APPLICATION OF ADAPTED WATER TECHNOLOGIES AND MANAGEMENT STRATEGIES IN EMERGING COUNTRIES
Experiences of IWRM Indonesia

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Abstract:
Within the German-Indonesian joint-project "Integrated Water Resources Management (IWRM) Indonesia", funded by the German Federal Ministry for Education and Research (BMBF), innovative technologies and management strategies are designed and adapted under the aegis of the Karlsruhe Institute for Technology (KIT) to improve the water supply situation in karst areas.

In this context, the implementation of the world's first underground hydropower driven pumping system was accomplished, securing the water supply for some 80.000 people [Oberle et al 2006]. The technology applied was designed in consideration of the local boundary conditions such as technical possibilities and capabilities of the operating personnel. After the successful initial start-up of the plant, followed by the handover to the Indonesian operating authority, it turned out, that continuous operation can only be ensured by an advanced adaption of the plant's operational concept. Furthermore, any optimization measure has to be associated with intensive knowledge transfer considering particularly the socio-cultural boundary conditions as well as the local administrative structures. Since 2011, the continuous operation of this hydropower plant occurs autonomously by the Indonesian project partners.

This present paper concentrates on the experiences and measures of the implementation phase as well as the handover process, which might be of use for other projects in emergent countries. Furthermore, technological aspects regarding the continuous operation and optimization of the hydropower driven conveying system will be discussed.

Keywords: Water extraction system, water scarcity, hydropower plant, pumps as turbines

Executive Summary

Lebih dari 25% penduduk dunia hidup di daerah Karst dan bergantung pada Karst aquifer. Tingginya angka inflitrasi dan tidak adanya kemampuan daerah Karst untuk menyimpan air permukaan mengakibatkan daerah Karst mengalami masalah kekeringan walaupun jauh dibawah permukaan tanah tersedia sumber air berupa sungai-sungai bawah tanah. Permasalahan klasik yang muncul adalah sulitnya akses dan teknologi pemompaan konvensional memerlukan biaya operasional yang sangat besar. Atas dasar ini maka diperlukan suatu innovasi dari konsep dan teknologi pemompaan untuk daerah Karst.

Di Indonesia banyak ditemui daerah Karst dengan problematika seperti disebutkan di atas. Salah satunya adalah daerah Karst di Kabupaten Gunung Kidul, Daerah Istimewa Yogyakarta. Dalam kerangka proyek kerjasama Indonesia – Jerman, "IWRM-Indonesia", salah satunya, telah dikembangkan teknologi sistem pemompaan dengan membangun hydropower bawah tanah yang terletak di Sungai Bawah Tanah Bribin. Saat ini sistem Bribin sudah dioperasikan dan sanggup memenuhi kebutuhan air untuk 80.000 penduduk.

Sebagai sebuah hydropower bawah tanah pertama di dunia, banyak sekali pelajaran yang dapat diambil untuk perbaikan dan duplikasi di masa depan, sepert konsep dasar, innovasi teknologi, kendala dalam konstruksi sampai pemilihan sistem operasi yang sesuai dengan kondisi sosial dan kultur di Indonesia. Sebagai *„Hard"*-infrastruktur, teknologi di Bribin sudah terbukti keberhasilannya dalam meningkatkan suplai air ke masyarakat. Yang diperlukan saat ini adalah pengembangan *„Soft"*-infrastruktur seperti institusi pengelola, *human capacities*, dll yang mampu melaksanakan *operational and maintenance* secara berkelanjutan dan mengintegrasikan sistem ini kedalam rencana jangka panjang untuk mengatasi kekeringan khususnya untuk daerah Karst.

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1. Introduction

More than 25 % of the world's population lives in karst areas resp. depends on karst aquifers as their source of water. Due to the karstified underground with high infiltration rates and lacking storage possibilities on the surface, karst areas are very often characterized by severe water shortages. At the same time there are large underground water resources which could be used for an improvement of the water supply situation. However, difficulties during exploitation of these water resources arise out of their poor accessibility associated with high extraction costs due to the location deep underground as well as out of the vulnerability to contamination due to the low filtration rate of carbonate rock.

The karst region Gunung Sewu suffers from the above mentioned problems. The Indonesian government has made a lot of effort during the past decades to improve the living conditions of the local population by exploiting the underground water resources. However, a sustainable solution has not been implemented yet. For improving the water supply situation in the project area sustainably, a German-Indonesian network of scientific institutions is working on the development of innovative technologies and management strategies. The goal is their exemplary implementation in cooperation with German and Indonesian industrial partners and public authorities, whereby a comprehensive knowledge transfer can be accomplished. Hydrologic, ecologic, socio-economic and -cultural boundary conditions of the project area are considered in particular [Nestmann et al 2010].

