

Korea Environmental Policy Bulletin

Water Quality Forecasting System

CONTENTS

I. Background	01.
II. Concept and Examples of the Water Quality Forecasting System	02.
2.1 Concept of the Water Quality Forecasting System	
2.2 Overseas cases for water quality forecasting	
III. Current status of the water quality forecasting system	04.
3.1 Overview of the Water Quality Forecasting System	
3.2 Establishing a water quality forecasting model	
3.3 Operating water quality forecasting system	
IV. Outcomes	08.
4.1 Case of Seungchon Weir, Yeongsan river (September 2011)	
4.2 Case of Changnyeong-Haman Weir, Nakdong River (September 2013)	
V. Future Policy Strategies	

I. Background

The Ministry of Environment and the National Institute of Environmental Research has been running the Water Quality Forecasting System at 16 weirs of the four major rivers since 2012, after conducting test-operation over the Sejong Weir segment since August 1, 2011. The Water Quality Forecasting System is a method of forecasting changes to water quality and reporting the result using numerical modeling based on pollution source, water quality assessment data, hydro-meteorological data, and weather forecasting data ¹⁾. Currently, it provides water quality forecast services on water temperature and Chlorophyll-a ("Chl-a") of 16 weirs of the four major rivers for the next week.

From 2009 to 2012, the Korean government conducted the Four Major Rivers Restoration Project to prevent floods and droughts in the four major rivers - Han river, Nakdong river, Geum river, and Yeongsan river and to restore the water quality and ecosystem. As part of the project, 16 weirs were constructed along the four rivers to secure 8 tons of water, to maintain the water levels of the upper regions and to prepare against extreme droughts²⁾. The Water Quality

1) Ministry of Environment. August 30, 2011 Forecast water quality as weather forecast. The Water Quality Forecasting System first introduced in Korea. Press Release

Forecasting System was introduced to detect the changes of the river water quality, and to enable proactive management. The results of water quality forecasting are quickly disseminated to relevant organizations, including agencies that operate dams and weirs, water intake facilities and DWTPs (Drinking Water Treatment Plants), and sewage and wastewater treatment plants. Relevant bodies in turn can adjust their water management processes under the

optimum conditions. In addition, the water quality forecasting system can predict changes to water quality according to different water management scenarios, and water quality managing bodies can use the outcome of the scenarios to derive an optimal alternative for each circumstance³⁾.

This paper will look at the components and operating structure of the Water Quality Forecasting System, outcomes, and future strategies.

II . Concept and Examples of the Water Quality Forecasting System

2.1 Concept of the Water Quality Forecasting System

The Water Quality Forecasting is a method of presenting changes in water quality according to changes in the weather conditions and pollution sources, based on diverse observed data including hydrological, hydraulic,

and meteorological data and state-of-the-art water quality forecasting technologies. Water quality forecasting is rooted in water quality modeling, which simulates the water quality of rivers based on the information of the hydrological/hydraulic conditions and pollution source of the river. Water quality modeling focuses on analysis of water quality at normal times, such as the impact of river maintenance

Table 1 : Comparison of water quality modeling and water quality forecasting⁴⁾

	Water quality modeling	Water quality forecasting
Features	Simulating complex changes to water quality in detail	Forecasting changes to water quality in the future in a stable and effective manner
Simulation conditions	Water quality conditions at normal times	Water quality conditions in an abnormal event
Simulation period	Short–long term	Short–middle term
Usage	<ul style="list-style-type: none"> - Provide water quality data needed to operate the TMDL (Total Maximum Daily Load) - Interpret water quality to preserve river ecology habit or establish alternative habitat - Provide data on water quality environment needed to restore river - Evaluate the impact of hydraulic structures including dams, floodgates, and dikes on water quality 	<ul style="list-style-type: none"> - Provide water quality Caution or Warning to waterintake facilities and the DWTPs in the event of water quality accidents - Predict algal proliferation and provides early warning in case of eutrophication - Prepare the management plan of turbidity flows induced by flooding

2) Ministry of Environment and Korea Environment Institute. 2009. Four Major River Restoration Project of Republic of KOREA. KEPB Issue 3, Volume VII, 2009

3) Ministry of Environment. August 30, 2011, op. cit.

