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# Hydrometeorological monitoring for hydropower reservoirs in remote areas

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**Abstract.** Operational hydrometric network is an essential element in hydropower reservoir operation. The data collected, to be used for reservoir management and decision making require high reliability with automatic data monitoring, processing and retrieval. However, the unique characteristic of every catchment and operational requirements raises the need to balance hydrometeorological monitoring objectives and site desirability. This paper describes the overall component of the Temengor Inflow Forecasting System developed as part of a decision support module for optimised hydropower dam operation for the Temengor Hydropower Dam system in Malaysia. The equipment used and challenges faced in deployment in a densely forested catchment in the Sungei Perak basin are discussed. The siting of the hydrometeorological network was made based on World Meterological Organisation guidelines and state of the art communication technology was utilized in overcoming accessibility to our monitoring sites. The real time data on power generation, river and reservoir level, rainfall that were collected are presented in this paper.

## 1. Introduction

The efficient and effective management of hydropower reservoirs is vital for hydroelectric power plant operation. The monitoring of rainfall, inflows and lake level provides benefits by optimizing hydropower generation with the goal of maximizing energy revenue, while taking into account dam safety risks. One of the critical factors that contribute to successful hydropower reservoir management is through reliable monitoring infrastructure, equipment and technology. Therefore, the continuous monitoring of inflows and lake level is an essential tool for hydropower dam operators by providing real-time data for decision making in power generation and planning [1]. Real time recording instruments provide the ideal means of recording the responses of rivers, lakes and reservoirs to short-term changes in weather [2]. Inflow forecasting simulates the run-off process in a catchment by taking all necessary elements collected from hydrometeorological data into account, providing insight into the future resource availability for hydropower generation and advance warning of water-related disasters such as flood. The collected information is beneficial in deriving optimal operation rule curves for long term planning and efficient water allocation for short-term hydropower plant scheduling. Nowadays, inflow monitoring techniques have become more advanced over recent years in response to increased demands for more accurate, timely and reliable information. The information, which is highly valuable and of national interest requires timely, detailed reservoir level warnings with maximum accuracy. Thus, the hydrometeorological networks in the catchment require high reliability with automatic data monitoring, processing and retrieval [3]. Monitoring of inflows through hydrological instrumentation and appropriate hydrologic modeling provide sufficient lead time to dam managers to efficiently operate hydropower plants and mitigate against floods, while maintaining appropriate lake level during monsoon and drought season. Additionally, financial advantages could be acquired through well-planned hydropower plant operations, bringing greater efficiency in power production, as well as the implementation of action plans through early warning for downstream flood risk areas effectively and ultimately reducing the occurrence of dam failure. However, based on catchment characteristic and operational requirements, consideration on some challenges and constraints are needed for efficient hydropower reservoir operation. Among the criteria considered includes adequate hydrometeorological network, forecast time required, specific operating issues, displays or warning requirements for the user interface and also communications and information technology system available.

Hydrometric network design for catchment monitoring aims to provide operators with timely, easily accessible water quantity data relevant to hydropower reservoir operation [4]. Although the installation of monitoring equipment as part of hydropower reservoir operation has been successfully implemented in many countries, however, challenges are usually site specific. For example, a review of operational and research applications demonstrates that satellite observations can improve accuracy and spatial detail in hydrological model estimation [5] in remote areas. It has been shown that rainfall, discharge and water level data collected from the hydrological network in Nam Ngum River basin can be effectively used as a management tool for hydropower reservoirs. The data were also checked for accuracy and reliability for hydropower expansion planning in the same catchment. However, limited data availability and accuracy may cause difficulty in the planning of subsequent hydropower project [6]. Taiwan Power Company use observed reservoir inflows and hydropower generation data to study an optimisation approach to find the representative operation rules which can replace operators' experience of reservoir operation and investigate climate change impacts on reservoir inflows and subsequent hydroelectric power generation [7]. Long-term, continuous, time-series collection of environmental data is fundamental to understand the environmental dynamics of aquatic systems due to climate change. Integrated system for environmental monitoring (SIMA) has successfully provided a long-term database used for limnological study for hydropower reservoir in Brazil [8]. Advances in information technology such as fibre optic technology for river monitoring provide additional sources of data. The monitoring system developed for Yangtze River Valley in China is part of a decision support system component for flood planning and management [9]. On the other hand, the Internet of Things (IoT) technology that combines wireless sensor network technology, communication technology, sensor technology and network technology were explored for hydrology monitoring system into a simple and low-cost sensor. The system consists of wireless sensor network, GPRS network and monitoring centre [10].