2. Underground Pilot Hydropower Plant for Drinking Water Supply

The following description of the plant's origination process is mainly referring to [Oberle et al 2006] and [Oberle et al 2012]: During an initial project phase (2002-2008), a pilot plant for drinking water supply has been realized (see Figure 1). Through an underground barrage, covering the cave's entire cross section, a cave system is partially dammed and a reservoir, elevated by 220 m, is filled by hydropower driven pumps. Regarding the implementation of appropriate technologies, reverse driven pumps, mechanically linked with feed pumps, are used as low-cost alternative to common turbines. Besides the low investment costs, reverse driven pumps are distinguished by high robustness as well as low operational and maintenance costs, especially for the application in emerging countries. Due to the lacking adjustability, the efficient application depends on the targeted selection of the pump type as well as on the compliance of the optimal hydraulic boundary conditions.

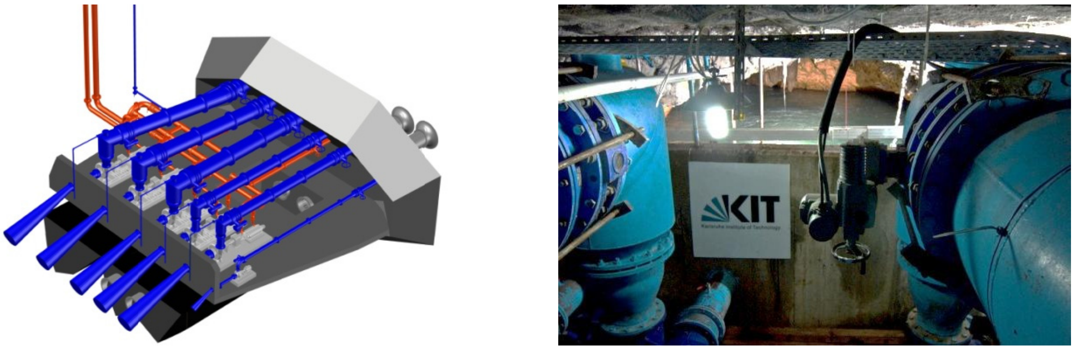

Figure 1: 3D-CAD model of the underground plant Bribin (left), view from the plant's machinery platform towards downstream (right)

Following, a summary of the most important milestones during implementation phase of the underground hydropower plant.

3. Administrative and technical Boundary Conditions

Contacts to different administrative and technical levels were specifically established during the previously accomplished feasibility study. Besides the responsible public authorities (central government, provincial, village and district level) and various scientific institutions, non-governmental organizations (NGO) as well as the local population were informed and involved in the decision making processes (e.g. site selection, plant size, labor division) through regular coordination meetings and workshops.

The Department of Public Work (PU) was responsible for the constructive realization, while the subsequent operation should be accomplished by the local water supplier (PDAM). Tasks like the development of a detailed conceptual design (status “pre-design”), provision of the machinery as well as a continuous accompaniment of the constructive implementation on-site were assigned to the German side.

Here, not only natural boundary conditions (i.a. narrowness below ground, high temperatures and humidity all-year, extreme discharge gradients), the uncertain hydrological and hydrogeological data base as well as the limitation regarding the local technical equipment and know-how were extremely challenging.

Difficulties also occurred because of frequent staff turnovers and competence changes within the Indonesian public authorities. Furthermore, various internal revisions of the budget planning lead to a massive temporal delay, which was contradicting to the narrow timeframe for the constructive measures during the six-months dry seasons. In addition, significant discrepancies occurred regarding demands for quality assurance and work safety on-site.

4. Construction Phase of the Hydropower Plant

Besides the construction of the vertical shaft, using a vertical drilling machine of Herrenknecht AG, for insertion of building material as well as for the subsequent maintenance works, i.a. the installation of the flood relief lines, leading the inflowing water during construction phase, was accomplished until end of 2005. Subsequently, comprehensive mining activities for widening the cavern [Mutschler et al 2009] as well as further preparing measures for the construction of the machinery platform, which was realized in November 2005, were carried out. Due to the rainy season starting in December 2005, the construction work was discontinued for safety reasons. A detailed description of the measures already accomplished before the interruption can be seen in [Oberle et al 2006].

A severe earthquake shortly after resumption of the construction works in May 2006 caused tremendous delays due to a downstream rockfall related with backwater effects. To overcome these obstacles great efforts were necessary, i.e. by assignment of German professional divers carrying out blasting activities. For detailed descriptions of this phase please refer to [Oberle et al 2006] and [Oberle et al 2012].

After remedying this situation successfully, the construction works had been continued by construction of the barrage [Mueller et al 2008] which closes the entire cave cross-section. Subsequently, the first conveying module as well as two controlling valves had been installed whereby the plant was finalized for the first test storage [Oberle et al 2012]. In August 2008, the river Bribin was dammed for the first time. Within less than 2 days, a storage level of 16 m was reached, so all expectations were exceeded by far. No evidence for water losses within the storage space was found during capacity balancing.