4) Seo, I.W. and Choi, N.J. 2007.1. Water Quality Modeling and Water Quality Forecasting. J. KSCE, v.55(1), pp.57-64

project on water quality or the improvement in water quality achieved through water quality management policies. On the other hand, water quality forecasting focuses on simulating water quality in an abnormal event that persists for a short to medium-term period, such as a water pollution accident or eutrophication (Table 1). In particular, water quality forecasting detects the impact of the temporary water deterioration on water use, in advance, and helps to take appropriate actions by water management organizations and water user.

Water quality forecasting proceeds in the order of (1) collecting and analyzing real-time observation data; (2) predicting future water quality; and (3) reporting the forecasting result and establishing measures to manage water quality. Above all, the observation data on hydrological/hydraulic condition, pollution sources and water quality are collected in the form of time series. Collected data are verified to check for missing values and outliers. Second, the forecasting of future changes in water quality is undertaken based on the collected data. To obtain an accurate forecasting of water quality, it is essential to understand the trends and history of water quality at the target site and establish a reliable water quality simulation model. Finally, water quality forecasting data should be created based on the water quality forecasting result, and then reported to water users such as water intake facilities, the DWTPs, fisheries and farms, waterborne traffic service providers, leisure facilities, and the public. When incidents occur that might affect water quality, or water quality deterioration is expected, bodies in charge of water management can select and execute an appropriate action for pollutant disposal, or an appropriate operation strategy for water facilities⁵⁾.

5) Ibid.

6) National Institute of Environmental Research. May 2011. Establishment and Research of Operation Plan (draft) of Water Quality Forecasting System

2.2 Overseas cases for water quality forecasting⁶⁾

■ HAB-OFS of the NOAA, US

The NOAA (National Oceanic and Atmospheric Administration) is running the HAB-OFS (Harmful Algal Bloom Operational Forecast System) to early detect HABs (Harmful Algal Blooms), also called red tide, and to predict future HAB occurrences. HAB-OFS of the NOAA provides information in the Gulf of Mexico about the occurrence of HABs and their anticipated movements, location and size. To forecast the occurrence of algae over wider areas, various data is used including satellite images, on-site measurement data, a water-quality predicting model, public health report, and buoy data etc. In particular, frequent observation is necessary to evaluate the state of algal proliferation conditions, areas, and their moving path. The report on the HABs contains information of their potential effect for the next 3-4 days. When their occurrence is confirmed, the report is released twice a week, and during other times it is released once a week. The reports on HABs can be accessed on the Internet, and additional analysis data is provided to state governments and coastal management agencies.

■ Water quality alert system for the Rhine in Europe

The Rhine river provides water resources to 170,000 km² of watershed over 6 countries. Approximately 20 million people use it as a source of potable water. The Rhine is also used as one of Europe's main traffic routes, and it is a river into which a significant amount

of sewage flows. In 1986, a chemicals factory was on fire in Sandoz, near Basel, Switzerland, and an enormous amount of toxic chemicals drained into the Rhine. Later in 1987, countries along the Rhine established the ICPR (International Commission for the Protection of the Rhine against Pollution) Those countries agreed to the Rhine Action Program (RAP), which would reduce the influx of pollutants into the river, and to restore salmon runs by 2000. The RAP also included an improved water quality alert system and management system of transboundary chemical movement.

In particular, the ICPR established the WAP (Warning and Alarm Plan) to prevent damages from industrial activities, main traffic, and leakage of toxic chemicals, and investigate the accidents. The Rhine Alarm Model was materialized at the 8th Rhine Ministers' Conference, which was co-hosted by the ICPR and the CHR (Commission for the Hydrology of the Rhine

watershed) in 1999. Since then, a model has been developed to calculate the time of flow of the leaked pollutants into the downstream of Rhine river, which is a key element of the WAP.

