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Analytics driven water management system for Bangalore city

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Abstract

Water systems are becoming increasingly complex and instrumented and require a rich set of features to deal with the complexity efficiently. We introduce a new water management software that is centered around powerful dash boarding, background analytics, management through exception and codifying standard operating procedures. This new water management software supports customizable key performance indicators (KPIs), business rules for managing water flow, real time reporting on a rich geo-spatial visual. The paper describes the implementation and results of the first phase of a roadmap to provide a state of the art water management system to Bangalore.

Selection and peer-review under responsibility of the CCWI2013 Committee

Keywords: Water Management; Automation; Smarter Cities; Analytics; Equitable Water Supply; Dashboard; Geo-spatial Map; Event driven; Visibility and Control;

1. Introduction

1.1. Bangalore city water supply

Indian cities have intermittent water supply and there is a huge gap between supply and demand of water. Bangalore, one of the fastest growing cities of India with a population of about 9 million is facing severe water problems and the supplied water is not able to meet the demand. Up to 20% of the normal water supply for

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Bangalore was from the Arkavathi River, from two reservoirs built on the river, the Hesaragatta which was built in 1896 and the Thippagondanahalli Reservoir (or T G Halli), which was built in 1933. These reservoirs have effectively gone dry due to change in land use pattern, overexploitation of groundwater and poor maintenance of its watershed, Mohan Kumar et al. (2011).

From 1970's, to till 2002, Bangalore Water Supply and Sewerage Board (BWSSB) has taken up the Cauvery River water supply project wherein treated water is pumped to the Bangalore city through the Cauvery Water Supply Scheme (CWSS) Stages I, II, III and stage IV Phase-I with different capacities as shown in Table 1. This water is treated at Torekadanahalli Water Treatment Plant (WTP) and supplied to city Ground Level Reservoirs (GLRs) with an elevation of about 400m and at a distance of about 100 km. Hence water is pumped to the city reservoirs through three stages of pumping with a large pumping station (PS) at each stage. The pumping is from TK Halli PS (TKPS) to Harohalli PS (HPS), from HPS to Thataguni PS (TPS), and from TPS to 55 GLRs as shown in Fig. 1(a). The city receives about 910 Million liters of water per day (MLD) which is distributed to GLRs and from GLRs to consumers on alternate days with a shift between different areas.

Table 1. Capacities of different stages of Cauvery water supply scheme

Source (supply scheme)	Established (Year)	Supply (MLD)
Stage – I	1974	140
Stage – II	1983	140
Stage – III	1993	315
Stage - IV -Phase I	2002	315
Total supply		910

1.2. Problems faced by Bangalore water board

With increase in population and higher standards of living, the supply is not sufficient to meet the demand, Fig. 1(b), and in the future it will be difficult to meet the ever increasing water demand unless alternative plans are made. In addition to the deficit in demand and supply, the Unaccounted For Water (UFW) is about 35-40%, Raju et al. (2008) of the total water supplied reflecting losses due to leakages, wastage, errors in meter readings and unauthorized consumption etc. Like many large cities around the world, infrastructure has become very complex over time. Water management is done by turning valves on and off at specified times by hundreds of valve men on the ground. These settings have evolved over several decades. Since there is no feedback mechanism, executive engineers at headquarters and at divisional level may not have a clear picture of how the water supply is managed throughout the city, how meticulously are valve settings being followed by valve men and what if any effect do changes in valve settings have on water supply to various areas of the city.

1.3. Introductory aspects of software and automation

Over the past decade convergence of several un-related technologies has led to potential for creation of new solutions for traditional problems. An example of this is water management through the use of software automation, instrumentation, actuators and GSM technologies, Hidaka et al (2011). Instrumentation has evolved from traditional analog instruments to digital instruments that are capable of measuring and storing data in digital form. Ultrasonic flow meters or electromagnetic flow meters capture the rate of flow and convert the analog value into digital form. This digital form is stored temporarily in data loggers adjacent to the instrument. GSM technology takes the digital data produce by the flow meters and transmit it through regular cellular networks to a central server. Economics of GSM technology makes transmission of data from source to destination nearly free, paving the way for proliferation of instrumentation to all parts of the network and obtaining real-time data. Data sent via GSM is then collated on a single SCADA server as shown in Fig. 2.

