costs significantly, the complexity of implementation, and associated risks have been identified, to enable the application of this technology even in challenging economic and technical settings, while maintaining its proven advantages.

For these reasons, the Hydroshaft concept has been developed further within the framework of Hydro4U. The partners, including scientists, engineers, and industry experts, have developed a new way for cost-effective and risk-reduced implementation of the Hydroshaft concept. The main difference in the design evolved is that all technical components of the powerplant are integrated into a standardized and modular system, with precisely defined interfaces. This way, the 'concept' can become a tangible 'product', which can be offered as a turnkey hydropower solution and can be implemented in a cost-efficient and risk-reduced manner, largely independent of site-specific conditions.

Whereas in past projects, all components of the powerplant had to be designed, manufactured and assembled individually to match each other and suit the site, the new design was chosen so that a standardized and modular system would allow for optimal adaptation to site conditions without the need for an individual design of each component.

The new design retains the advantages already identified of the previous solution, while significantly lowering the barriers to successful implementation, primarily by reducing overall costs, complexity, and, subsequently, risk of failure.

Within the Hydro4U project, this new technology will be implemented at an existing weir structure, built in the 1970s for the diversion of water for irrigation, in the At-Bashi region of the Kyrgyz Republic. The weir is on the At-Bashi river, a left tributary of the Naryn river.

### 2.2 Francis Container small hydro system

The Francis Container Power Solution (see Fig. 4) is a concept for standardizing and optimizing small hydropower plants. This solution was developed by Global Hydro Energy GmbH, Austria (GHE), which is a partner of Hydro4U consortium. A conventional hydropower plant needs a considerable amount of engineering, civil works, and time from designing through to commissioning. The FCPS addresses this issue by reducing the technical complexity by the modular design and manufacturing strategy. This aims to make the requirements for construction on site as simple as possible, and installation time as short as possible. Therefore, this compact solution is also cost-effective, which makes it favourable in challenging economic markets.

As the name suggests, the concept of the FCPS is based on the placement of the electromechanical equipment, the turbine and generator, inside a standard container allowing for maximum prefabrication and minimum on-site work. Because of the size constraint of a standard container, a maximum output of 1 MW can be obtained with this type of solution. Details of the FCPS are shown in Fig. 5.

## 3. Planning and implementation of innovative SHP

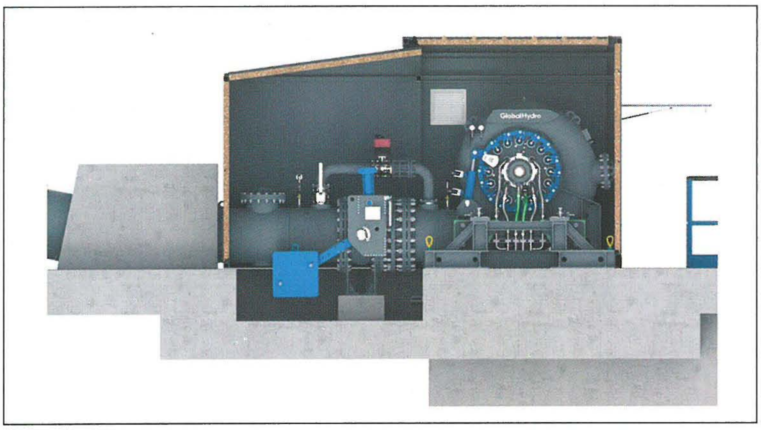
A total of five small hydro sites will be planned and designed as part of the Hydro4U project, and two sites, representing the two innovative technologies, will be built jointly with local investors. The sustainability aspect is demonstrated by the fact that high quality and site-specific design of the electromechanical equipment will result in a better technical and financial performance of such projects throughout their lifetimes, although the initial investment may be higher. The idea is to spread the sites chosen to be included in the project across various different Central Asian countries.

Two locations have been selected as so-called demonstration sites. To demonstrate overall sustainability, the operation of the small hydro plants must be monitored at least for one year within the ongoing project. The project has a five- year duration, and therefore the operation of the two demo-site schemes must start four years after the start of Hydro4U. This is a challenge and can only be achieved jointly with experienced local investors capable of handling licence applications for water rights and construction permits, as well as the actual construction works. Potential local investors and possible sites had been identified well before the project was even approved by the EU to be able to meet these challenges.