The water quality forecasting model for the Rhine's WAP covers the whole Rhine River basin from Bodensee Lake to the North Sea. From the warning posts which are set out along the Rhine, the water quality of the main stream and tributaries is observed, and when an accident breaks out, the post sends out a report to the other posts across the downstream. If water quality is severely threatened by an accident, the closest post will send out an alarm or warning. Using the water quality model, it is possible to analyze pollution sources, the diffusion potential and the discharged amount. The arrival time of pollutants can be calculated with an accuracy of 89%, and pollutant concentration can be predicted with an accuracy of 95%.

III . Current status of the water quality forecasting system

3.1 Overview of the Water Quality Forecasting System

The water quality forecasting system has been operating for two water quality parameters, chlorophyll-a ("Chl-a") and water temperature, at 16 weirs and major sites of the four major rivers since January of 2012 (Fig. 1). The water quality forecasting can be classified into two time frame: short-term forecasting, which predicts changes to water quality over the next few days, and long-term forecasting for the next few months or the year. Currently, a seven-day short-term forecast is provided for the main stream of four rivers twice a week (at 5 pm every Monday and Thursday).

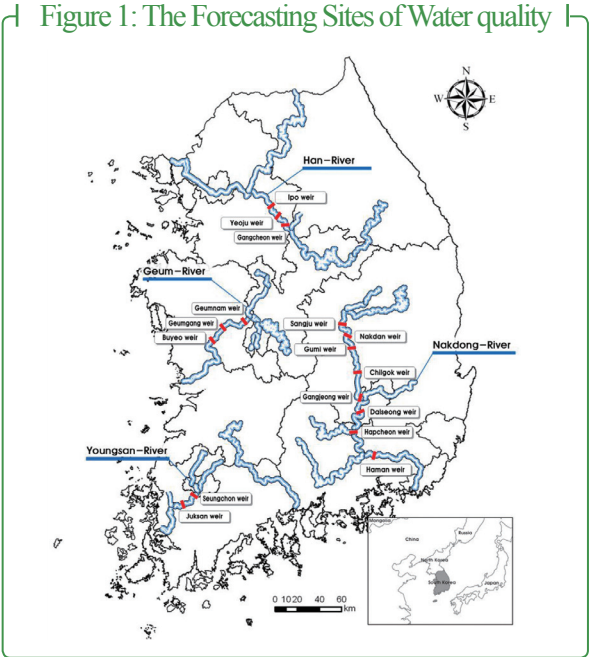


Figure 1: The Forecasting Sites of Water quality

3.2 Establishing a water quality forecasting model

As the short-term water quality forecasting models for the main stream of four rivers, the HSPF (Hydrological Simulation Program - Fortran), a basin model, and the EFDC (Environmental Fluid Dynamics Code), a hydrodynamic and water quality model were adopted. The HSPF model can simulate hourly, and in particular, can predict water temperature with a relatively high degree of accuracy. The HSPF model was applied to the upstream of Paldang lake, Han river basin and other basins at other three major rivers. HSPF model can calculate the flow, water temperature and water quality from basins to the main river streams and the result is sent to the EFDC. The EFDC model, a river water quality model, can show stable simulation results at the conditions where rivers become dry during the dry season and river flow is discontinuous due to the weirs. The EFDC model was established at Chungju Dam - Paldang Dam (Namhan river) and Cheongpyeong-Paldang Dam (Bukhan river), in Han river basin. For Nakdong, Geum, and Yeongsan river basins, the EFDC model was constructed at Andong Dam - Nakdong R. estuary, Daecheong Dam - Geum R. estuary, and Woochi - Yeongsan R. estuary, respectively. To improve the resolution of water quality forecasting, grids of the EFDC model were structured as densely as possible, and for the weir segment, the density was particularly strengthened.⁷⁾

As previously described, a variety of observation data is necessary for water quality forecasting: weather measurement data provided by the KMA (Korea Meteorological Administration), data of water quality monitoring program provided by the Ministry of

Environment, water level/flow and dam/weir operation provided by the MOLIT (Ministry of Land, Infrastructure and Transport). These basic data are automatically collected by the water quality forecasting system and converted into the format necessary to run the water quality forecasting model⁸⁾. Notably, the water quality forecasting system is automatically connected to the TMS (Tele-Metering System), which measures the concentration and flow of pollutants discharged from approximately 700 point sources across the country. As a result, the water quality forecasting system can identify the flow, pollutants' concentration, and their load from each point source and those data are used as input for the water quality forecasting model. Meanwhile, the regional and global weather forecasts produced by KMA are also automatically collected by the water quality forecasting system, and input data for weather forecasts is created by combining these two results from weather forecasting models.