This paper discusses on the hydrometeorological monitoring equipment installation and requirement of optimal network challenges encountered at the selected site with high-density forest catchment in Temengor, Malaysia. The monitoring data obtained from real-time hydrometeorological data and application for hydropower reservoir operation and forecasting is discussed. The overall objective of this study were to develop a system capable of monitoring rainfall, inflows and lake level at Temengor for hydropower reservoir operated by Tenaga Nasional Berhad (TNB).

## 2. Temengor catchment

Sungai Perak (Sg Perak) is the second largest river system in Peninsular Malaysia. It has an approximate length of 427 km and a catchment area of 15,180 $km^2$, which is about 71% of Perak State.

Along the upper Sg Perak basin, a series of lakes have been created with the construction of 4 hydropower dams, namely the Temengor, Bersia, Kenering and Chenderoh Dams, collectively known as Sungai Perak Hydroelectric Scheme, shown in Figure 1. These dams are used for hydroelectric power generation, operated by Stesen-stesen Janaelektrik Sungai Perak (SSJ Sg Perak). This study focuses on the hydrometeorological network in Temengor catchment designed as part on Temengor Inflow Forecasting System (TIFS). Sg Perak Power Stations cascading hydro power plant was built in 1970 with a total generating capacity of 1,248 Megawatt from 22 unit generators, built either for peak or base load. The hydroelectric power for Temengor is generated by 4 generators with total design capacity of 348 MW. The electricity generated if fed to the Grid System through a switchyard and tower line and distributed to customers in Peninsular Malaysia [11]. The Temengor catchment is about 3,500 km$^2$ with catchment elevation ranging from 206 m to 2,156 m. The catchment is mostly forested with about 150 km$^2$ occupied by Lake Temengor and located within then Belum Forest Reserve. The Royal Belum State Park (RBSP) was gazetted as a protected area under the Perak State Parks Corporation Enactment in 2001.

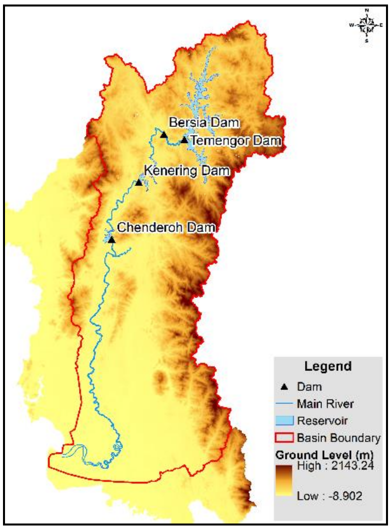


**Figure 1.** General Location of Cascading Hydropower Scheme in Sg Perak

## 3. Temengor monitoring system

The requirements of a hydrometeorological monitoring system are site specific depending on local objectives. The Temengor system was developed to support reservoir and power generation requirements taking into consideration local catchment and climate conditions. The rain gauge network required for the site should reflect the nature of the climate drivers involved in the flood-producing rainfalls and ease of operation and maintenance. The requirements of operators need to be considered in terms of warning times required, trigger levels, and the type of information needed. Operators will consider the output from the forecasting system as an input for decisions in operation of hydropower generation and respond to floods.

The high-level system requirements include inflows and lake level, which is mainly needed for advanced warning of floods into Temengor Reservoir and used in hydropower plant operation and optimisation. The operation of hydropower generation at Sg Perak Power Stations is based on the requirement by National Load Dispatch Centre (NLDC), however, additional lead time of lake level information offers advantages in operation planning while taking into consideration dam safety aspects. Therefore, a rainfall forecast would be required to give sufficient lead-time that can be available from the local meteorological service. Another important requirement for monitoring equipment is installing and upgrading the new water level and rainfall stations in Temengor catchment. Site visits were undertaken by the project team to understand the requirements for the hydrometeorology network, the data available and the proposed locations and logistic arrangement of the selected sites.