Software acquires, transforms, aggregates and dissects data from the SCADA server and presents it via web interface and mobile applications to end-users. Sophistication in software means that data is now available at your finger tips in a form that is consumable and actionable. In subsequent sections, we will discuss the system context that describes the entire ecosystem along with end-users; different cases that describes how end-users use data for water management; the architecture of software that transforms and presents data; and the results we have obtained to date in Bangalore city.

We will conclude how BWSSB is on the cusp of utilizing this management system of changing the way it manages water supply in the city.

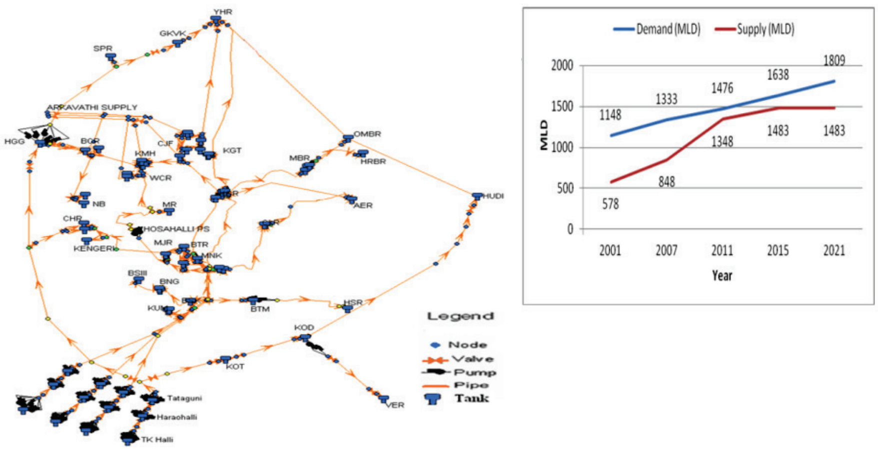

Fig. 1. (a) Schematic of Bangalore Water Supply inflow system; (b) Comparison of Water Demand and Supply in Bangalore City, Mallick and Vasudevan (2008).

2. Water Information Hub

2.1. Instrumentation

Bangalore Water Supply and Sewerage Board established 219 ultrasonic flow meters at various critical points on the water network as shown in Fig. 1(a). Each flow meter measures the rate of flow of water at a given moment of time and the cumulative water that has flown through that section of the pipe since the flow meter was initialized. Subtracting the previous reading from the present reading provides water flow rate for the required time period. Data is transmitted through GSM from the flow meter and received via a GSM modem. Data obtained from the GSM modem is transferred and stored in a SQL database on a SCADA server at a central location. Data from the SQL database is retrieved and used by the water management hub software for transformation and presentation.

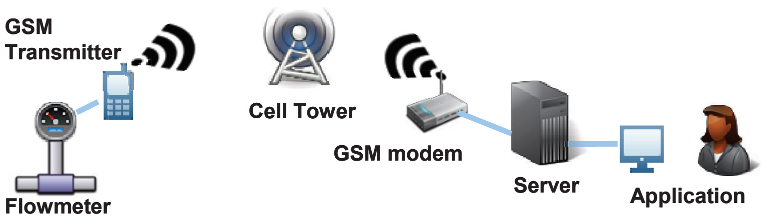

Fig. 2. Schematic of Instrumentation and Server System.

