# Water Quality Forecasting Systems: Advanced Warning of Harmful Events and Dissemination of Public Alerts

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### ABSTRACT

Operational systems developed to monitor and forecast water quality can play a key role to counter and reduce the impact of harmful water quality events. Through these systems, many of the steps required to provide relevant information to the water quality manager can be automated, reducing the lead time required for a warning to be issued, as well as the potential for human error. The systems can also facilitate the routine dissemination of water quality forecasts to relevant parties in order to trigger early warnings or crisis response. This paper outlines some general characteristics of such water quality forecasting systems, focusing on the various elements from which such systems are composed. In addition, examples of existing systems to forecast bathing water quality and harmful algae blooms are provided as illustration. Such systems are either in a development stage (bathing water quality) or already used in operations (harmful algae blooms).

### Keywords

Operational systems, early warning, harmful algae bloom, bathing water quality.

### INTRODUCTION

Circumstances change, events happen. Every water authority or water manager likes to know the consequences of and the options for measures to be taken, as he/she is required to (re)act timely on changes or events. When faced with such events related to, for example, bacterial contamination or harmful algal blooms, this timely reaction can be crucial to decrease or avert the impact on public health, industry and local ecology.

Whether these water quality related events occur due to human influences or have natural causes, a shared characteristic is that the onset is usually rapid and unforeseen, and the time available to take preventive measures is limited. To facilitate operational management to reduce the impact of such events in both coastal and inland waters, there is an increasing demand for detailed real time water quality monitoring and information. In addition, timely dissemination of the relevant information to key stakeholders may be important to achieve an adequate response. Operational systems developed to monitor and forecast water quality can play a key role in achieving the above. Through these systems, many of the steps required to provide relevant information to the water quality manager can be automated, reducing the lead time required for a warning to be issued, as well as the potential for human error. These systems can also facilitate the routine dissemination of water quality forecasts to relevant parties in order to trigger early warnings or crisis response.

This paper deals with operational water quality systems developed with the aim of water quality forecasting and dissemination of forecast results. It will do so by focusing on generic system characteristics, as well as example applications setup to forecast harmful algal blooms and bathing water quality.

**Reviewing Statement:** This short paper has been fully double-blind peer reviewed for clarity, relevance and significance.

## WATER QUALITY FORECASTING SYSTEMS

In Madsen et al. (2000) the primary elements of a forecasting system are outlined from the perspective of flood forecasting. A number of elements are distinguished in this case; (i) a real time data acquisition system for observed meteorological and hydrological conditions,(ii) hydrological and hydraulic models for simulation, (iii) a system for data processing and process control, and (iv) a system for updating and data assimilation. Augmenting these elements for a water quality forecasting system would add; (i) real time data acquisition for observed water quality conditions, and (ii) water quality models for simulation. Following Werner et al. (2004), the outline described by Madsen et al. (2000) reflects a model centric approach to forecasting systems. A different approach described by Werner et al. (2004) places the data process central to the system (data centric), in which case data management can be considered an additional element of a water quality forecasting system (v). From the requirement to provide information to external parties, a sixth and final element may be added: (vi) a system to disseminate forecast results to user groups. These six elements are illustrated in Figure 1, where the blue and orange arrows indicate data flows.