The design of the hydrometeorological network is based on a combination of rainfall, river level and reservoir level monitoring points reporting in real time, or near real time, to a central operation and control system. An adequate number of monitoring equipment is essential to report the development of an impending flood, providing sufficient time for forecasting models to produce outputs before warning dissemination and adopting operational decisions of hydropower generation [12]. Having an inadequate number and improper measurement locations can result in the poor establishment of a database for forecast model development, which may result in the less accurate predictions. Nevertheless, the challenge is to find the right balance between hydrometeorological monitoring objectives and site access. The most reliable and affordable solutions depend on proper site selection [13], and a mismatch between local conditions and appropriate technology results in poor quality data and high maintenance requirements for both field and administrative operations. It is also vital to check the data transmission method. The best system must be at minimum operating cost with high quality data transmission. The specific tasks undertaken in this stage are summarised below:

### *3.1. Hydrometric network design and installation*
Hydrometric network for Temengor catchment composed of a group of rainfall and water level stations that are designed and operated to collect the necessary data. Observation data collected in the network will be used as in the development of predictive models for reservoir water levels.

### *3.2. Configuring modelling server configuration to the real-time and forecast data*
The Temengor Inflow Forecast System server arrangement consists of two servers; one for telemetry (AQWEB server), and the other for forecasting. Both are installed in the Bersia Group Control Centre (BGCC). The forecasting server takes data from data storage in the telemetry server, and stores it in the hydrometric database which is then accessed by the forecasting model. This task involved configuration of the TNB forecast server with the telemetric data network, telemetric server, forecast data and TNB Supervisory Control and Data Acquisition **(**SCADA) inputs.

### *3.3. Forecast model development*
This includes development of the forecast model, which consists of inflow and reservoir storage models, and generation of reservoir water level forecast ensembles.

### *3.4. System interface development*
The task for this component involved development of web based display of the real-time data and results from the water level forecast model.
The final output from this activity is system architecture of inflow forecast system as shown in Figure 2.

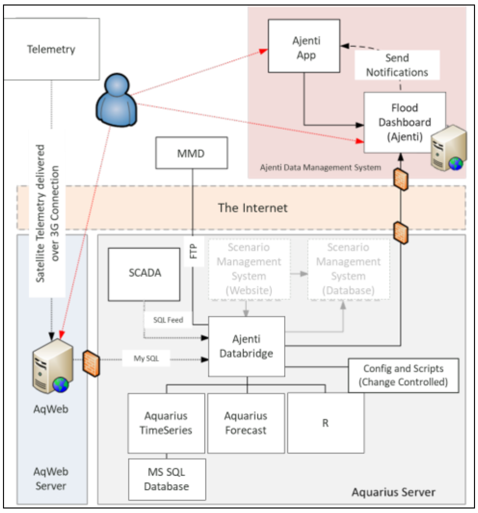


**Figure 2.** System Architecture of Temengor Inflow Forecasting System

The Aquarius server is located in BGCC located at Bersia Dam. This server is responsible for the collation of all the relevant data and the execution of the inflow forecasting models. This server hosts a number of key components:

*3.5. Ajenti DataBridge:*
this is the software that manages the data collection and forecasting services, and is pivotal in ensuring a robust and reliable inflow forecasting system. The software is designed to synchronise data between different systems using a plugin architecture that allows data to be read from databases and seamlessly synchronised with systems like Aquarius TimeSeries. The software also includes a highly configurable scheduler that can be setup to manage the execution of mission critical tasks. It allows for customised processes to be executed to manage simple to extremely complex hydropower reservoir operation scenarios. Forecast rainfall data from Malaysia Meteorological Department (MMD) also will be transmitted to Ajenti DataBridge.

*3.6. Aquarius Forecast:*
this software runs the core inflow forecast models. It is built on the latest .NET platform and features a versatile Application Programming Interface (API) that allows for easy and efficient interaction by third party systems like the Ajenti DataBridge. This makes Aquarius Forecast easier to manage automatically than other modelling system.

