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WATER QUALITY SURVEILLANCE AND EARLY WARNING IN SURFACE WATERS - INTEGRATION OF MATHEMATICAL MODELS AND ON-LINE MONITORING

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The technology for integration of mathematical models and on-line monitoring has been available for almost a decade and the use of mathematical models for forecasting of flow has been adopted worldwide. When it comes to surveillance and early warning systems for water quality the coupling of pollutant sensors with mathematical models in real time has only recently been introduced, one reason being that the available technology for online monitoring of water quality was limited to a few components only. However, in line with the rapid development in on-line sensor technology the possibility of coupling on-line monitoring with state-of-the-art water quality modeling techniques and forecasting is now available. A prerequisite for such a system is a data assimilation routine to update the models in real time and hence minimize the difference between measurements and model simulations. Indeed the forecasts of pollutant concentrations ahead in time require an updated model at all times. In this context the Kalman filtering techniques have proven to be very efficient. In particular the Kalman filtering updating algorithm may be structured in such a way as to provide information on the amount and location of the pollutant updating. The latter is a key issue when tracing pollutant sources.

This paper presents the above elements integrated into a real time decision support system for water quality in the complex canal system in Bangkok.

INTRODUCTION

Bangkok and the surrounding area have a network of canals or khlongs, which over the past decades have been in serious decline. The network of channels covers hundreds of square kilometres, linking the Chao Phraya with the neighbouring river Tha Chin to the west and the river Bang Pakong to the east. The network is an invaluable asset containing numerous uses such as

- drainage channels for storm water and flood overflows
- navigation routes for water transport
- conveying of sewage via the main rivers to the sea
- conveying of irrigation water to the northern area
- circulation of brackish water among the shrimp farms in the south

To improve the water quality a number of measures are undertaken by the Bangkok Metropolitan Administration (BMA). In parallel with the construction of sewage treatment facilities an advanced quality surveillance and decision support system is under implementation. The decision support system comprises advance sensor and database technology, mathematical modelling and model updating in real time. Finally, data dissemination is provided via the Internet.

Below a description of the system and its functionalities is shown.

MONITORING TECHNOLOGY

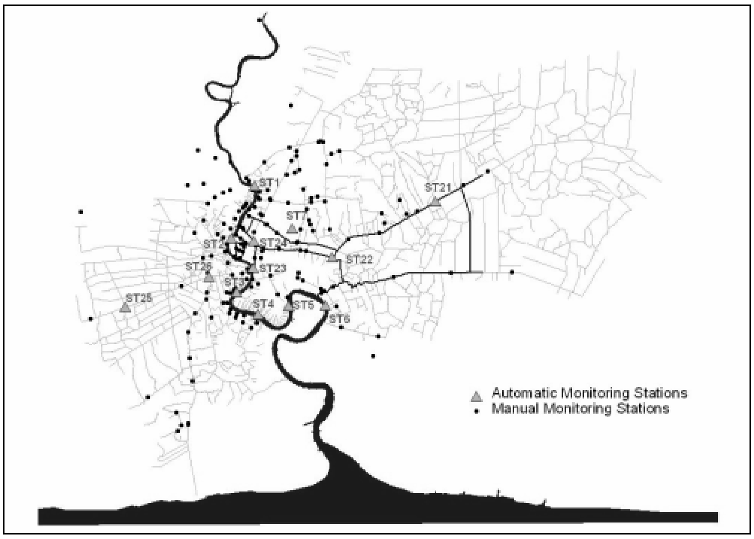

Figure 1. Location of manual and automatic monitoring stations.

A total of 12 automatic monitoring stations are installed in Bangkok. Six of these are located along the Chao Praya River, while the remaining stations are located along three selected channels; Padung Krung Kasem, Saen Saeb and Phasee Charoen, two stations in each. Water is pumped into the stations, analyzed and subsequently transmitted via phone to the main servers and database system (ENSIS as supplied by COWI)) at BMA. All stations measure the basic parameters; water temperature, water level, conductivity (salinity), dissolved oxygen, pH and turbidity, while the parameters COD, nitrate, RedOx potential, chlorophyll-A and trace metals (Zn, Cd, Pb, Tl, Cu and Ni) are measured on selected stations.

Figure 2. Automatic monitoring station.