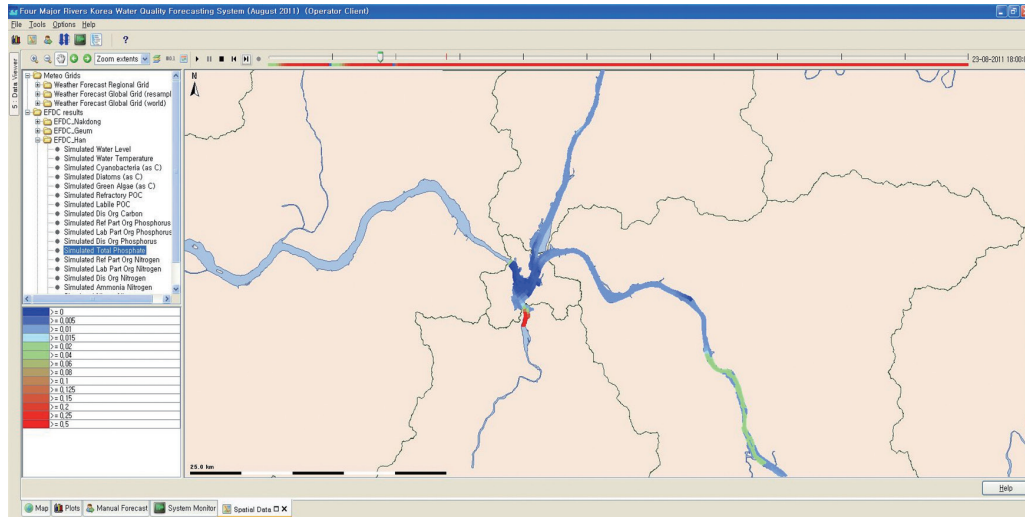
By using the input data which have been collected and verified by the water quality forecasting system, the basin model simulates changes to the flow and water quality of tributaries. Results from the basin model are converted into input data for the water quality model. Finally, water quality model runs and water quality forecasting data are created. At this moment, the data assimilation is included to improve the forecasting accuracy.

Results of the water quality forecasting system can be output in various forms depending on the purposes. For example, forecast results by the hour in major spots can be displayed, or spatial distribution of water quality items can be displayed (Fig. 2). Finally confirmed results are published in the form of average daytime (09:00 am - 6:00 pm) water temperature and Chl-a concentration.

7) Kim, K.H. 2011.6. Water Quality Forecasting and Management of River Water Quality. *Water for Future*, v.44 (6) pp.8-10.

8) Ibid.

Figure 2: T-P concentration display at Paldang area in WQ Forecasting System



3.3 Operating water quality forecasting system

Based on the water quality forecasting results on Chl-a concentration, frequency and duration of the exceedance of water quality standard, and Cyanobacteria cell density, the water quality management levels are divided as follows: "Attention", "Caution", "Warning", and "Serious", and these are determined by Chl-a concentration, excess rate, duration

period, and Cyanobacteria cell density (Table 2). Here Cyanobacteria cell density refers to the total number of cells in *Anabaena*, *Aphanizomenon*, *Microcystis*, and *Oscillatoria*. The first level for water management is announced when Chl-a concentration exceeds 70mg/m² and it is expected to increase. In the meantime, when Cyanobacteria cell density is less than 10,000 cells/mL, the minimum Chl-a concentration for announcing each water quality level is alleviated to 70mg/m³, 120mg/m³, 160mg/m³, and 200mg/m³, respectively. For any