*3.7. Aquarius TimeSeries:*
this is a hydrographic software used around the world for managing water data. All data collected by the Ajenti DataBridge is archive into Aquarius TimeSeries. The software features data editing and quality control tools and also features a ratings editor to manage the conversion of water levels to flows. Aquarius TimeSeries retains information in the database.

*3.8. R:*
this is a statistical software package that allows for easy manipulation of data. This is used by the system to conduct pre-processing of data before the models are executed, and post-processing of the modelling results.

*3.9. SCADA:*
the SCADA system provides real-time data to the inflow forecasting system via a feed through a SQL database. This allows the models to see the latest dam level as well as various outflow values. This part of the system can be changed to use an Open Platform Communication (OPC) server in the future if required.

*3.10 . AqWeb:*
this is the Telemetry System responsible for collecting the data from all the remote telemetry sites. The data that is captured is stored in a MySQL database on the AqWeb server. The Ajenti DataBridge uses a MySQL plugin to poll for new data. Users can access the web interface of this system to see the latest telemetry data. This access is via a 3G connection that is also used for the data feed from the satellite based telemetry stations.
In addition to the server located at BGCC, the data is synchronised into Ajenti Data Management System (ADMS). The ADMS provides both an offsite backup of all the associated data and provides a secure view of all data that is accessible via the internet or through a smart phone application.

## 4. Results and discussion

*4.1 Operational Hydrometeorological Network in Temengor Catchment*
The complete system was setup under a commercial contract. Hydrometeorological equipment installed in the study area included rain gauge, hydrostatic level measurement system for river level

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monitoring and radar water level sensor for reservoir level monitoring. The monitoring equipment and its specifications are shown in Table 1**.**

**Table 1.** Hydrometeorological Monitoring Equipment for Temengor Catchment [14–18]

| Equipment | Description | Specifications |
|---|---|---|
| <br>Hydrological Services Tipping Bucket Raingauge (TB3) | Rainfall measurement equipment for remote and unattended locations | • World standard 200 mm catch.<br>• Resolution: one tip at 0.2 mm<br>• Long term stable calibration<br>• Accuracy : +/- 2%<br>• Dual output signal data collection and transmission. |
| <br>Water Level Sensor (Bubble) | A stand-alone hydrostatic level measurement system that requires only a 12V DC power supply and bubble tube (capillary) | • Measurement range : 10 m<br>• Resolution: 16 bit (digital)<br>• Accuracy : +/- 0.05%<br>• Fully self-contained precision piston air compressor |
| <br>Remote Terminal Unit (RTU) | Highly reliable and cost-effective remote terminal unit and data logger for data collection, communication, logging, alarming, control and analysis applications | • Built-in pressure, level and water quality transmitters, I/Os, cellular, WiFi, Ethernet, RS485 and GPS module.<br>• Communication selections: Cellular, Wi-Fi, Ethernet |
| <br><br>Satellite Data Transmitter (INMARSAT) | • High speed data transmission services.<br>• Communication is achieved by interfacing RTU to a satellite transmitter, which in turn transmits the data from the field site to a receiving station. | • Specially design for remote unmanned SCADA application<br>• Qualified for special INMARSAT m2m pricing plans.<br>• Build in GPS receiver.<br>• Remote configuring and debugging. |
| <br>Waterlog Radar Series – SDI-12 Water Level Sensor | • Accurately measure lake levels through non-contact transmission. | • Measuring distance: 3 m to 40 m<br>• Frequency range 26 Ghz<br>• Continuous operation, no warmup or “lock on” |

The following criteria were adopted in designing and installing monitoring equipment in the study area.