2.2. System context

There are several actors and data sources associated with the Water Information Hub (WIH). Flow data is messaged by various flow meters to the SCADA server which is the repository of all flow meter data. Data is queried by the WIH and brought into a data store for processing. A historian stores historical flow meter data and also some transformed data. The hub contains a Geo-spatial database which stores the locations of all flow meters in Bangalore as a latitude and longitude. The Geo-spatial database also contains a digital representation of all the major transmission pipes for the city. This information is stored in separate layers in a Geo-spatial database. The real database has several other details such as sewerage pipelines, valve, manholes, locations of overhead tanks and ground level balancing reservoirs. A subset of this data is saved as .shp files and imported into the water information hub's geo-spatial database.

The hub is accessed by two different kinds of users – a privileged user that has the ability to design business rules and change settings, provide access to users based on roles and responsibilities and a normal user who accesses data for day to day management. The normal user is an executive engineer or an assistant engineer who will monitor the water flow in various sections of the city. He/she will view current data, historical data and view any alarms or events. A privileged user is able to make changes to settings such as thresholds to be described later. The water information hub is a centralized operation center for water management. At the center of the hub is a map of the city with layers that depict pipes, flow meter locations, GLR locations and administrative boundaries of divisions and sub-divisions, called the geo-spatial map. A filter allows selection of necessary assets on the map. When a flow meter is selected, current data associated with the flow meter is displayed on the right of the map and historical data (24 hour data and 7 day data) is displayed below the map. This is the primary means of monitoring data. Described below are a few tested cases. Additionally the privileged user is able to set thresholds for all flow meters. When the flow rate of the water for the flow meter is below the low threshold or above the high threshold it creates an alarm which is displayed in the event window.

2.2.1. Managing water supply

Water supply is Bangalore's vast network is controlled by valve men on the ground who turn water on and off to different sections of the city at different times. Today there exists no mechanism to manage and cross check the action of valve men because there is no feedback, no visibility. WIH provides a clear and concise view into water supply for the entire city. If valve settings are mismanaged, data of water flow is available in 24 hour reports and an engineer can detect the problem and correct the situation immediately. Once engineers determine overtime that operating range of water flow in a specific pipeline section, they can set necessary thresholds, which trigger alarms if the actuals violate the set thresholds. Alarms are another effective way for engineers to manage water supply.

2.2.2. Water Balance

For an enclosed network, water flowing in, should be equal to water flowing out, after accounting for consumption. If water flowing in is greater than water flowing out, this represents water loss due to leakage or theft. Water balance is an important use for water engineers to determine integrity of operations and water loss. WIH provides a portal at the bottom of the screen to produce water equations described in greater detail in a subsequent section. The portal allows algebraic equations using flow meters as parameters or variables.

2.2.3. Equitable water distribution

In a city like Bangalore, water supply is less than water demand by a considerable amount. Rough calculations show that water supply is adequate for only half of Bangalore's water demand. This gap in supply is partly met by groundwater, Mohan Kumar et al. (2011). In such a situation, the water authority is forced to allocate water equitably to all citizens. However this is a hard problem since water cannot be controlled to such precision by user or household. The first step is to allocate water equally per person or per connection by division and sub-division.

Water equation portal can be extended to determine equitable water distribution. Flow meters are positioned at the boundaries of a division or sub-division to calculate water flowing in or out of the region.

The difference in water flowing in and water flowing out is water supplied to that division. Dividing the water supplied by population served provides an indicator for water supplied per capita. Tuning water supply to achieve parity for all divisions and subdivisions is a first step towards equitable water distribution.

2.2.4. Water loss

Water is lost due to leakage or theft. Revenue is lost to the water authority although it spends money and effort to get the water nearly to the doorstep of the consumer. Water loss can be computed as the difference between water supplied and water consumed, measured by the integration of water meter readings for the zone. Water loss by zone is an important parameter for good governance. Providing this data enables administrators to focus on areas that have the highest losses and investigate and fix the sources of water loss. As most water experts know, water loss is a continuous process.

As new leakages spring up, water loss by zone changes overtime. WIH provides that dynamic view of water loss by. Water loss has not been implemented in this phase of the project because each sub-division is not adequately instrumented. It is planned for implementation in the next phase of the project.