### 3.1 Demo-site 1, Shakimardan in Uzbekistan

The first demonstration project is a 2 MW diversion-type run-of-river small hydro scheme, to be built on the Koksu river within the Uzbek enclave of Shakimardan, located in Kyrgyzstan, west of the city of Osh. The Koksu and Aksu rivers join and flow towards the Ferghana valley, where the water is used for irrigation. The enclave, which has approximately 6000 inhabitants, is provided with electricity from Kyrgyzstan and suffers from power outages during times when electricity supply is limited in Kyrgyzstan. Such outages are limiting local economic development in tourism, and fruit and vegetable farming and processing, and a first attempt to build a small hydro plant dates back to the 1980s. The project was eventually abandoned, but an intake structure and a 2.3 km-long buried penstock is still there. The project is strongly supported by the local population, because it will provide a stable and reliable source of electricity, able to operate in island mode, and thus creating at least a partial independency from the electricity supply from Kyrgyzstan.

An analysis of the topography and the hydrological situation showed that climate change will not have a significant impact on the hydrology of this catchment. Flow duration curves at the end of the lifetime of the project (assumed to be 40 years) will be almost the same as today, independently from the climate change model applied in the simulations. This is quite unexpected, and among the reasons might be the presence of two natural lakes, formed by a massive landslide, some hundreds of year ago, together with the glaciers in the upstream catchments. There is a shift, however, with snowmelt runoffs tending to occur earlier in the year, and drier summers.



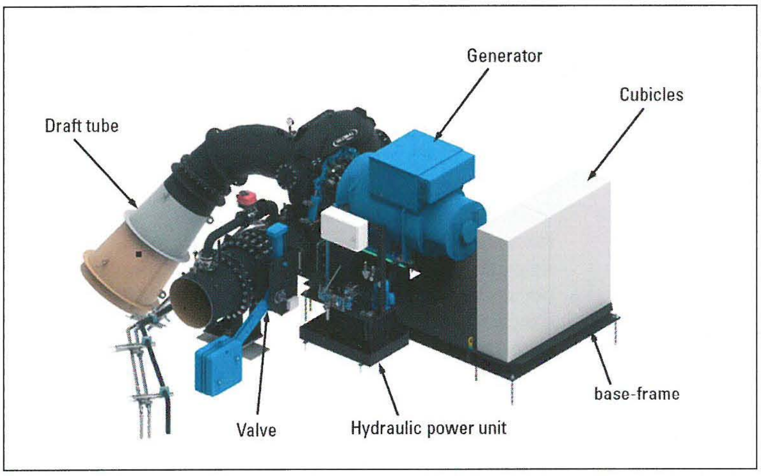



*Fig. 4 (upper image). The Francis Container Power Solution (FCPS) developed by Global Hydro Energy.*

*Fig. 5. Detail of the features of the FCPS.*

*Existing intake structure for the planned Shakimardan SHP on Koksu river in Uzbekistan*

*The existing weir at At-Bashi, Kyrgyzstan.*

It was decided that today's runoff regime can generally be used for the design and general layout of the plant. It is planned to install two Francis Container units with a rated discharge of 1.6 $m^3/s$ each and a head of about 90 m, and to connect these with new bifurcation pipes to the existing penstock. The installed capacity will be about 2 MW, and annual generation of 13 GWh is expected, despite the Environmental flow (E-flow) regulation that will be implemented.

The present ecological situation is unfavourable. Snow trout is generally abundant in the river system but cannot migrate upstream through the future dewatered reach because of an artificial drop created during road construction works in the 1980s. No snow trout could be found upstream of the drop despite suitable habitat conditions. The project foresees that this artificial upstream migration barrier will be removed or a fish pass will be built. In addition, the diversion weir will be refurbished with new gates and also retrofitted with a new fish pass to enable upstream fish migration in the future.