Table 2 : Criteria for water quality management level

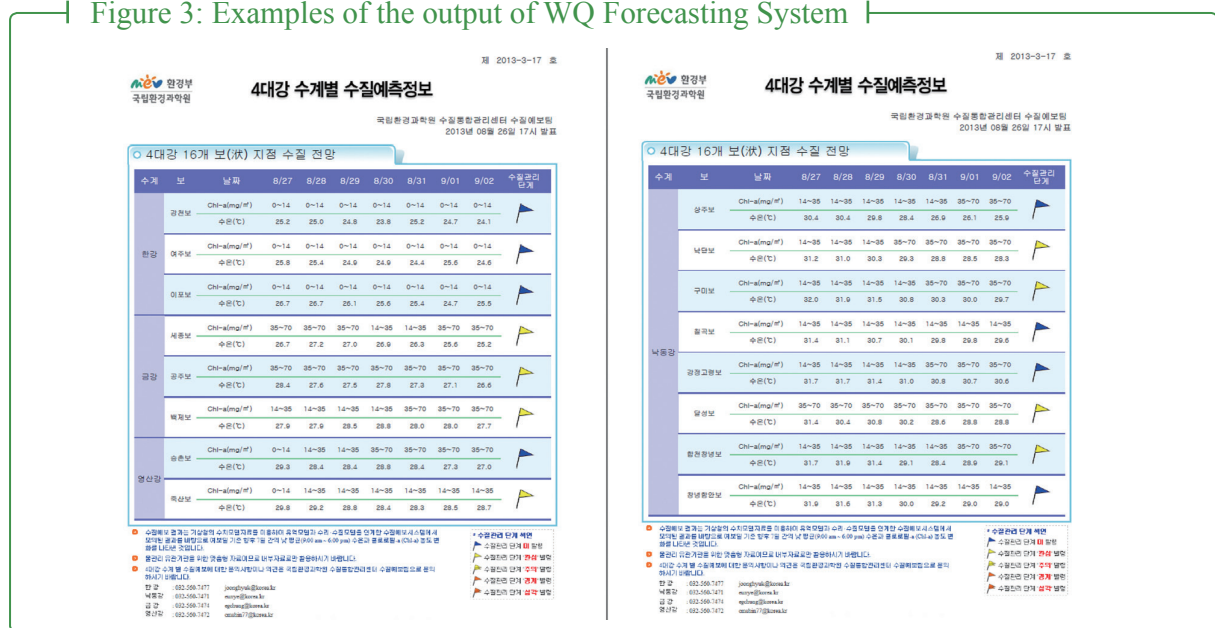
Chl-a concentration forecast (mg/m ³)	Cyanobacteria cell density (cells/mL)			
	Less than 10,000	More than 10,000	More than 50,000	More than 2x10 ⁵
More than 35mg/m ³ 4 days out of 7	-	Attention	Caution	Warning
More than 70mg/m ³ 4 days out of 7	Attention	Caution	Warning	Serious
More than 105mg/m ³ 4 days out of 7	Caution	Warning	Serious	Serious
More than 140mg/m ³ 4 days out of 7	Warning	Serious	Serious	Serious
More than 175mg/m ³ 4 days out of 7	Serious	Serious	Serious	Serious

concentration of Chl-a in excess of 10,000 cells/mL, "Attention" is announced.

Water quality forecasting information is provided to related institutes via various media, including website and SMS (short message service) (Fig. 3). When a countermeasure is required to strengthen water quality management after the water quality management level

is announced, a notification will be sent to relevant institutions such as Basin Environmental Offices. In particular, when the management level is "Warning" or "Serious", scenario analysis results for water quality improvement are provided to the relevant bodies and submitted to the Water Quality Management Committee in charge of each water system.