2.2.5. Monitoring water supply by command area

Water in Bangalore city is supplied through 55 ground level reservoirs (GLRs) to each command area. Monitoring the water supplied to each of the GLRs and the water level in the GLR forms an important part of water management at a local level.

Water balance at GLR level has not been implemented because of lack of level sensors in most of the reservoirs.

2.3. Architecture of Water Information Hub

We conceive that a water information hub is made of the several connected software architectural layers described below and shown in Fig. 3, and also described in IBM Intelligent Operation Center (2011), IBM Intelligent Water (2011) solutions.

2.3.1. Data Acquisition:

Data has to be acquired from SCADA devices such as flow meters, pressure gauges, level sensors. Data is transmitted through wired or wireless means from the sensor and data logger to a data gateway or server where data is stored for use by the management software.

Data packets contain data associated with the particular device (such as flow rate) and a unique timestamp to make it OPC compliant.

2.3.2. Data Transformation and Storage:

A database is required to store flow meter data in a time series form, so that it can be retrieved for the presentation layer on demand. Data transformation may be required to convert data into a format suitable for storage and retrieval.

2.3.3. Presentation Layer:

This layer supports the visualization of the underlying functions. The key state of the art feature is the integration of Geo-spatial maps which allows users to click on assets or icons to get the appropriate information and the geo-spatial map provides the necessary context such as location of the asset. This is central to the end-user friendliness and therefore wider acceptance. Aside from the geo-spatial map, the presentation layer also has the following important features:

- Ability to interface with mobile devices and thin clients to provide access to the users on smart phones or ipad like devices.
- Mobility for command and control operations.
- Ability to authenticate viewers who access data remotely through standard browsers.
- Provides safe and secure accessibility and environment for employees to access mobility devices.

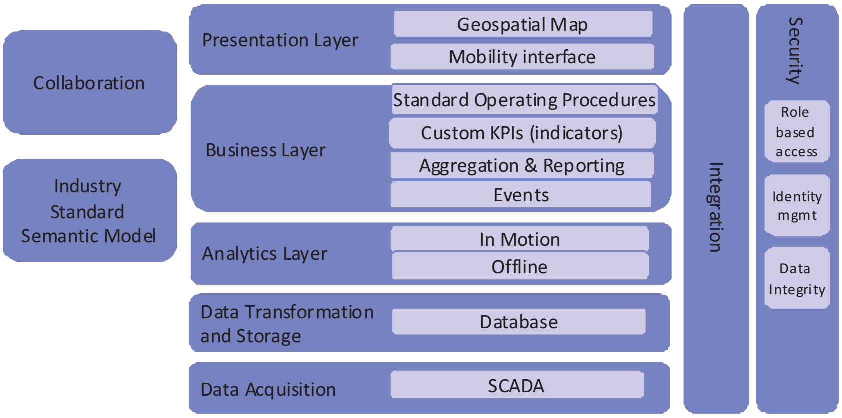

Fig. 3. Architectural overview of Water Management Software.

2.3.4. Business Layer

This layer supports necessary automation and customization of business specific requirements, such as reporting, aggregation of data, standard operating procedures, creation and monitoring of customized key performance indicators (KPIs).

- Provides reports in various formats for users in different roles and at different levels. Example is 24 hour and 7 day report of flow rate.
- Provides key performance indicators (KPIs) that are used as the primary gauge of the organization's health and success. Example of KPIs is water supplied / consumed / lost by division for a city.
- Business rules that define event triggers and responses. Example is flow rate threshold that can be customized for a specific section of the network, also by time of day.

2.3.4.1. Events / Alarms

Events or Alarms can be generated by aggregating conditions and inputs based on business rules. A simple form of alarm is triggered when water level in a section of pipe falls below a low threshold or exceed a high threshold. This can be augmented by setting limits or thresholds that vary by time.

