Smart Watershed Monitoring for near Real-time Hydrologic Modeling in a Tropical Environment: The Case of Magat River Basin in Luzon, Philippines

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Abstract. An important input in the hydrologic system that we translate into a hydrologic model is precipitation. In the Philippines, its tropical location and orientation being subjected to the Southwest Monsoon winds make it abundant with rainfall. It is one of the countries in the world with the greatest recorded rainfalls. Nevertheless, during the dry season, the country experiences water scarcity, compromising water supply for various uses. In impoundments such as the Magat Dam, water allocation to different stakeholders – irrigation and hydropower – has to be optimized for fair water distribution. Much needed in decision-making is to have an accurate information of what is to be measured. Rainfall in a watershed is a distributed phenomenon, hence, rain gauges in a large catchment has to be in distributed in the area to be able to get a more correct representation of the rainfall distribution.

Introduction

The automated system developed for the remote measurement of hydrological parameters started as the need for the National Water Resources Board (NWRB), a government agency whose mandate is to coordinate and regulate the water resources of the Philippines, becomes very necessary. The consistent dry spell brought about by the El Nino and El Nino-like summers made the allocation of water for different sectors – e.g. domestic water supply, irrigation, and hydropower – made it an import decision-making tool the Automated Real-time Monitoring System (ARMS) for Magat Dam. For Magat Dam, however, only one type of usage is needed, i.e. irrigation. Hence, Magat Dam is managed by the National Irrigation Administration's Magat River Integrated Irrigation System or NIA-MARIIS.

The existing data collected from NIA is limited only to precipitation which is measured in an hourly and daily basis by the satellite feed stations. On the other hand, other parameters such as temperature, evaporation, humidity, wind speed, wind direction, and atmospheric pressure are measured by Weather Philippines in real-time but can only be accessed by subscribing through their web-based application. A more directly accessible collection of these important hydrological parameters is needed by the NWRB. Effective operation and management of dams and reservoirs require reliable real-time estimates of the available water. Absence of effective monitoring could lead to mismanagement.

Hydrologic Modeling Parameters

To measure the amount of water in the available in the reservoir, and hence for distribution, it is necessary to determine the water level in the dam, the incoming flow to the dam, and/or the outflow to the dam. If we know two of the three variables we could have a check of the unknown from the continuity equation in the form of the water balance equation. For the project, we decided to measure the input to the system which is the runoff to from the headwaters to the reservoir and the water elevation at the reservoir itself which shows the change in storage.

Hydrologic processes vary in space and time, and are random in character [1]. The relationship among moisture content in the atmosphere, temperature, and vapor pressure determines the occurrence and amount of evaporation and precipitation and should be understood to understand precipitation.

The input is measured from the remote sub-catchments which includes the most important parameter which is rainfall [2]. Another important parameter is the infiltration which is taken into account in the hydrologic model's loss equations. Nevertheless, an important input to the loss equation is the amount of antecedent moisture content in the soil.

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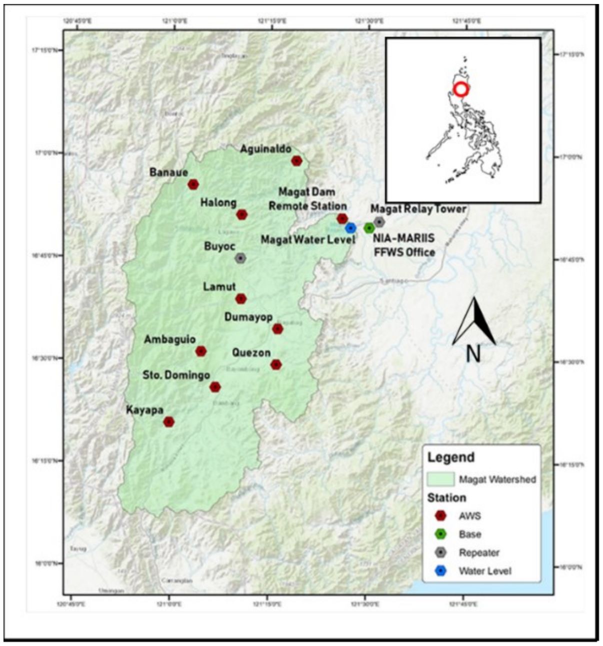

Figure 1. Location of Magat Dam and the distribution of the AWS, AWLS, repeaters, and base station.