5. Operating experiences

Bribin's pumping system consists of five parallel conveying modules, each as unit of "pump as turbine" (PAT), gearbox and feed pump. This concept was developed in order to guarantee the operability also during strongly fluctuating discharge. During preliminary stages the partial efficiencies of all components were evaluated on test rigs in cooperation with KSB (see Table 1). Through specific modification of the standard design of the PAT the efficiency was increased to η_{PAT} = 83 %, whereby the module's overall efficiency increased to η_{total} = 55 %.

Table 1: Components of the conveying modules

Component	Manufacturer	Model	Partial efficiency
PAT	KSB AG	ETANORM-R 300-340	83 %
Spur gear	Walther Flender GmbH	RXP1/808	95 %
Feed pump	KSB AG	Multitec D 65/9 6.1	70 %

For verification of the plant's theoretical dimensioning as well as for validation of the test rig results, the plant's output, depending on the number of driven modules and the variation of the storage level, was evaluated through comprehensive in situ measurement campaigns as shown in Figure 2 [Oberle et al 2012].

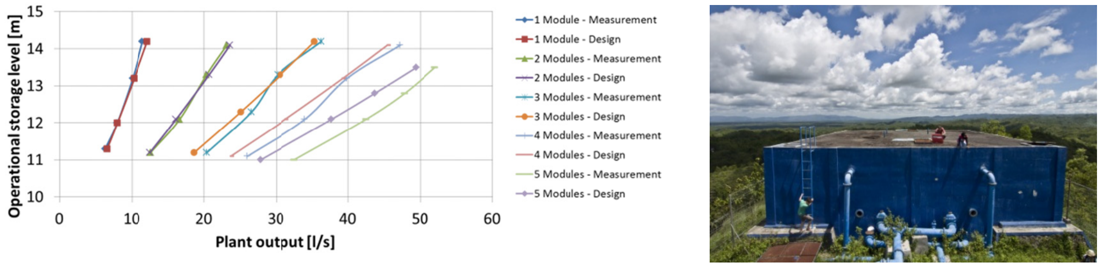

Figure 2: Output performance depending on number of driven modules and storage level (left), reservoir “Kaligoro” elevated compared to the plant by approx. 220 m (right)

Due to lower actual losses the above mentioned measurements predominantly show a higher output compared to the design values, especially with increasing discharge. Thus, the calculated output rates as well as the test rig results were entirely validated.

Since mid of 2011, the plant is in full 24/7 operation under the aegis of PU. Since then, more than 1 billion liters of water have been delivered to “Kaligoro reservoir” resp. to the supply network in order to enhance the living situation of the people in Gunung Sewu. This big success was enabled by adapting the operating system to the given boundary conditions, which was accomplished as follows.

Due the plant’s cascaded structure, consisting of five parallel conveying modules, the storage level should be controlled to a given value. In case of exceeding the plant’s discharge capacity, the relief should be accomplished by opening the plunger valve, which is one of the above mentioned controlling valves. By targeted vernier adjustment an additional discharge up to max. 2.5 m³/s can be realized. The butterfly valve as second controlling valve, with a discharge capacity up to 7 m³/s, does not allow partial opening and is only in use during extreme discharge events. First a fully automatic SPS-based system was implemented for system control to the normal storage level. During events of slight deviations from regular operation as well as during events of simple malfunctions, considerable uncertainties of the operational personnel, partially related to downtimes for weeks, were observed due to the “black box” character of the system [Oberle et al 2012] [Walcher et al 2009].

Figure 3: Check of an alert situation by the operating personnel (left), training for the staff on the machinery platform (right)

Therefore, an adapted controlling system for manual operation was developed by the IWG (see Figure 3), which contains the continuous monitoring of the relevant operating parameters (i.e. upstream and downstream water level) as well as various alert settings. All alerts are linked to a siren located at the shaft's upper end right next to the system's central control cabinet. On the cabinet's front panel the current values of the operating parameters as well as the particular alert setting are shown by displays and indicator lamps. Thus, the operating personnel assess the situation immediately and decide about the required steps for remedying the alert situation [Oberle et al 2012].