Figure 3: Examples of the output of WQ Forecasting System



The Water Quality Management Committee is a consultation body established under the "Regulation on Water Quality Forecasting and Counter-measures" (Instruction No. 1053, Ministry of Environment, June 28, 2013), to promote joint efforts by organizations that manage water quality. Specifically, the Water Quality Management Committee consults, adjusts, and makes decisions regarding countermeasures at each step, water quality management polices for each water system, dam/weir operation plan, adjustment of opinions among related bodies, and emergency contacts. The Water Quality Management Committee consists of the national government, experts, local governments, and related agencies. For example, the

Water Quality Management Committee of Han River Basin includes the following members:

- National government: One official each from the Han River Basin Environmental Office, Wonju Regional Environment Office, Han River Environment Research Center, Ministry of Land, Infrastructure and Transport, and Han River Flood Control Office.
- Experts: Two water quality management experts recommended by the Ministry of Environment, two water quantity management experts
- Local governments: One official each from Seoul Metropolitan City, Incheon Metropolitan City, Gyeonggi Province, Gangwon Province, and

Chungcheongbuk Province

- Organizations concerned: One staff member each from Korea Environment Corporation, K-water, Korea Hydro & Nuclear Power, and Korea Rural Community Corporation.

For example, when the occurrence of algae is expected in the river, the Water Quality Management Committee can make decisions as follows, to prevent water use from

being affected. Bodies responsible for managing water quality step up their efforts to monitor water quality and pollution source, and bodies responsible for managing rivers can open the operational weirs and the gates of dams at the upstream so that algae can be flushed to downstream. Intake facilities can run aeration around intake towers, and the WWTPs (Wastewater Treatment Plants) can increase advanced treatment for T-P (Total Phosphorus).

IV. Outcomes

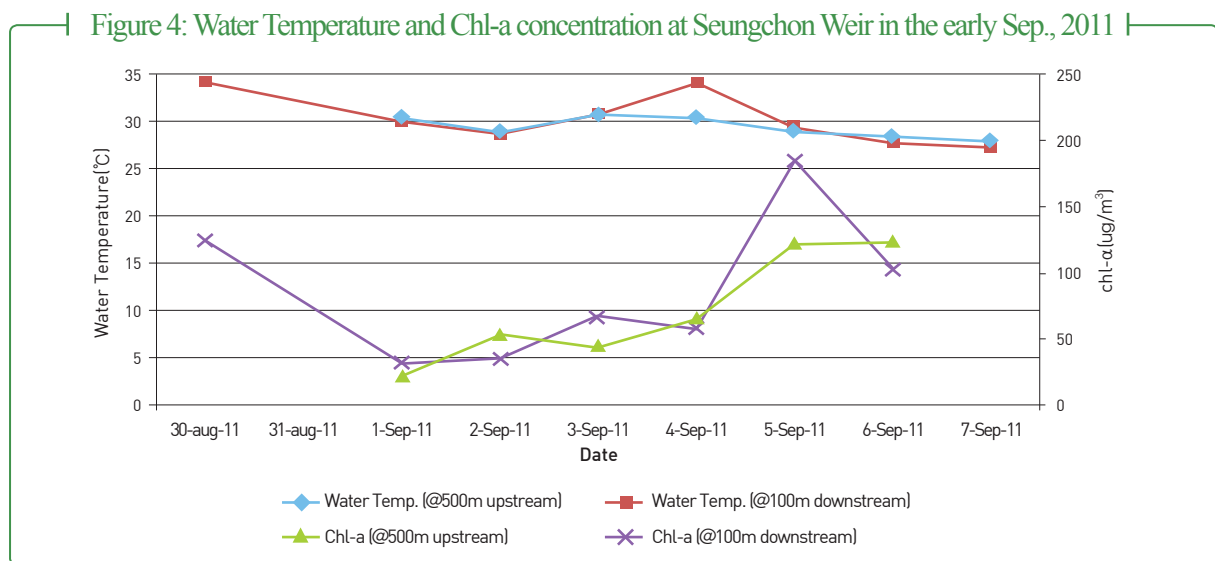
While not much time has passed since the water quality forecasting system was adopted, proactive measures to manage water quality have been made

by adjusting the operational conditions of dams in the upper region and operational weirs, or intensifying enforcement on water pollution sources, as below.