Other parameters are also of importance especially in times of the dry season where loss in water is greatly influenced by evaporation. In addition to the rainfall data, other parameters – temperature, humidity, soil moisture, wind speed, and atmospheric pressure – which are a standard in an automated weather station (AWS) and are an important parameter to determine the losses or abstraction in the area, are monitored. Evaporation is determined from available equations using data of wind speed and humidity form the AWS.

The hydrologic model is executed using the US Army Corps of Engineers' Hydrologic Engineering Center's Hydrologic Modelling System or HEC-HMS. Rainfall data inputted in the model is in 10-minute interval. Hence, the ARMS System is also set in the same interval. The 10-minute interval is used to be consistent with the other models produced and rainfall stations data available in the nationwide river basins inventory discussed in [3] & [4].

The ARMS Wireless Sensor Network System

The ARMS for Magat is composed of sets of sensors, relay station, and base station located in the Magat watershed shown in Figure 1. The Magat watershed is a sub-basin of the Cagayan River Basin located in Luzon Island and drains to the Philippine Sea in the north part of the island.

The sensors installed have the capability to measure physical attributes of the hydrologic system. The information gathered by the sensor is converted into signals for the observer. The ARMS system is a wireless sensor network (WSN) composed of several components called nodes. These nodes are smart devices that are used to collect the data needed for applications. The basic function of the sensor network includes the 1. Sensing; 2. Communication; and 3. Computation using hardware, software, and algorithms [5]. The distributed nodes that collect the info are called sensor nodes. These nodes are connected to the base station wirelessly by SMS or WiFi. It could also be communicated using line-of-sight data transmission by long range radio frequency. Figure 2 show the conceptual framework of the ARMS System that is similar to the ones used in a hybrid network topology of [6] and demonstrated in [7].

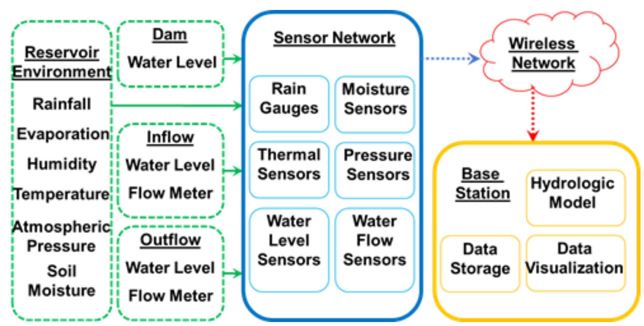

Figure 2. The conceptual framework of the ARMS wireless network.

In Figure 1 and Table 1, the distribution of the SMS/Internet and line-of-sight is shown. For the line-of-sight, a repeater is needed to boost transmission to the next station such as the base station.

Effective runoff in rivers which is also equivalent to the effective or excess rainfall in the watershed is not just a measure of the precipitation. It is also a measure of the different parameters that represent losses or abstraction in the area covered by a certain rain gauge.

Table 1. The mode of transmission set for each AWS

LOCATION	COORDIN-ATES	MODE OF TRANSMIS-SION
1. Aguinaldo	16.98624, 121.3168	SMS/Wifi
2. Banaue	16.926346, 121.05219	SMS/Wifi
3. Halong	16.8541, 121.1774	SMS/Wifi
4. Magat Dam	16.830278, 121.453894	Line-of-Sight
5. Lamut	16.6489, 121.1774	Line-of-Sight
6. Quezon	16.48889, 121.2683	Line-of-Sight
7. Kayapa	16.34694, 120.9956	SMS/Wifi
8. Dumayop	16.5764, 121.2717	Line-of-Sight
9. Ambguio	16.51985, 121.0761	SMS/Wifi
10. Sto. Domingo	16.43335, 121.1134	Line-of-Sight

In this research project, we develop a relatively novel way of measuring rainfall thru a device called disdrometer which uses vibration to measure the intensity of the impact of rainfall on a surface which is translated to rainfall depth thru calibration using existing conventional rain gauges. The disdrometer used here is of the dome-type which is for the purpose of better capturing rainfall from different directions as compared to the flat sheet-type used for the ARMS for Agno River Basin Project [8].