The ENSIS system is a module-based system for environmental surveillance and information and is used for storing and presentation of data. The database includes on-line data as well as data from manual sampling, statistics on emissions and other background data. The data can be explored and presented as tables, graphs, thematic maps and even used directly in reports composed by a report generator. ENSIS is a client/server solution giving an object-oriented view of a relational database. The system is developed using MS VisualBasic and uses ORACLE as database platform. MapObjects is used for building GIS-components. The on-line data are checked for inconsistencies and malfunctions of the sensors before further processing and storage. The overall data flow is provided in the figure below.

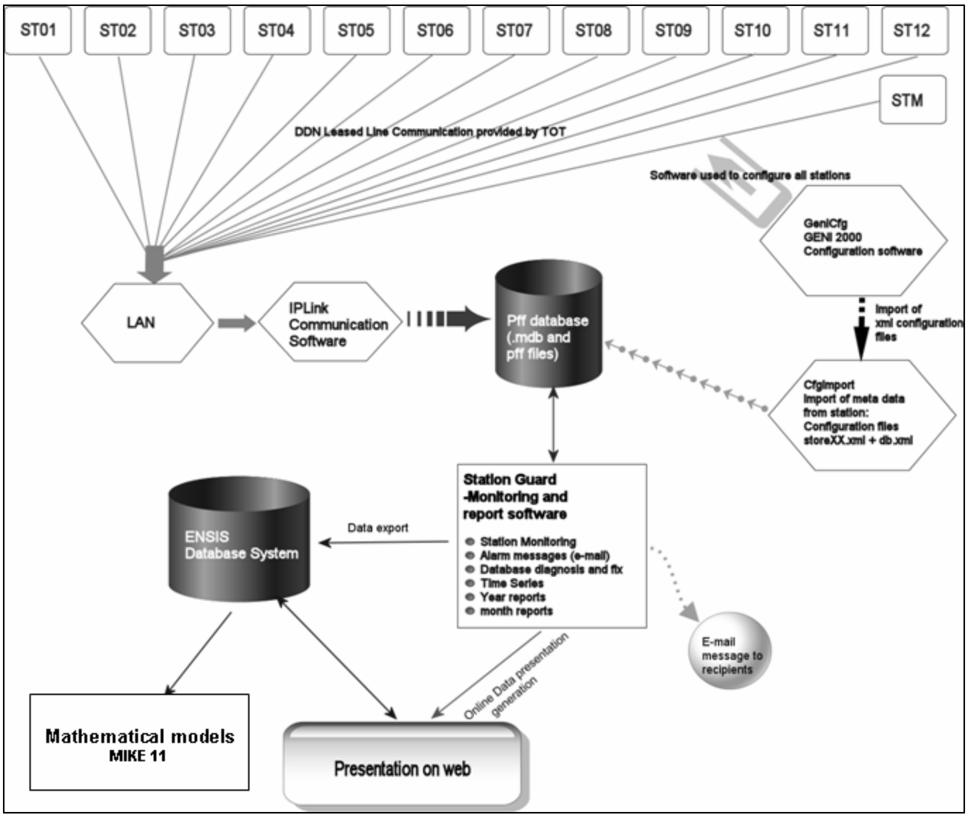

Figure 3. Data flow.

MATHEMATICAL MODELS AND DATA ASSIMILATION

Hydrodynamics

The hydrodynamic components of the system consist of MIKE 11 which solves the cross-sectional averaged momentum and mass conservation equations, the so-called Saint-Venant equations.

The solution is obtained from a finite difference formulation of the equations, using a numerical scheme, which solves discharge and water level at alternating grid points. The alternating grid results in a scheme with a high degree of numerical stability (see [1]).

Pollutant Transport and Water quality

The transport and degradation of pollutants are modeled with a 1 - D advection – dispersion scheme coupled with a water quality equation solver for chemical and biological processes. The model utilizes MIKE ECO Lab, an open equation solver integrated with MIKE 11.

The pollutant loading comprises non-point diffusive load combined with domestic, and Waste Water Treatment Plant (WWTP) effluents are extracted from the MIKE and ENSIS database system during model simulation.

The water quality modelling comprises BOD / DO processes in addition to nitrification and denitrification and thus includes the state variables Temperature, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonia, Nitrate and Salinity .