The Shakimardan site is a classic example for the Water-Energy-Food-Environment nexus in transboundary small river conditions. The electricity supply to the Shakimardan enclave, Uzbek territory, comes from Kyrgyzstan. There are also Kyrgyz villages with 120 households who get electricity via the Shakimardan Enclave, including a cable car touristic attraction located in the Kyrgyz upper part of the valley.

The construction of the Shakimardan small hydro plant will therefore not only serve the Uzbek Enclave territory, but will also provide electricity to Kyrgyzstan, and boost further transboundary cooperation. Local stakeholders expect that the additional electricity will stabilize and improve the electricity supply in the enclave. Social well-being will be supported, it will boost the tourism industry as well as help food security by providing the opportunity to irrigate additional land in the hilly area by pumping water. The economy will be supported by the construction of refrigerators to keep fruit and vegetables for export during the winter time to neighbouring regions.

### 3.2 Demo-site 2, At-Bashi in Kyrgyzstan

The second demo-site, At-Bashi, is on the At-Bashi river, southeast of Naryn City in Kyrgyzstan. This site has been identified as a demonstration site for the modular Hydroshaft Power Solution, which is being developed within the Hydro4U project. The company Orion LLC, was found, as a competent and strong investor for the joint implementation of this challenging project. At this site there was already a gated diversion weir to divert part of the natural flow of the At-Bashi river into the right side irrigation canal. The river valley is several hundred metres wide at the site, and an embankment dam made of local alluvial sediments spans the wide river bed. Flows, up to regular flood flows, remain in the river bed which is impounded by the diversion weir. Higher flows inundate the alluvial floodplain, and can be spilled through an additional concrete spillway. Very large floods will erode the embankment dam and largely avoid damage to the diversion weir. Once the flood has receded, the embankment dam can be rebuilt and the river redirected into its river bed.

The situation is highly suitable as the Hydroshaft plant can be directly attached to the existing gated spillways of the diversion weir. Two of the three spillway sections will be used as a bay to expand the lateral walls in the downstream direction, and individual Hydroshaft sections can be installed in those bays.

Based on a preliminary design, two Hydroshaft modules will be installed, with a discharge capacity of 9 to 10 $m^3/s$ each, to operate with an average head of 7 to 8 m. As a result of the nivo-glacial discharge regime with low flows during winter (October to March) and peak flows in April to September, the two-module setup makes it possible to exploit the highly variable flow rates in an efficient manner. One module will work over the entire flow range, while the other will cover the upper ranges of flows. Therefore, a planned capacity of around 1 MW and an annual output of 6.6 GWh/year are estimated for this site.

In addition to the demonstration sites, three planning sites will be identified, for which bankable feasibility studies for small-scale hydropower will be developed within Hydro4U. So far, one such site has already been defined: Badam reservoir in Kazakhstan. This site is significantly different from the demonstration sites as it is located in an existing irrigation system consisting of (interbasin) diversion structures, irrigation channels, and two reservoirs. The new hydropower facility will be located at the reservoir's water outlet. It is, therefore, an example of how advantage can be taken of an existing water diversion and storage system to produce hydropower, without affecting or reducing the water availability for irrigation. Based on an analysis of the water allocation and natural hydrological conditions, the reservoir operation can be optimized to increase the hydro plant's efficiency. In addition, the ecological situation will be improved within the two rivers linked to the irrigation system (the Sairam and Badam rivers), as the feasibility study includes detailed ecological surveys and the design and implementation of mitigation measures such as fish migration facilities and environmental flow regulations at the sub-basin scale. Based on the current planning status, a Francis Container solution with an installed capacity of around 1.4 MW is a feasible option here.

## 4. Ecological sustainability

The mountain rivers of Central Asia constitute regional freshwater biodiversity hotspots. Compared with the region's rivers that flow through the valleys, mountain streams are not yet as heavily impacted by human activities such as water abstraction and dam construction [Gozlan *et al.*, 2019[5]] and thereby sustain a diversity of habitats and species. However, the call for renewable energies and increasing demand in less developed areas increases pressure on these vulnerable ecosystems. Particularly the development of hydropower can put species and ecosystems at risk.