Powered by solar radiation, these disdrometers are automated to send rainfall information to the end-user which is the NWRB. In addition to the rainfall data, other parameters – temperature, humidity, soil moisture, wind speed, and atmospheric pressure – which are a standard in an automated weather station (AWS) and are important parameters to determine the losses or abstraction in the area, are monitored. The design of the system is based on guidelines provided by the World Meteorological Organization (WMO) [9].

The solar power setup is composed of 100W monocrystalline solar panel and 200AHr deep-cycle battery. This enable the system to stay alive for more than a week without or with minimum solar radiation usually during tropical storms. There are watersheds in the Philippines that could have rainy days that extends beyond weeks especially during the Southwest Monsoon or Habagat season coupled with a tropical cyclone. Prolonged rainy days is common on consecutive tropical cyclones occurrence that sometimes could lead to the Fujiwhara Effect where the eye of one typhoon gets back after being pulled by a nearby tropical cyclone.

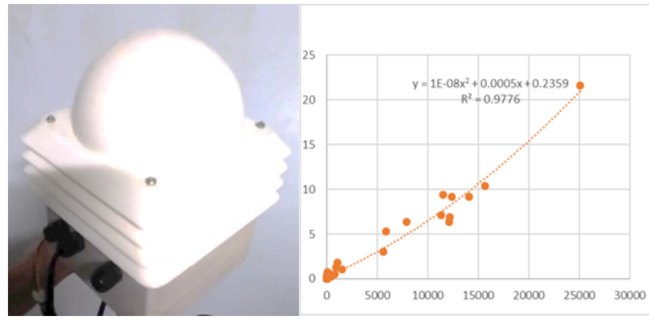

Figure 3. The disdrometer which is 3D printed in the Yuchengco Innovation Center of Mapua University. It also shows the calibration curve that defines the equation embedded in the algorithm to translate the vibration data into rainfall data.

The setup is installed in an enclosure to secure the equipment with pole to elevate the sensors as per requirement of PAGASA and WMO [9]. A schematic of the setup is shown in Figure 4 vis-à-vis the actual installation. Since the study involves a storage area by impoundment which is by the Magat Dam, water level is important input in the hydrologic system. Hence, an automated water level sensor (AWLS) is developed using lidar technology. At the reservoir area, an AWLS is installed alongside a set of AWS. Ten (10) sets of AWS and one (1) AWLS were installed.

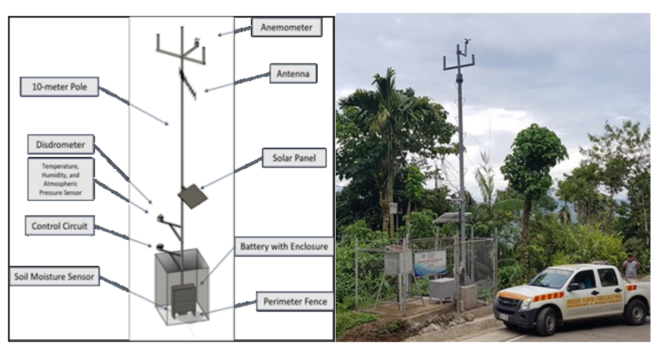

Figure 4. Schematic of the AWS setup and the actual installation for the Halong station

