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Real time control of urban groundwater levels

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Abstract. This paper introduces the application of real time control in the urban groundwater levels management. Real-time control (RTC) of water systems has become an advanced methodology to fully use the available capacities of a water system. Real time control, which applied to regulate structures in urban water systems, can eliminate the need for major investments in water-systems infrastructure. However, since the latest developments in information technology and computer science, RTC has now become indispensable for integrated urban water management.

1. Introduction

In densely populated areas accurate control of water quantity and quality variables is necessary to prevent flooding, poor water quality and water scarcity. Water authorities have to take into account the various requirements, which make control of water systems a complex, multi-criteria problem generally.

1.1. Real-time Control

Real-time Control (RTC) System is a reference model architecture, suitable for many software-intensive, real-time control problem domains. The system is a reference model architecture that defines the types of functions that are required in a real-time intelligent control system, and how these functions are related to each other.

For the real-time control of water system we can define the system dynamically adjusts the operation of facilities in response to online measurements in the field to maintain and meet the operational objectives, both during dry and wet weather conditions [1].

1.2. Urban groundwater level control

Real-time control in groundwater levels control ensures a close match of groundwater level performance with the time-varying requirements of water uses. In addition, real-time control supplies essential information on groundwater-system behaviour to water managers for support of day-to-day operations and for mid- and long-term evaluation purposes.

The groundwater is becoming a great issue in urban areas due to the land over using and the increasing population. The construction period of civil engineering works and the draw-out of groundwater for drinking water have caused the compaction of aquifers in the local area and lead to subsidence. The urban groundwater level also can be very high which caused by unexpected events or extreme precipitation, and also transportation channels, garden, park, flood crawl spaces, etc. with a huge economic loss.

It is intricate to control the urban groundwater level because the temporal and spatial variation of urban groundwater system. For the temporal aspect, different seasons have different precipitation features, and different extremely weather events. For the spatial aspect, the places near sewer system face a higher possibility of polluted water interference; the areas with higher infiltration rate will cause higher urban groundwater level; the area with a steep slope has a short concentration time against flood event. Nowadays, the measurement of urban groundwater level is normally with a low frequency measuring, which cannot ensure a good control of timely groundwater level [2]. Consequently, there should be a reliable and rapid reaction groundwater level control system in urban groundwater control system.

Normally, a static control has been used, which measures the groundwater levels within a regular interval and predefined instruction (In most places of The Netherlands, urban groundwater level is measured twice a month). The groundwater is usually being discharged at some shallow aquifer with full filling capacity while the other parts of the same system still not fully used during the conventional measures. In consideration of the quality issue, the industrial pollutants and the leaking sewage is easily infiltrated into the shallow aquifer, further infiltrate into deeper groundwater, especially in some areas with deeper layer extraction for drinking water supply.

Consequently, in these sensible areas, timely retain these polluted sources can be achieved by beneficially direct the polluted flow to wastewater treatment plant (WWTP) or by allowing high groundwater level or overflow discharge to occur only if the system is at full capacity and only at certain locations with the least economic damage.

Otherwise, during the extreme precipitation period, the storage capacity of the whole system may face its limitation, while real time control can regulate the overland flow in the order of priority.

2. System performance

2.1. Important factors of the RTC system

In general, an urban underground water system is controlled in real time if process variables are monitored in the system and at the same time, used to operate actuators during the flow process.

The real time control of the process can be schematized by means of control loops (figure 1). These control loops could be implemented by hardware components which including sensors (monitor the process evolution), regulator (influence the process variable from its desired value), and the data transmission systems transmitting data between the different devices.