*4.1.1.* All sites with telemetry should have a daily automated power reset to override communications lock-ups. This can be done with a relay or within the logger program

*4.1.2.* Due to the difficult access of these sites, remote interrogation for troubleshooting and making changes to the program as well as diagnostic analysis should *be enabled via telemetry*

*4.1.3.* It is recommended that if a dataset fails to transmit from site the system should automatically retry and send all files that have not been sent previously, not just the last file

*4.1.4.* Data transmission fail rate, satellite signal strength, site voltage, and electric fence voltage should be logged and transmitted to the database to provide an understanding of what the fault may be before a site visit is undertaken

*4.1.5.* For water level sites an automatic gas line purge is recommended on a daily basis to clear the orifice of sediment and debris

*4.1.6.* All issues after site commissioning should be addressed as soon as possible into the warranty period rather than leaving until the end and possibly *handing over legacy problems*

*4.1.7.* All instrumentation should be accessed safely and easily without the need for portable ladders and other height safety equipment

There are currently 5 telemetered rainfall stations and 4 non-telemetered rainfall stations in Temengor. The TNB Hydrology division conducts manual download from data logged at non-telemetered sites once every 3 months. The hydrometeorological stations in Temengor are shown in Figure 3. Currently, the telemetered hydrographic network is mainly confined to the north part of the catchment and does not have coverage to the south.

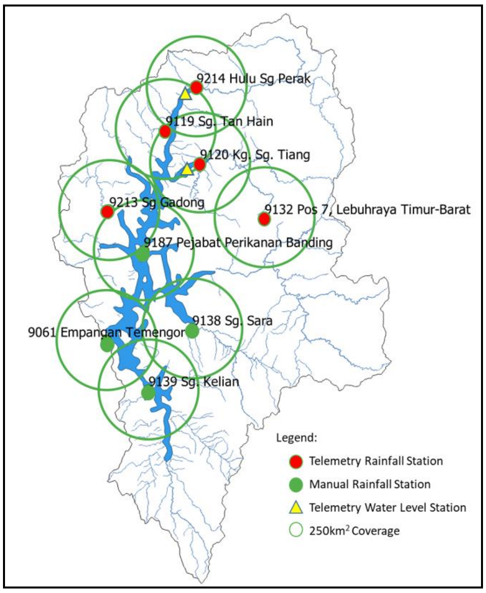


**Figure 3.** Temengor catchment telemetered hydrographic network

Difficulties arise when the monitoring locations are in high density forested areas. Site accessibility is crucial to ensure continuous maintenance activity. In this project, the site selection also needs to take into account surrounding flora and fauna, and approval from local authority is required to install the hydrographic stations as the site is within a reserved area.

The existing rainfall network was first analysed since sufficient rainfall data of sufficient coverage is needed to ensure success of the monitoring and forecast system. The analysis was made based on recommended minimum density of rain gauge stations for various physiographic types [19]. In this project, three existing rainfall stations were upgraded to a telemetry system (Station 9119, 9120 and 9132) and two new telemetry rainfall stations (Station 9213 and 9214) were installed to provide additional rainfall network coverage. The upgraded and new telemetered rainfall stations (Station 9119 and 9213) mostly cover rainfall occurring over the northern part of the catchment, storms occurring towards the east and south of these stations are as yet unrecorded. The locations of proposed upgrading and new installations of rain gauges were decided by an analysis of the existing data. The historical rainfall records show that the gauge 9132 located to the east part of the catchment generally records the highest rainfall, as illustrated in Figure 4. It is therefore important to provide more coverage to the east of the catchment. Nevertheless, good coverage of rainfall stations is also required to the south of the catchment, as this will ensure any storms occurring in the south are not missed and, importantly, help provide a better estimation of the spatial distribution of rainfall occurring in the catchment.