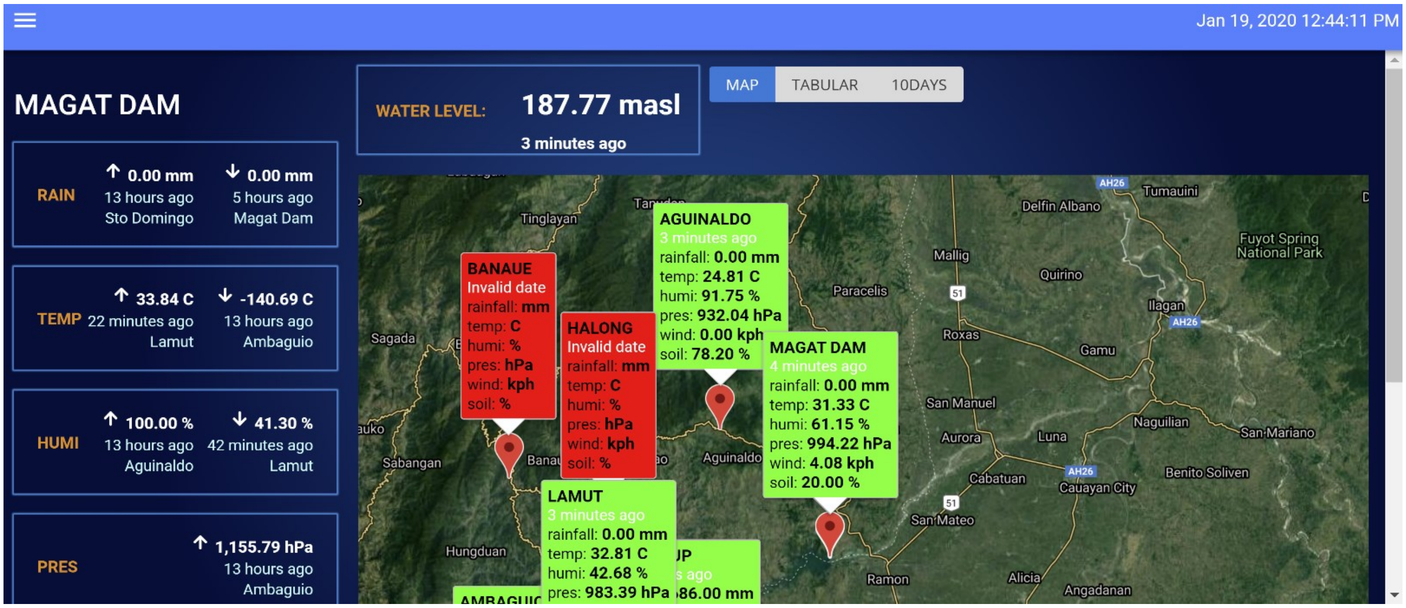

Figure 5. A screenshot of the GUI of ARMS for Magat Dam showing the near real-time hydrological parameters readings of the AWS and AWLS

Half of the 10 AWS uses line-of-sight. The line-of-sight communication utilizes LORA (Long-Range) technology to transmit the data over long distance with low power requirement. In this project we used 433MHz frequency with power output of 5W. The line-of-sight was originally preferred since it has a more stable signal even during destructive typhoons. It is also independent of third party network provider for signal availability. But due to the very rugged topography of the headwaters and limitations in device installations such as an increase in power consumption to boost the transmission, we were constrained to use the SMS/WiFi method usually in 2G or 3G.

The AWLS and AWS are all wirelessly connected by radio frequency thru SMS or internet to the base station in NWRB where a near real-time information is displayed in a monitor showing the readings of the different sensors. Sample of the graphical user interface (GUI) is shown in Figure 5. The web-based portal shows the different hydrological parameters for the Magat Dam. It also displays the status of the sensors if live (in green color) and stalled (in red color).

Conclusions

Data gathered from the AWS is used as input to the hydrologic model to have a near real-time estimate of water flows. Together with the data of AWLS, the water balance is computed and the total water outflow is determined. The development of the wireless sensor network and components in connection to the hydrologic model proved to be a feasible and useful tool for near real-time information of the status of the watershed and the dam's reservoir. The use of disdrometer as a device to capture rainfall data has been proven feasible for deployment in the watershed. The information from the sensors directly to the computers in the offices or even to the mobile phones of the decision-makers and even to the public are a valuable numbers that we can obtain remotely in near real-time. Data from AWS and AWLS and their derivatives thru the hydrologic model is a useful tool to help the water agency arrive in better decisions for a more efficient use of the limited water resources of the country. These information is made available at a data center in NWRB and even to anyone granted access to the ARMS System. The data and information provided by the ARMS System is an important tool of the water agency of the Philippines to better plan for the future and better decide in a current problems such as in times of water scarcity or in times of water excess that may impose danger to the lives of many.

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