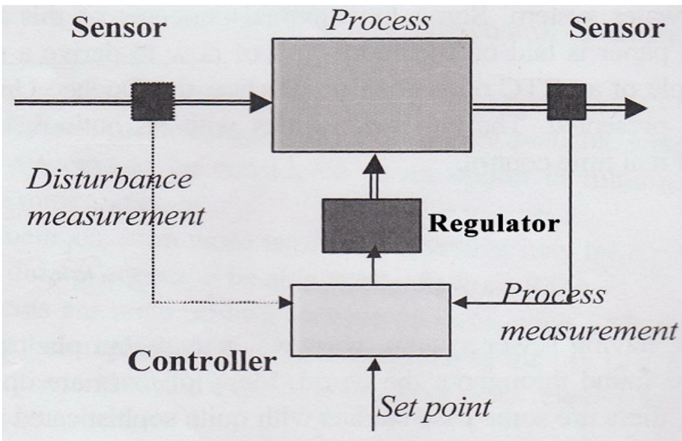

Figure 5. Feed forward (disturbance measurement) and feedback (process measurement) control loop. Simple arrows indicate data flow, double arrows indicate hydrodynamic action. Bold letters indicate hardware and italic letters indicate variables [3].

The RTC in underground water systems shows rigorous requirements on sensors, that such as measurement accuracy and reliability, physical and chemical resistance and suitability for continuous recording and remote transmission. The main sensors used include:

(1) Rain gauges (such as weighing gauges, tipping buckets and drop counters.) Rain measurement can also be obtained by meteorological radars enabling also short term rain forecasts;

(2) Water level gauges (such as floating hydrometers, bubblers, pressure inductive gauges and sonic gauges.) Water level gauges are important for monitoring the state of u nderground water storage or to convert levels to flow rates where backwater effects are not dominant;

(3) Flow gauges (such as level-flow converters, ultrasound velocity meters, and electromagnetic meters.)

The regulators in urban underground water systems include:

(1) Pumps (axial or screw with constant or variable speed);

(2) Gates (sluice, radial or sliding, which are usually activated by motors and used for generate in-line storage or for diverting flows into other parts of the system);

(3) Weirs (transverse, side spill, which can either be static structures and also be moveable and adequately positioned in order to generate storage volume);

(4) Valves are used to restrict flows.

The controllers include:

(1) The standard controller used for continuously variable regulator settings are the proportional-integral-derivative (PID-controller) and its simplifications (P,PI,PD). Its signal to the regulator is a function of the difference between the measured variable and the set point.

(2) Two-point or on/off-control is the simplest and most frequently applied way of discrete control. It has only two positions: on/off or open/closed.

(3) Nowadays, digital programmable logic controllers (PLC) [3] mostly replace analogue controllers.

2.2. The main principle of the RTC system

The procedures of the RTC system can be explained as:

(1) The sensors collect real time data of groundwater level and report to local RTC device (mostly is PLC or Remote Terminal Unit, RUT).

(2) The device transmits data to central station with a Supervisory Control and Data Acquisition (SCADA) system, where all incoming and out coming data are managed. The current level is compared to the desired level and determines the settings to be implemented.

(3) The feedback was transmitted back to local regulator and controls the process. Data transmission systems may be realized by means of leased or dedicated telephone lines, or by wireless communication systems, such as radio, cellular systems or satellite telecommunication devices.

The control loop defined above is the basic elements of any real time control system, which can be mainly classified into feedback algorithm and feedforward algorithm, command of former is actuated depending on the measured deviation of the controlled process from the set point, while the latter anticipates the immediate future values of these deviations using a model of the process (just like the rainfall-runoff model). Then controls are activated ahead of time to avoid the deviations.

As a result of different situations, control strategies are defined in the managerial level. For instance, the strategies can be maximally reduce the street flooding; reduce the sanitary overflow; reduce energy consumption of pumping; limit the inflow to Waste Water Treatment Plant (WWTP), it can also manage the groundwater level during anticipated system disturbances, also the emergency situation (equipment failure, unpredictable incidents). Then, these strategies have to be transferred and translated into the system level, defining the specific controlled elements and set-points.

2.3. The data processing

Data processing provides the main information for decision-making, it is a main procedure in RTC. The data will be filtered, validated, and aggregated, as some data is missing; out of range; incorrect (frozen situation); inconsistent (different measuring periods). Statistics can be summarized to show variation of value in different regimes and periods, and thus gives references to extrapolate observed groundwater series, and provide information of groundwater dynamics [3].

Besides internal processing, the data from precipitation and evapotranspiration also can be combined in the monitoring program to accurately detect and quantify the effect of groundwater level changes as soon as possible, and thus estimate structural changes in groundwater region and support decision making in long-term water policy.