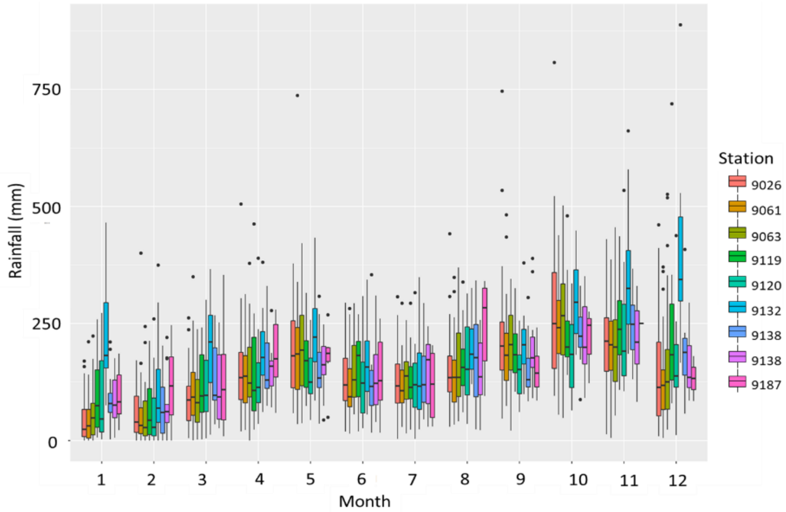


**Figure 4.** Distribution of monthly rainfall totals over the 12 months

The existing lake level sensor provides sub-hourly monitoring of the Temengor reservoir levels and the turbine discharge. However, the lake level data recorded by the sensor were noisy and needed to be upgraded. Thus, through this project, a radar water level sensor unit was installed on a small mounting bracket on the intake structure directly above the water surface as shown in Figure 5**.**


**Figure 5.** Lake Level Monitoring Location

Data transmission methods include terrestrial, radio and satellite-based solutions. The selection of the most suitable transmission platform depends on site suitability, system coverage availability, initial cost and operation & maintenance cost. Satellite data transmission technology has been successfully used for remote sites. The technology is able to address the difficulties in the management of hydrometric network in the Amazon [20] where telephone lines are not always present and the quality of radio transmission may be compromised. Additional challenge to this work scope is communication facilities for the transmission of data. There are no available radio and GSM network at these locations. Therefore, a communication system using satellite technology, Inmarsat, was used for data transmission from monitoring stations.

Electrical fencing was installed to protect the instrumentation at the site from being disturbed by animals and local tribesmen. All rainfall and water level stations were installed with electrical fencing for each site. An electrical fence system comprises an energizer and an insulated fence. The energizer transmits short pulses of electrical energy onto the fence line, in the form of short electrical pulses for a very short duration. The electric fence is not only a physical barrier, but is also a strong psychological barrier. Figure 6 shows a picture of a typical station.

**Figure 6.** Completed Electrical Fencing for existing Sg. Tan Hain Rainfall Station

### *4.2* Presentation of Monitoring Data

As this project aims for the operation of Temengor hydropower reservoir, the hydrometeorological monitoring data and forecast simulations are displayed through a website. The website is configured with private access by TNB engineers. The Temengor Inflow Forecast System Display (FSD), contains information on real-time measured variables and simulated outputs. Data from the hydrometeorological network are processed in a dedicated Ajenti Data Bridge server located at BGCC. The displayed variables include real-time rainfall, river level measurements, power generation and turbine release from SCADA system. Figure 7 shows a typical example of hourly rainfall data from 5 telemetry stations. The graphs shows hourly rainfall for a period of one-month, and the highest rainfall observed at Station 9120 and Station 9213, located at the upper catchment. The real-time raw rainfall inputs are read as cumulative rainfall totals at 15 minutes interval. The data will then be aggregated data to hourly time steps by automated configuration script and written in the form of 5 text files.

Figure 8 shows the power generation data, river level and reservoir level. This data is used by TNB in managing and planning hydropower plant operation. As shown in the graph, the river level corresponds with rainfall depth. With increasing inflows due to high rainfall, the graphs show increase in power generation, as flows are released through the turbines, as an effort to maintain safe reservoir level. The inflows, reservoir level and hydropower generation trend can be used as reference to optimize hydropower generation while maintaining the reservoir safety. Currently, Grid System Operator (GSO) and Single Buyer (SB) provides electricity demand information to the hydropower operators. Therefore, the availability the long term data is valuable to operation team for planning of operation rules. Furthermore, the advance reservoir level information of 5 days ahead through inflow forecast output will assist hydropower station operators and other related department in TNB to prepare short-term plan of optimized hydropower generation. These information are captured by SCADA system at BGCC that monitors, controls and set alarms at the generating facilities operating system from Sg Perak Power Stations [11]. Thus, it will complement the overall SCADA system objectives to ensure safe plant operation, lower generation cost, improve plants efficiency, and increase plant profitability. Data visualisation enables real-time monitoring of current condition in the catchment and any alert such as non-functioning stations, and the rainfall has exceeded the threshold value. For reservoir operations and decision making, model simulations results are also presented in graphical output displayed in the TIFS dashboard.