2.3.4.2. Standard Operating Procedures(SOPs)

Every organization has 100s of standard operating procedures, mostly created through years of operational experience. Codifying standard operating procedures ensures that processes are followed evenly across the organization, can be tracked for efficiency and root cause analysis, and ensure that tribal knowledge is not lost through retirement of experienced engineers. SOPs can be kicked off based on events or alarms by a privileged user. As an example when water flow in a certain section exceeds a threshold, it indicates that the valve man may have been negligent in shutting off a valve or a valve that does not completely shutoff due to aging.

2.3.5. Analytics Layer:

As instrumentation and software automation become norms, data by gigabytes stream in daily producing data overload for managers and engineers. It is crucial that the software platform support analytics with the intent of simplifying insight and making data more consumable and actionable. Analytics is defined as augmentation of data by any mathematical or scientific method to improve insight and improving decision making. In Bangalore city analytics has been used to produce 24 hour and 7 day reports for each flow meter. Viewing this data makes it possible for water engineers to see if valve timings have been followed correctly to ensure water supply to their divisions and sub-divisions correctly. A second use of analytics is to produce a key performance indicator called water supply by division which helps water engineers assess if water is supplied to each division equitably.

2.3.6. Integration Layer:

This layer integrates various architectural layers by allowing messages and data to flow between various components. An industry standard integration layer such as enterprise service bus connects various software components.

2.3.7. Collaboration Layer:

Once data is available in the right form, the question is how a large organization can leverage data. This layer allows users to collaborate with other users through instant messaging, emails, message boards and forums.

2.3.8. Security:

Finally the security layer surrounds all the above layers and includes several components such as identity management, role based access, and data integrity. Security is essential for every organization because without adequate security, an application can be rendered useless by external threats or data can be misused or misappropriated.

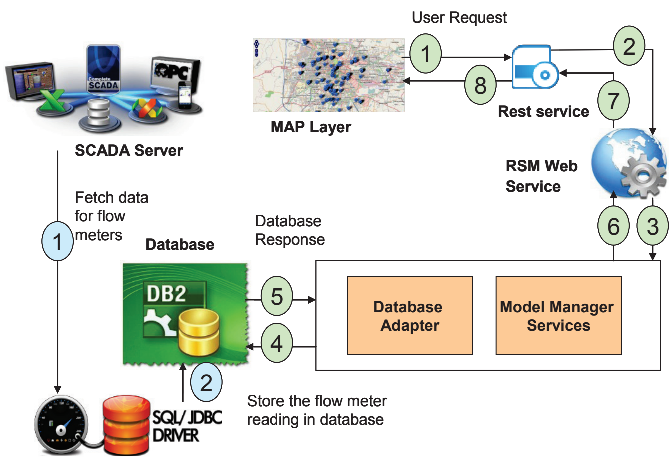

Fig. 4. Data flow inside of the Water Management Software.

2.4. Data flow

Data transmitted by data loggers attached to the flow meters are collated at the central SCADA server in a SQL database. An adaptor retrieves the data acquired in raw format from the SQL server and organizes it in a time series in a DB2 database. When a user queries the status of an asset (example flow meter) on the map (in the presentation layer), it produces a query that is sent to the model manager. The model manager maintains a symbolic or logical representation of water network for the city. It converts the query into a DB2 query and retrieves the data from the DB2 database, sends it back to the presentation layer for display as shown in Fig. 4.

2.5. Contextualizing the water management software for Bangalore

The dashboard of the water management software for Bangalore city implemented as of April 30th, 2013 is shown in Fig. 5. The central geo-spatial map of Bangalore city has a number of assets: flow meters are in blue, GLRs are in green and event or alarms are in red. On the right of the map is the current status of the asset and on the bottom are 24 hour and 7 day historical trends. Below the current status are portals for alarms and divisional supply.