The data processing system in RTC implies the effort will transfer from maintenance and on site measurement of static control to data management and decision support system, requiring different engineers, managers, operators working together.

2.4. The practicability of applying RTC in the groundwater system

Nowadays, RTC is a likely method to control Groundwater level (GWL), but the appliance of RTC has lots of restrictions, in technically part also managerially part, which should be compared with other alternatives before final adoption. Some scoring system is used in evaluating the potential of RTC in urban groundwater system.

For applying RTC, there are lots factors [4] need to be considered:

(1) Existing facilities: Existing control devices, discharge devices, storage facilities;

(2) Sensitivity of the area:

- Lots of protected area (swimming pool), economic centre;
- Places with high ecological value and environmental value;

(3) Available storage capacity:

- Large dimensions of tanks, pipes, which is not fully used;
- Available receiving areas for storing extra storm water;

(4) Distribution of the area: Non-uniform temporal and spatial distribution.

It is also necessary to mention that the difficulty of RTC implementation may not from technical part, but more from organizational or procedural management. The main reason is that RTC has a big difference from the traditional on-site regulation. Also due to the presumed complexity of RTC, practicing engineers are usually reluctant to convert to RTC technique. Moreover, the communication between the managerial level and practicing level is hard to coordinate. As control strategies are mainly given by the central managers who are not familiar with the local situation, while those regulate the instruction are practical engineers with lots of filed experiences. Thus a closer and effective communication between the two levels is essential to guarantee the RTC implementation.

3. The real application of the RTC on GWL modelling

According to the records, Southern Florida has implemented a global real-time control in groundwater level system [5], which utilizes real-time GWL data and metrological data to predict impacts on groundwater as a result of extreme weather condition, and urbanization.

3.1. The goals of the implementation

(1) The system provides accurate monitoring of sensitive areas which is susceptible to water level related problems;

(2) The system provides real-time data for water managers to deal with the adverse effects caused by changing aquifer conditions, and signal the events;

(3) The system integrates data from rain gauge to give timely control of GWL;

(4) The system builds up the long-term trend of groundwater level for future prediction.

3.2. *The main methods of the implementation*

The US. Geological Survey (USGS) collects data from over 200 continuous GWL records to provide decisions in water management of Southern Florida. The monitoring wells are selected according to well construction conditions and the data periods. These monitoring wells are equipped with satellite telemetry to transmit to USGS every 4 hours.

Data processing is the main procedure to obtain a good long-term trend of GWL and select the most representative monitoring wells for future network modelling. The statistical analyses are implemented:

(1) The Seasonal Kendall trend is used to examine long-term trend in each aquifer;

(2) Summary Statistics of all wells to find the most susceptible wells to drought condition;

(3) Frequency analysis is also used to compare the relation between rainfall events and GWL in order to find the representative wells for future GWL prediction under extreme metrological condition;

(4) Regression analysis is used to compare relations between each candidate wells within the same aquifer so as to find the most representative monitoring wells.

3.3. The results and the advantages of this implementation

The results of this project is that a total of 33 water-level monitoring wells are selected to provide good coverage of GWL condition in Southern Florida, based on which a representative long-term GWL trend is built up.

The advantages of this project are as follow:

(1) Although the cost of model calibration and verification is quite high, it also reduces the costs of building new tanks and extending the existing capacities

(2) Through selecting the most representative wells, the linear relation between precipitation and groundwater level can be used

4. Conclusion

Nowadays, improved devices, methodologies and tools for are available which allow RTC of GWL systems to be considered as an option to minimize adverse impacts and to minimize costs. Due to improved methods, even those GWL systems may have potential for Real Time Control which, in the past, did not appear to be able to benefit from RTC. Further improvements are required in a number of areas, such as sensoring and consideration of uncertainties. Particular emphasis should also be given to the use of a clear terminology to enable better cooperation of scientists and experts of different areas relevant to RTC.

In urban groundwater management, if the preconditions of the system are favourable, RTC is a promising method of controlling GWL, which allows information from all parts of the system to be used for systematic control. RTC eliminates the local overland flow caused by temporal and spatial heterogeneity while maximally using the available system capacity; it also serves more accurate prediction of GWL by modelling the real-time urban groundwater level with the rainfall data [5].

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