4.1 Case of Seungchon Weir, Yeongsan river (September 2011)

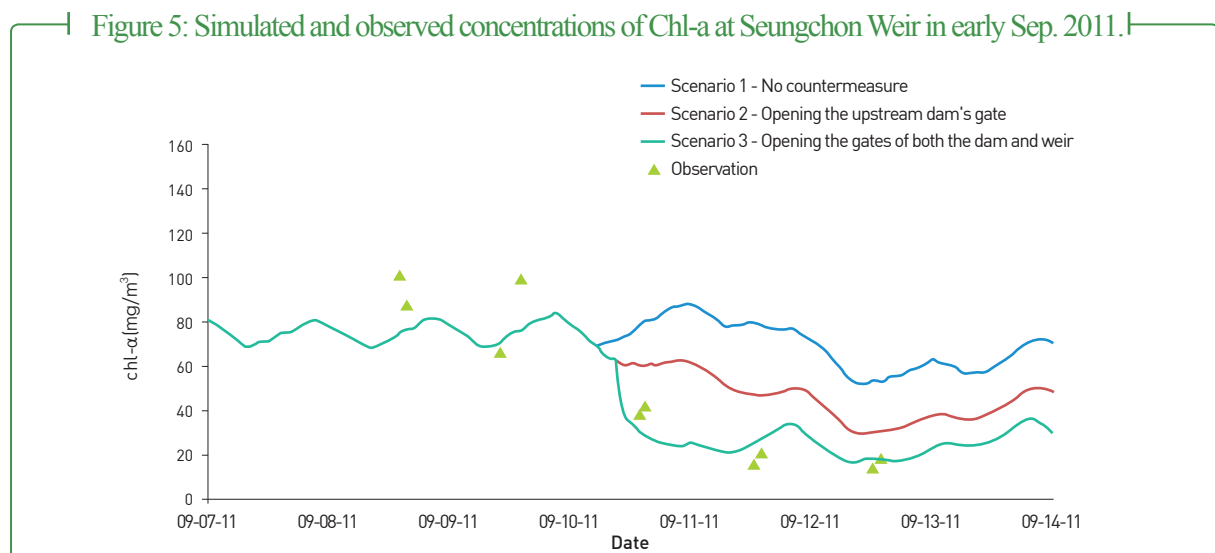
In early September of 2011, high temperatures persisted for more than 10 days in the Yeongsan river basin after rainfall finally stopped after a long period of

rain in the summer. The water level for the Seungchon Weir segment was maintained at around 6-7 m while Juksan weir was open. As the temperature rose to greater than 30°C, the Chl-a concentration of Seungchon Weir rose up to 123.6 mg/m³ (Fig. 4).



The Ministry of Environment asked the Yeongsan River Agricultural Dam at upstream to increase discharge flow so that algae could be diluted and flushed downstream. Accordingly, water equivalent to 3.3% of the total water storage capacity of the agricultural dam was discharged for four days, starting at 6 pm, September 9, 2011, and Seungchon Weir was open in the morning of September 10 when flux from the dam arrived at the weir, lowering the

water level down to 4.5 meters. According to the analysis, the additional discharge from the agricultural dam could reduce the Chl-a concentration at the river by 37 % compared with no action. If the agricultural dam and Seungchon Weir were open at the same time, Chl-a concentration was expected to decline to 20 mg/m³ as of September 12. Indeed, Chl-a concentration decreased to 19 mg/m³ after the dam & weir operation (Fig. 5).



4.2 Case of Changnyeong-Haman Weir, Nakdong River (September 2013)

In the summer of 2013, the algal concentration of Nakdong River rose due to lower rainfall than normal years. As a result, days on which water quality management level was announced were gradually increased. Since the "Attention" management level was re-announced for Changnyeong-Haman Weir on August 29, 2013, and "Warning" on September 5, the Nakdong River Basin Environmental Office asked the

National Institute of Environmental Research to estimate the available discharge flow at the weirs and dams in the upper region that could be used to flush algae in the rivers downstream. Water quality forecasting system was used to analyze the impact of the operation of weirs and dams in the upper region on the algal concentration of river, and the scenario for additional discharge was suggested as follows. If the water level for Changnyeong-Haman Weir is reduced from 5.2m to 4.4m, which is the minimum water level for fish ladder, and Namgang dam discharges an additional 28 million tons of water, the algal concentration could be expected to drop by

14% (maximum 29% on daily average). Based on this scenario, Dam-Weir Connected Operation Consultation Committee decided to increase the dam release and Nakdong River Flood Control Office discharged an additional 8 million m³ from Namgang dam in total for three days starting on September 10, 2013.