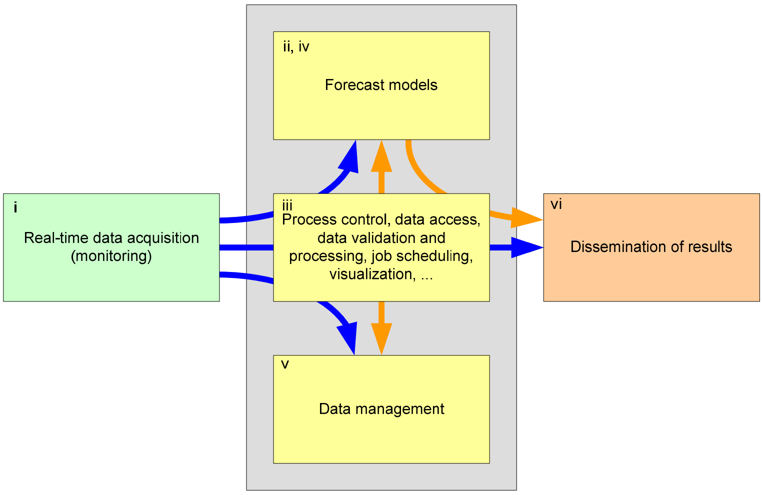


**Figure 1. Elements of a water quality forecasting system**

### Data centric forecasting systems: Delft-FEWS

Central to the elements indicated in Figure 1 is a data processing and process control system (iii). For the operational water quality systems described in this paper, the Delft-FEWS ("Flood Early Warning System") was used and provides this functionality (Werner and Heynert, 2006). Delft-FEWS is a proven, state-of-the-art, real time software infrastructure for operational water management and forecasting. The system is a sophisticated collection of data centric modules designed for building an operational water management system customized to the specific application. The philosophy of the system is to provide an open shell system for managing the operational management process. This shell incorporates a comprehensive set of general data handling utilities, including extensive data import functionality (i). The modular and highly configurable nature of the system allows it to be used effectively both in rudimentary systems and in highly complex systems utilizing several simulation models. Delft-FEWS can be driven as a fully automated distributed client-server application, where tasks can be carried out in a scheduled mode (Gijsbers et al. 2008).

The heart of the Delft-FEWS forecasting system is formed by the central database (v). The focus of the database is on the management of time series data, both at equidistant and non-equidistant time steps, with time series being either point, vector, raster or polygon data. All components of the system communicate through this central database, with requests for data retrieval and storage being handled by a data access module (Werner et al. 2004). The Delft-FEWS system provides an open interface to model integration (ii, iv). Through this XML based exchange interface dynamic data is passed to and from the models. For each of the models run by the system, an adapter has been developed that picks up the XML formatted data and metadata and transforms this to the native formats required by the model. The data management and process control units facilitate model state management. An extensive list of models is supported this way (Deltares, 2011). To disseminate forecast results and monitoring data to external parties, Delft-FEWS provides a range of functionalities, ranging from simple data export to automated e-mailing and generation of web server content (vi).

## EXAMPLE: BATHING WATER QUALITY FORECASTING SYSTEM BASED ON DELFT-FEWS

The 2006 Bathing Water Quality Directive issued by the European Union requires member states to monitor the water quality at both coastal and inland recreational beaches (European Commission, 2006). Operational water quality management systems can play an important role in providing accurate and timely information about the bathing water quality to beach operators and the public at large, and to move towards a more pro-active approach to bathing water quality management. To demonstrate this principle, Deltares supported the UK Environment Agency (EA) in operating a pilot system based on Delft-FEWS throughout the 2009 bathing season. For a number of pilot beach sites, daily bathing water quality forecasts were run and summarized forecast bulletins were issued to selected end-users. In Figure 2 specific aspects of this system are shown in relation to the general system elements outlined in Figure 1.

Forecast results were disseminated to selected end-users by means of automated e-mail bulletins. The e-mail bulletins provide a concise summary of the foreseen bathing water quality conditions, intended for beach operators. An example of such an e-mail bulletin is shown in Figure 3.