*A snow trout, which was the dominant species identified at Shakimardan, and was chosen as the target species for environmental flow assessment studies.*

Around 25 per cent of Central Asia's 120 fish species are already on the Red List [Gozlan *et al.*, 2019[5]]. In reality, the situation could become dire, considering that 30 per cent of the region's fish fauna is classified as data-deficient [Karimov *et al.*, 2022[6]]. Also, too little is known about fish ecology, particularly related to topics that constitute the basis for the sustainable development of hydropower. Knowledge of fish morphology, migration, habitats, and hydraulics is urgently needed to design fish passes, guidance and protection systems, and to assess environmental flows [Rutschmann *et al.*, 2022[7]].

The Hydro4U project aims to ensure sustainable SHP development at its sites, for example by applying a 'no net loss of habitats' criterion. For the two demonstration sites, the ecological situation, specifically for fish, is not satisfactory at present, because there are artificial migration barriers. The situation will even be improved by the construction and operation of the small hydro plants.

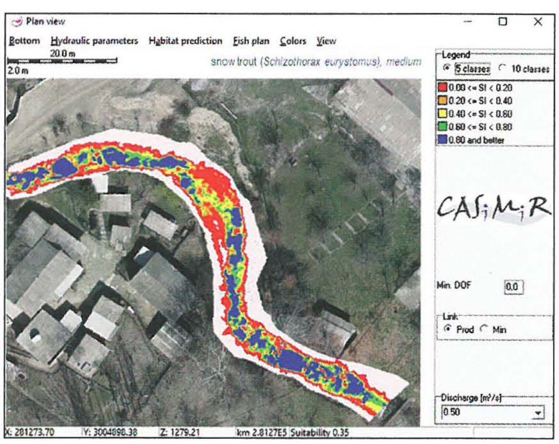
To gain a general understanding of the ecological situation of fish at the sites, extensive field surveys are being conducted as a foundation for the ecological sustainability assessment. The first of these sampling campaigns took place in early 2022 at the Uzbek demonstration site located in the enclave of Shakimardan.

The ecologists sampled 21 sites in the Shakimardan river basin, consisting of 41 mesohabitat units (for example, pool, riffle, run) with backpack electrofishing gear. Snow trout (*Schizothorax eurystomus*), see photo above, was identified as the dominant species, and so was chosen as the target species for assessing environmental flows in the 4 km dewatered reach of the Koksu river [Karimov *et al.*, 2022[6]]. The team recorded flow hydraulics (water depth, velocity), riverbed substrate, and flow protection cover of >200 microhabitat locations where the target fish were caught.

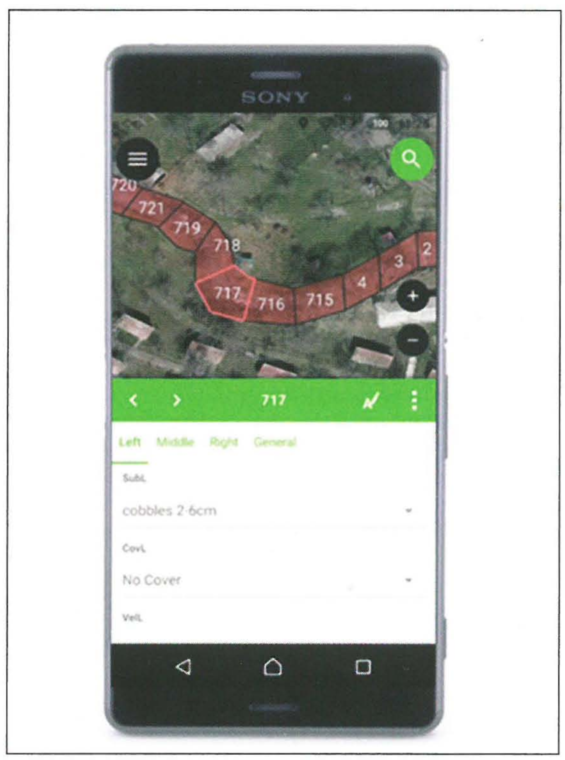
These data were analysed to specify habitat preferences for three age/length classes (juvenile, sub-adult, and adult) of snow trout. Preferences were transformed into input data for the habitat modelling system CASiMiR [Noack *et al.*, 2013[8]] that is based on a formulation of habitat criteria based on fuzzy logic and capable of operating with still limited knowledge about snow trout ecology. In combination with hydrodynamic models of the dewatered reach, CASiMiR can thus predict how habitat quality and quantity will change once the hydropower plant is in operation. The model is used to simulate and optimize suitable E-flow regulations, describing how much water must be released into the dewatered river bed downstream of the intake weir to maintain a certain percentage of the habitat for snow trout that existed in natural hydrological conditions.