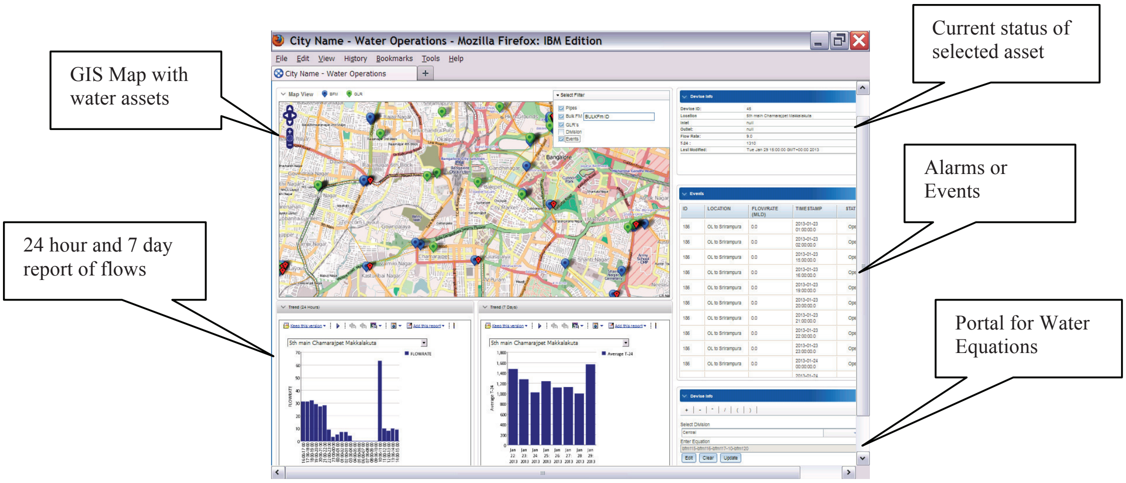

Fig. 5. Water Management Software for Bangalore City as of April 30th 2013.

3. Results

3.1. Water Management through reports and events

Shown in Fig. 6 are example reports from the water management system that show water supply for a 24 hour window and 7 day window for two parts of the city for the selected flow meters. As can be observed, water is supplied for specific hours to these areas in the 24 hour report. Alternate day supply, which is the norm for certain areas in Bangalore city is shown in the 7 day report.

3.2. Water Supply Equations for each division

Shown below in Table 2 are water supply equations and computed values of division-wise water supplied for several divisions in Bangalore city. West division has not been shown because one of the flow meters was not reporting values. This flow meter is currently being investigated. In some equations, a fixed quantity has been added or subtracted to make up for the missing records. The Portal allows estimated values to be added or subtracted.