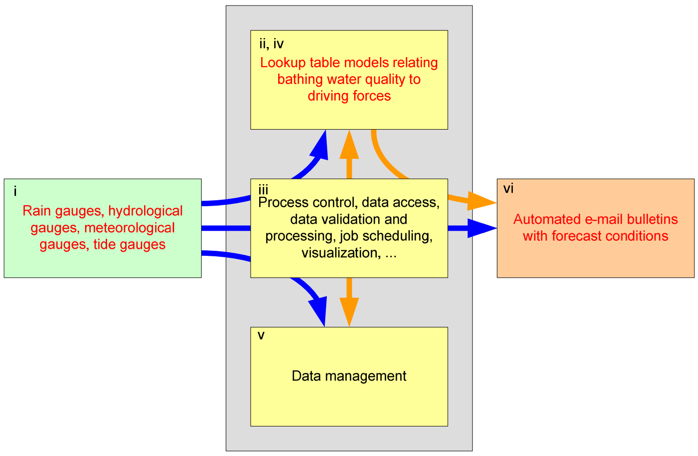


**Figure 2. Elements of a water quality forecasting system to forecast bathing water quality**

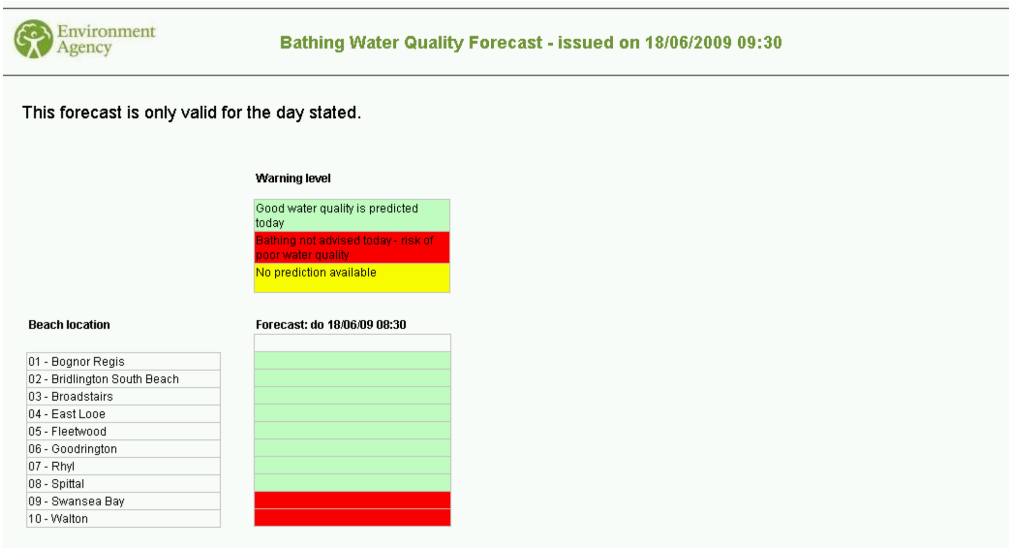


**Figure 3. Example of e-mail bulletin disseminated during trial period**

The modeling framework run from this system consists of a series of lookup table models relating adverse bathing water quality to driving forces such as precipitation, river discharge and tidal conditions at sites of interest. These relations were derived by statistical analysis of a available measurement data. Given the limited availability of real time water quality measurements required to drive complex process models, and the nature of local bathing water quality issues in relation to local discharge events and flow conditions, this can be a beneficial modeling methodology. The models provide a lead time of one day.

## EXAMPLE: REAL-TIME FORECASTING OF HARMFUL ALGAE BLOOMS BASED ON DELFT-FEWS

Harmful algae blooms are an increasing problem in coastal waters worldwide. In the Dutch coastal waters, harmful algal blooms of Phaeocystis are believed to have caused mass mussel mortality in the aquaculture area Oosterschelde in the recent past Peperzak and Poelman (2008). To provide early warnings to the aquaculture industry and other stakeholders, an operational forecasting system for the North Sea has been developed in the Delft-FEWS environment (Blauw et al., 2010; Van der Woerd et al., 2010). The system is currently run operationally by the Rijkswaterstaat ("RWS", the Dutch Ministry of Infrastructure and the Environment). For an extensive description of a similar system in SE Asia, see Weerts et al. (accepted).

The system combines model forecasts using dedicated process models for transport and water quality in the North Sea with in-situ measurements and remote sensing images of chlorophyll-a. The model component of the system provides forecasts of up to two days, while the remote sensing images are used for verification of the current conditions. In Figure 4 specific aspects of this system are shown in relation to the general system elements outlined in Figure 1. Forecast results are disseminated by means of web based bulletins. These bulletins are issued twice weekly during the spring bloom season, and combine model forecasts with remotely sensed images and an expert analysis to interpret results. See Figure 5 for an example of output from the system.