Depending on the discharge variability the readjustment of the plant settings require during dry season 1-2, during rainy season up to 4-5 daily inspection rounds to the platform for readjustment of the modules and/or the controlling valves. Against the background of the high discharge variability within the cave system as well as of the sparse data basis at the beginning of the project, the dimensioning of the machinery regarding design discharge of the PAT and discharge capacity of the flood relief system were afflicted with substantial uncertainties. Nevertheless, the initial design was based on the data available, whereas later adaptions resp. optimizations were scheduled as far as required. During rainy season 2011/2012 an extreme flood event was observed, which caused the exceedance of the discharge capacity of the flood relief system. Due to peak discharge values of more than 10 m^3/s as well as due to ongoing high discharge values of more than 7 m^3/s for days, impermissible high storage levels occurred. This situation, especially critical in terms of leakage at the barrage and the risk of a hydraulic breakthrough, did not cause any damage. Because a statistical classification of this event was impossible, the discharge capacity was decided to be extended through implementation of an additional bypass at one of the PAT pressure pipes. Thus, storage levels of more than 20 m should be avoided in the future whereby the plant safety will be increased [Oberle et al 2012]. The implementation of the bypass was accomplished in September 2012 by cooperation of German and Indonesian scientific and industrial partners.

However, the crucial advantage of manual operation is the comprehensive collection of experience by the operating personnel, whereby exceptional situations like the flood events mentioned above can be handled more easily and in an appropriate way. Due to low local labor costs the plant can easily be monitored 24/7, whereby the higher manual controlling expenditure compared to full automatic operation only results in low O&M related financial disadvantages. The changeover of the operational concept was accompanied by comprehensive trainings as well as by the development of bilingual operation and maintenance instructions and various posters, each adapted to the educational background of the operating personnel. But all of these measures cannot replace the learning effect gained through daily practical experiences [Oberle et al 2012].

Since commissioning of the plant, the operating personnel show a high identification and commitment with the pilot plant and proved their ability to handle critical operating conditions during the past rainy seasons. Besides the improvement of the supply situation for the people in the project region, the plant also shows economic advantages by generating revenues. Since Bribin is operated utilizing hydropower, O&M-costs only consist of labor as well as of maintenance related costs (e.g. generator operation, consumable materials, spare parts, labor costs for technicians, etc.). Based on the experiences of the past two years, these costs were calculated to approx. 36.000 € p.a. by IWG/KIT. Comparing the Bribin system with a conventionally driven system (use of electrical power supply instead of hydropower), which was furthermore accessible directly from the surface, the above mentioned O&M-costs would change as follows:

Assuming a lower overhead for this fictional plant, the remaining O&M-costs will still amount to ca. 20.000 € p.a. In order to exploit the real 2012 output potential of Bribin, the required electrical power supply for high-pressure pumps will lead to costs of approx. 92.000 €. Thus additional charges of ca. 76.000 € p.a. will occur compared to the Bribin system. Furthermore, these calculations postulate the all-season availability of electrical energy as well as a constant electricity rate. Both aspects show significant uncertainties which might lead to even higher savings in the future by operating the Bribin system.

As expected, the total output potential of this plant has not been entirely exploited yet. According to schedule, the operational storage level, as parameter for the plant's output performance, is being increased step by step. This process is already in implementation since commissioning of the plant and will presumably be finished in 2014. This procedure was chosen in order to enable an accompanying analysis of all relevant technical aspects (Bribin's function as pilot plant) associated with the accomplishment of eventual optimization measures. Furthermore, hereby the operating personnel can gain important experiences which lead to a safe and sustainable operation of this unique plant as described above.

6. Conclusion

Despite enormous underground water resources, the people of the karst area Gunung Sewu, Java, Indonesia, are partially faced with extreme water scarcity. During the past years, German scientists analyzed the feasibility of an underground water extraction plant for improving the local supply situation. Furthermore, the subsequent implementation of the hydropower plant was realized in cooperation with German and Indonesian partners.

Despite numerous difficulties and setbacks during the implementation phase, the plant was successfully finished and handed over to the Indonesian partners. The usage of reverse driven pumps as turbine substitute proved to be a robust and easy to handle technology for utilization of the underground hydropower potential. The originally implemented fully automatic control system did not meet the requirements of a sustainable plant operation by the local operating personnel. Subsequently the operating concept was changed to manual operation considering the local socio-cultural and socio-economic boundary conditions. The related increase of operating costs due to personnel overhead was negligible due to low labor costs in Indonesia.

Since 2011 the plant has been operated continuously and autonomously by the Indonesian operating personnel. According to a survey of the Geographic Institute of the Justus-Liebig University of Giessen, Germany, the people of Gunung Sewu have been continuously supplied with water during entire dry seasons for the first time.

Due to lacking data availability at the beginning of the project, the dimensioning of the plant was associated with uncertainties. Against the background of an extreme discharge event at the beginning of 2012, an extension of the flood relief system's discharge capacity through additional bypasses at the conveying modules was strongly required and subsequently implemented.

Since commissioning of the plant it was further be proven, that it can be operated economically due to the robust and low-maintenance design of the supply system. The operating characteristics will further on be monitored by the German side. An adaption of this concept to other karst regions (e.g. Indonesia, Vietnam) is in progress. We would like to thank the German Federal Ministry for Education and Research (BMBF) for supporting these R&D-activities.

7. References

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