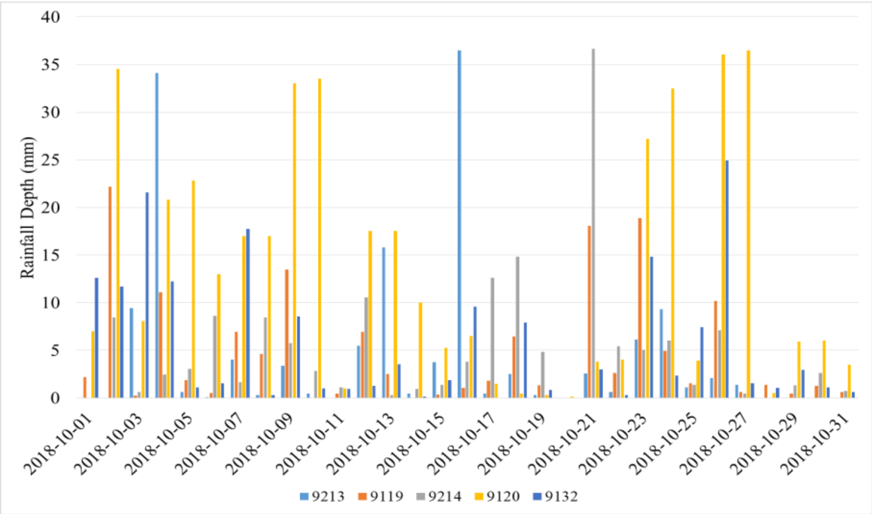


**Figure 7.** Rainfall Data from Five Rainfall Stations

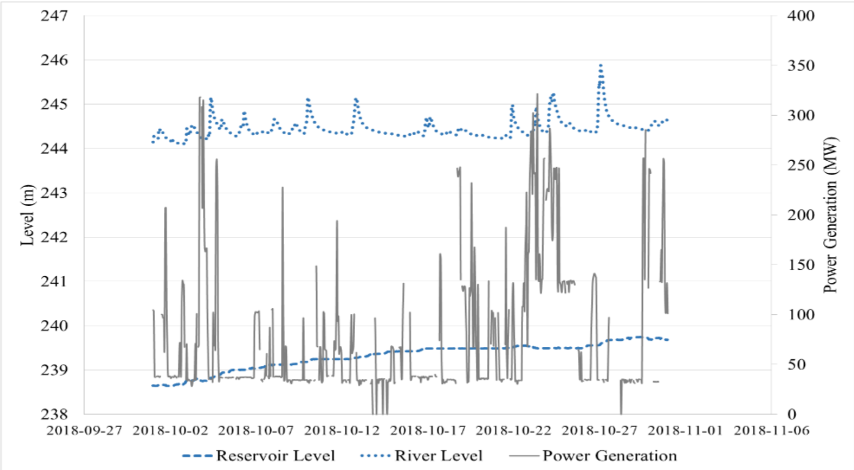


**Figure 8.** Typical plot of Power Output, Reservoir Level and River Level obtained from SCADA and telemetry stations

## 5. Conclusions

Installation of hydrometeorological monitoring equipment is an important element in implementing the hydropower reservoir monitoring framework. In any inflow forecasting system, reliable monitoring equipment is essential to provide advance information to dam owner to better planning and management of reservoir operations. Utilisation of advanced technology is beneficial in overcoming site constraint while providing the best information at site for modelling and monitoring purpose. Most importantly, it is critical to conduct periodical maintenance including equipment calibration of any equipment to ensure data reliability and longer equipment lifetime. This study demonstrates that a functional specification of equipment and system are essential for any operation, maintenance and management purposes. Additionally, continuous and strategic research is needed to verify our understanding and assumption of the underlying hydrological process occurring in the catchment. Wherever possible, research efforts are needed to support and communicate the findings for improved integrated hydropower reservoir operation and providing high reliability and availability of electricity supply throughout the country.

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