A 2D hydrodynamic model for the whole diverted river section of Koksu river (about 4 km long) and for four detail reaches was developed. Information on the river bottom morphology and hydro-morphological units was collected using a QField-based mesohabitat mapping tool for smartphones (see photo below). Recorded habitat parameters included bottom substrate, fish cover, flow velocity, and water depth. Overall, ten hydro-morphological unit types were recorded and spatially allocated to polygons 10 m long for the left and right riverbank zones and the central part of the river. The mesohabitat information supported the interpretation of the results derived from electrofishing surveys, and assisted in the evaluation of the habitat simulation results for the detail reaches against the background of the habitats in the whole river section.

Orthophotos based on aerial pictures from drone flights supported both mesohabitat mapping and the




*Far left: Screenshot from the CASiMiR habitat modelling system, showing snow trout habitat quality.*




*Left: Interface of the Smartphone application (based on QField) for mesohabitat mapping, using a high quality orthophoto.*

development of a digital elevation model as part of the hydrodynamic model. This large-scale model was used to investigate the fish migration corridor along the diverted section. For the four detail reaches, drone pictures with additional terrestrial survey data were used to set up high-resolution hydrodynamic and fish habitat models. The models were used to analyse habitats for the various age/length classes of snow trout for different flows. Seasonal flows and respective habitat in such flow conditions served as reference to define minimum environmental flow recommendations. Several E-flow scenarios with different priority settings have been developed as input for the final planning and dimensioning of the hydropower plant. Modelling results are used to prove the 'no net loss of habitat' strategy, to ensure migration throughout the entire dewatered reach, to define the most suitable location for the fishpass entrance for upstream navitation [Kopecki *et al*, 2002[9]], and the bypass for downstream migration as parts of the diversion weir.

When constructed, the fish ladders at the artificial drop and at the intake weir will open access to several kilometres of suitable fish habitat upstream of the intake where at present no fish are found, most likely because of the artificial migration barrier in the dewatered reach. In the dewatered reach there will be flows of 0.3 to 0.5 $m^3/s$, depending on the season. This will ensure a migration corridor for snow trout throughout the year and protect about 70 per cent of suitable habitat as compared with the existing situation. In combination with the newly accessible river reaches, there will be a net gain in habitat once the small hydro plant is in operation.

Similarly, the situation at the second demonstration project, At-Bashi in Kyrgyzstan, will also be improved. The existing irrigation weir is a migration barrier for upstream migrating snow trout and the construction of the Hydroshaft SHP will be accompanied by the construction of a new fish ladder which will enable upstream migration in the future. Fish data collection has so far shown an abundance of snow trout, and detailed river bed surveys are now under way.

## 5. Summary and outlook

Hydro4U, an EU-funded project, advances the development and implementation of sustainable small hydropower in Central Asia as regards technical, ecological, economic and social aspects. Within the first year of the project, major steps have already been achieved in further optimizing the two small hydro technologies of the project (Hydroshaft and Francis Container), designing the hydropower plants at the demonstration sites, analysing the hydrological conditions in Central Asia and gaining knowledge on the ecological condition and native fauna.

The next steps will be the detailed design of the hydropower plants and their implementation, including ecological mitigation measures based on intensive ecological surveys, as well as the assessment and the extensive monitoring of the works. With a view to having a long-lasting and sustained impact on the region, the project includes further important steps to support and develop sustainable hydropower in the region further. These include tools for identifying hydro potential within the region, and simplifying the replication of sustainable small-scale hydro projects, with particular attention to the Water-Energy-Food-Climate (WEFC) nexus context. ◊

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