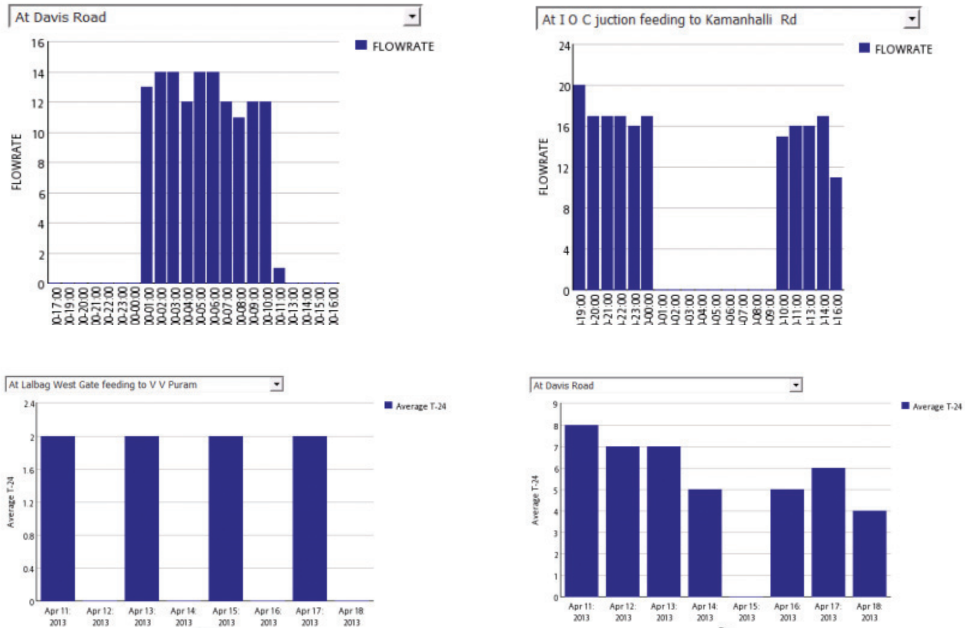

Fig. 6. 24 hour report of water supply to Davis Road and to Kamanhalli Road.

3.3. Water Balance

As described above, Bangalore's water is supplied by four distinct stages. Water balance equations governing water supplied by each stage from the edge of the city to the input for each command area's reservoir is shown in the Table 3 below. Roughly 2-3% of water is unaccounted for and could be attributed to leaks or calibration of the instruments. Instrumentation error for ultrasonic flow meters is in the range of 2-3%.

Please note that this is not the total water lost in the city which possibly exceeds 40% and most of which is in the distribution.

Table 2: Water supply for each division in Bangalore city

Division	Water Supply Equation	Measurement date	Measured Value (ML)
South	(f7+ f31+ f12+ f15+ f29+ f32+ f47+ f28+ f19-f63-f64) - (5 MLD of VER)	17th April	212.4
South East	(f48+f62+f49+f50+f51+f9+f63+f64) + (f3+5 MLD of KOTR and VER)	17th April	165.4
East	(f115+f95+f116+f101+f80)	17th April	368.6
Central	(f117+f121+f122) + (30 MLD of HGR)	17th April	114.0
West	(f133+f145-f155-f156) - (6 MLD of YHR)	17th April	Not meaningful
North	(f174+f175+f120+f155+f156) + (6 MLD of YHR)	17th April	125.0

***R Indicates name of the reservoir. For Example: VER represents Veerasandra Reservoir.

Table 3: Water Balance for each stage in Bangalore city

Stage	Water Supply Equation	LHS (in ML)	RHS (in ML)	UFW (%)
I	f1 = f7 + f31 +f48 +f62	147.4	143.1	2.90%
II	f2=f12+f15+f29+f32+f47+f49+f50+f51	143.8	138.1	3.97%
III	f3 = f28 + f115 + f95 + f116 + f101 +f117 + f121 + f122 + f174 + f175 + f120 + HGR estimate (30 ML)	323.4	315.1	2.59%
IV phase 1	f6 = f19 +f 9 + f63 +f64 + f80 + f133 + f145 + f155 + f156 + KOT est (3 ML) + VER est (5 ML)	306.4	303.1	1.09%

4. Conclusions

We believe that even for cities that do not have 24x7 water supply, there is a case to be made for automation and water management through the use of "smart" software. The combination of events and SOPs greatly simplify water management for aging and complex water systems by focusing on exceptions. Through the use of mobile platforms these events and SOPs can lead to near instantaneous cross organizational collaboration spread across a large geography. Analytical capabilities can be programmed to provide pro-active alerts to commonly occurring disruptions. Analytical tools can be tuned to provide business level optimization such as pressure management to reduce energy bills or water loss from leakage. Aggregation of data through user supported water equations can provide a higher level of functionality such as water balance equations by zones or wards. By giving users the ability to integrate real time data and continuously refine their equations, this software provides the flexibility for water engineers to slowly converge to higher levels of precision for water supply, audit and balance. In future, this software can be utilized to control actuators, pumps, valves to automate water operations with far greater precision than would have been otherwise possible. Further, for Bangalore city our goal is to provide information to the workforce on their mobile phones, integrate more instrumentation, provide KPIs for water supply by sub-division, help BWSSB create benchmarks for valve timings and settings, triggering alarms when valve timings and settings are violated and thus providing a platform for BWSSB to manage the operations efficiently.

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