Data assimilation

The data assimilation methodology applied in the present set-up is the so-called ensemble Kalman filtering algorithm. The method is based on a stochastic representation of the MIKE 11 water quality modelling system formulated in a form where the state of the system (instantaneous values of water level, discharge, temperature and concentrations) at a particular time step depends only on the state of the system in the previous time step plus the forcing terms (boundary conditions and pollutant sources). Hereby the model is formulated as a one step discrete dynamic system.

Furthermore, the model is based on a number of assumptions and simplifications. These assumptions and simplifications give rise to uncertainties or model errors in the predictions. By introducing a description of the model errors and their propagation in time the model errors may be included as state variables in the system. Thus the composite model estimates not only the state of the system but also the model errors. In the present set-up the model errors are related to errors in the forcing terms i.e. boundary conditions and pollutant sources.

In the ensemble Kalman Filter the statistical properties of the state vector are represented by an ensemble of possible state vectors. Each of these vectors is propagated according to the dynamical system subjected to model errors, and the resulting ensemble then provides estimates of the forecast state vector. In the measurement update, the update is applied for each of the forecast state vectors.

The Kalman filter is a succession of two steps. First, the model is employed to issue a forecast, and then the observed data are meld with the forecast to provide an updated state (analysis step). Further details of the methodology may be found in ([2],[3]).

INTEGRATION OF REAL-TIME DATA AND WATER QUALITY MODEL

In order to provide on-line water quality forecasts based on data acquired in real-time, the MIKE FLOOD WATCH ([4]), normally used for flood forecasting, has been configured to meet the specific needs. The main purpose of this platform is to ensure automatic pre- and post processing of model data, execution of models and subsequent data assimilation and model forecasts as illustrated in Figure 4.

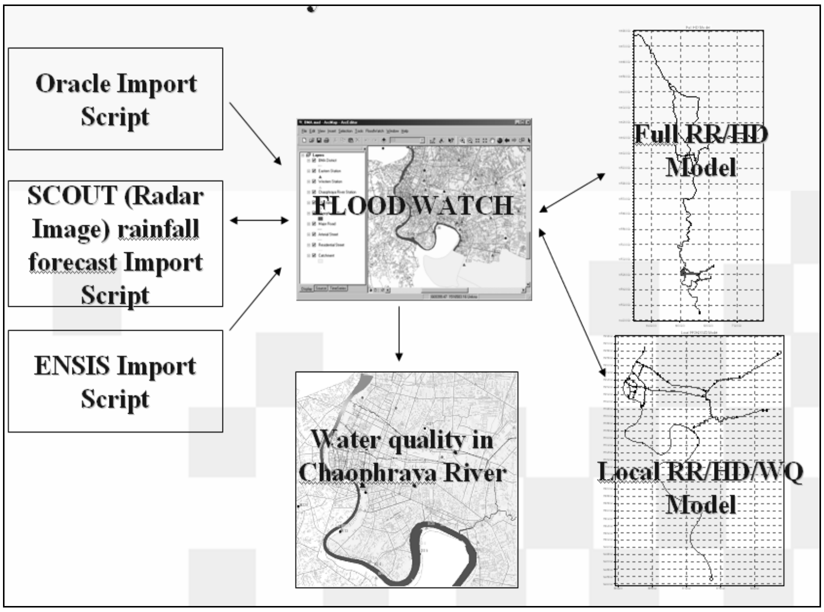

Figure 4. The mod l execution control platform and computational modules for rain fall runoff (RR)f, hydrodynamics(HD) and water quality(WQ).

The system has been configured to operate 24 hours a day without the need for any human intervention. Every three hours, the system carries out the following steps to produce the information required by system personnel to establish a firm overview of the situation:

1. The system queries an ORACLE database for recent point observations of rainfall, water level and discharge at hundreds of locations within the city of Bangkok.
2. The system queries the rainfall forecasting system, which applies both point based rainfall observation, radar images from two radars to compute a mean area weighted rainfall time series for each subcatchment in the numerical model. The rainfall forecasting system includes also the capability to propagate the centroid of the rainfall clouds into the near future, thus making it possible to include a rainfall forecast for each subcatchment.
3. The system queries the ENSIS database for recent point observations of selected water quality parameters.
4. The data are quality assured, boundary estimated (if needed) and passed to the MIKE 11 computational modules, which compute catchment runoff (based on forecasted rainfall), river flows, water levels, biological and chemical processes and pollutant concentrations in a computational grid

with an average distance of 100 - 200 m between grid points in the canals and the Chao Phraya River. Based on online measurements of flows and pollutant concentrations the river model is updated utilizing the above Kalman Filtering technique in order to produce reliable model results in space and time.