In addition, according to "Regulation on Water Quality Forecasting and Counter-measures" (Instruction No. 1053, Ministry of Environment, June 28, 2013), Nakdong River Basin Environmental Office requested the organizations concerned to take necessary steps for the management level, and hosted the Water Quality Management Committee on September 11, 2013, establishing the following measures. At the "Attention" level, Gyeongsangnam-Province, cities and counties would jointly carry out efforts to strengthen enforcement on wastewater-discharging facilities, to list and inspect the high-load discharging facilities of organics, total phosphorus and total nitrogen, to strengthen enforcement and

instruction on concentrated animal feeding operations, to lower the effluent standards of environmental infrastructures, to strengthen monitoring for intake facilities and water supply facilities, and to clean the wastes around rivers. Under "Caution" level, city and county governments would lead efforts to check intake facilities and pollution response equipment, to prepare for emergencies related to the water supply, to strengthen monitoring of intake facilities and water supply facilities, and to jointly check environmental infrastructures and wastewater-discharging facilities by related bodies.

As a result, the management level of Cyanobacteria cell density in the Changnyeong Haman Weir segment was reduced from "Caution," its level on September 10, 2013 before the Namgang dam discharge, to "Attention" on September 13, proving that the discharge was effective in reducing Cyanobacteria cell density (Fig. 6).

Figure 6: WQ Forecasting Report for the 8 Weir Sites at the Nakdong R. on Sep. 2013



V . Future Policy Strategies

So far, most of the countermeasures on water quality have been adopted after water quality has already been deteriorated, and scientific review on the effects of the measures on water quality has been insufficient. On the other hand, a water quality forecasting system is an anticipatory water quality management method that scientifically predicts changes to water quality, reviews the effects of water quality measures, and implements optimal measures. Therefore, water quality management based on a water quality forecasting system is an advanced and proactive policy compared to the conventional water quality management. In particular, considering that it covers major rivers and lakes nationwide, it can be regarded as a leading policy that is found in only few other countries.

For successful operation of the water quality forecasting system, it is necessary to improve the reliability of water quality forecasting and the effectiveness of the water quality management measures taken. Above all, to improve the reliability of the water quality forecasting system, the number of site for water quality monitoring program should be increased. And a data assimilation function that prevents the water quality forecasting model from being

disconnected from the reality should be added⁹⁾. Similarly to the weather forecasting system, the reliability of the water quality forecasting system can be enhanced only when a significant investment is made in hardware, including super-computers, as well as in the capacity building of staff members.

To increase the effectiveness of water quality management measures, cooperation among water management bodies is essential. Considering that the IWRM (integrated water resource management) is not fully established in Korea, the current water quality forecasting system can be the cornerstone of the IWRM as it helps promote consultation and decision-making among the water management bodies. Information sharing among the forecasting systems of the bodies that predict flood, drought, and water quality should be encouraged. In addition, a consultation structure should be established on the operation of water infrastructures in regard to water quality forecasting, such as hydro-structures, environmental infrastructures, etc. and it is necessary to strengthen the legal obligations of water management bodies in the area of cooperation according to the water quality forecasting level.

9) Kim, K.H. 2011.6. op. cit.

Published by

- **Ministry of Environment**

Government Complex Sejong, 11, Doum6-Ro, Sejong-City,
339-012, Republic of Korea
Tel. 82-44-201-6568

- **Korea Environment Institute**

215 Jinheungno, Eunpyeong-gu, Seoul 122-706, Republic of Korea
Tel. 82-2-380-7777

- **Written by Dr. Hojeong KIM (Korea Environment Institute)**

ISSN 1976-6246



9 771976 624002