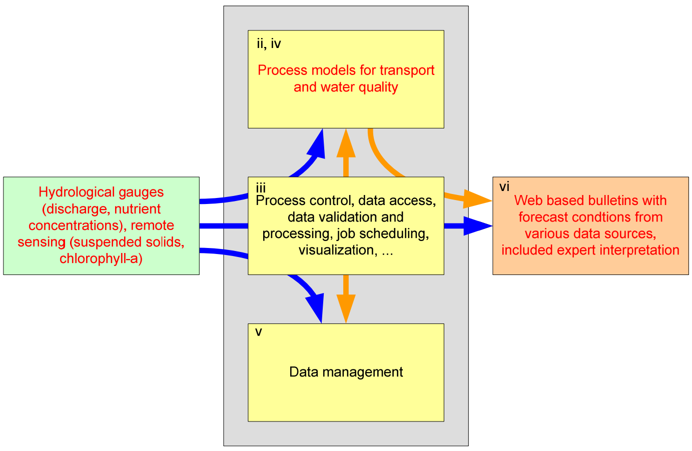


**Figure 4. Elements of a water quality forecasting system to forecast harmful algae blooms**

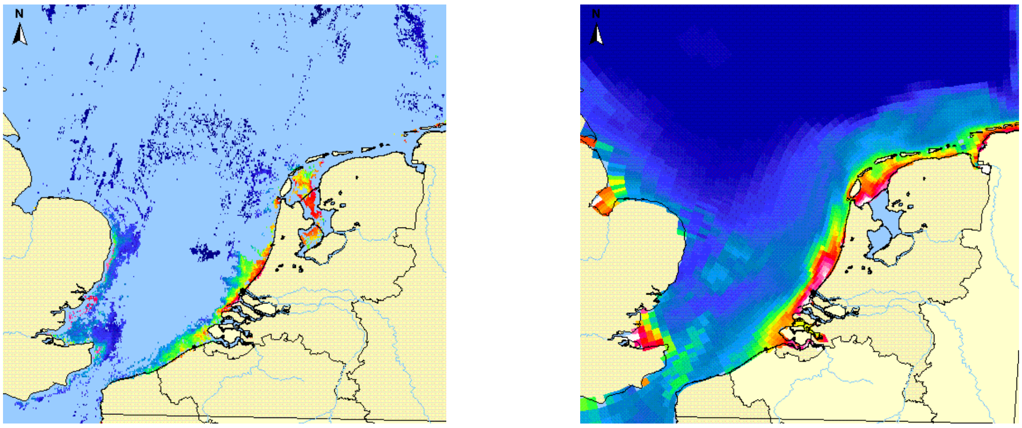

**Figure 5. Remotely sensed (left) and modelled (right) chlorophyll-a from the algae bloom operational system**

## CONCLUSIONS

In this paper examples of operational water quality forecasting systems are described. Whereas these systems differ among others in their goal (bathing water quality vs. harmful algae blooms), in the modeling methodologies used (statistical lookup models vs. process modeling) and in the methods used to disseminate the forecast results (e-mail vs. web based), they share the same generic, common building blocks and consist of similar elements.

Both applications were developed using the same generic forecasting system, the Delft-FEWS. While Delft-FEWS was originally developed with the aim of flood forecasting, the package also proved very useful to develop water quality forecasting systems. Extending the applicability of Delft-FEWS towards water quality is an ongoing process, of which the case-studies described in this paper are work-in-progress components.

Early warning of different phenomena also allows for the investigation of different ways to disseminate alerts to end-users, and to determine the best method and the appropriate level of information for each user group. In the bathing water quality example, forecast results are summarized at a very basic level for non-expert end-users, whereas in the harmful algae bloom example the system was designed to provide more elaborate forecast bulletins to expert end-users. Whether the level of information is adequate and the format of the bulletins is appropriate is something to evaluate with these end-user groups.

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