5. After completion of model simulations an interface to the intranet is established, and selected thematic maps and results are automatically transferred to the BMA web pages for viewing by the public or selected groups of users.

The output from the system includes detailed information of water quality parameters along the Chao Phraya River and in the canals in the city. An example of the spatial distribution of COD in the city centre is illustrated in Figure 5. Accompanying the map-based results is a table of statistical measures of the water quality at selected locations. This information helps system operators to identify the sources of pollutants.

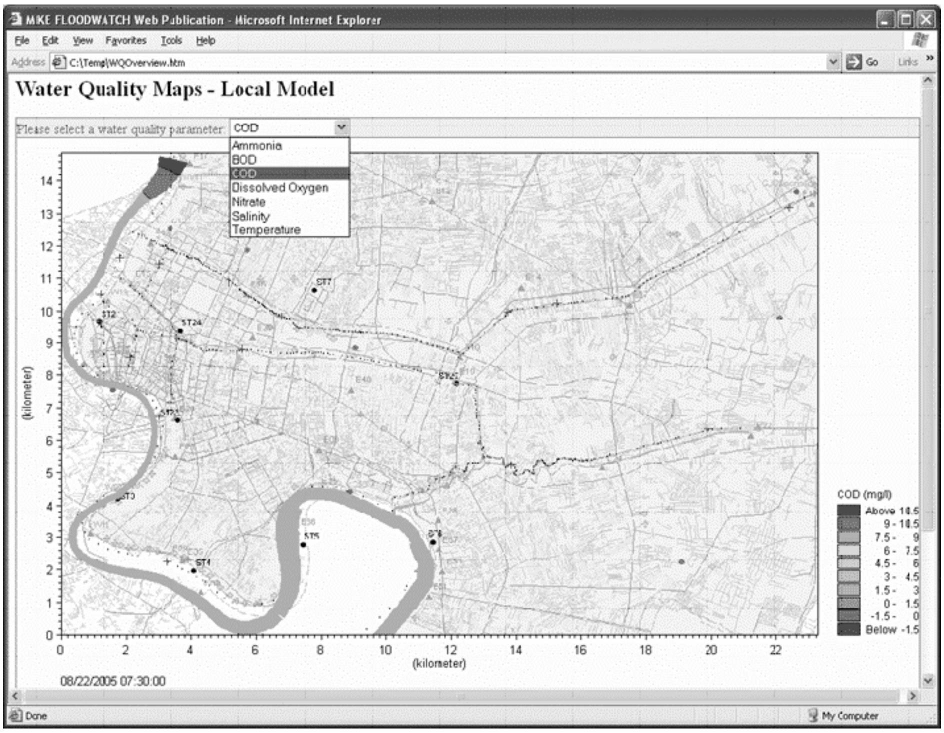

Figure 5. Example of model results on the BMA web page.

CONCLUSION

A real time water quality decision support system has been implemented for Bangkok Metropolitan Administration, The system integrates meteorological forecasts using radar images and point rainfall, sensors for pollutant concentrations, data analysis and transmission in real time, data base storage, numerical model systems, GIS presentation and communication of information to the end users and stakeholders.

The modelling and the subsequent data assimilation serve different purposes:

- They fill the gaps of information between monitoring stations.
- They provide uncertainty on pollutant loading and help to identify polluters.
- They provide forecasts of water quality ahead in time which can be used to take proper action. In Bangkok particular focus is on flushing pollutants in the channel network and issues relating to salt intrusion.

The project has demonstrated that the concepts work and indeed provide rapid dissemination of online monitored data and model results. However, it has been difficult to quantify pollutant uncertainty and polluters.

Although the system elements are running fully automatically the project implementation period has clearly demonstrated that without proper maintenance the system may fail. The maintenance comprises regular cleaning and calibration of online instruments (caused by debris in the river and the khlongs) and securing of online data transmission via the existing data network.

ACKNOWLEDGEMENT

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