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# Application of CE-QUAL-W2 [v3.2] to Andong Reservoir: Part II: Simulations of Chlorophyll *a* and Total Phosphorus Dynamics

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**The calibrated Andong Reservoir hydro-dynamic module (PART I) of the 2-dimensional hydrodynamic and water quality model, CE-QUAL-W2 [v3.2], was applied to examine the dynamics of total phosphorus, and chlorophyll *a* concentration within Andong Reservoir. The modeling effort was supported with the data collected in the field for a five year period. In general, the model achieved a good accuracy throughout the calibration period for both chlorophyll *a* and total phosphorus concentration. The greatest deviation in algal concentration occurred on 10$^{th}$ October, starting at the layer just beneath the surface layer and extending up to the depth of 35 m. This deviation is principally attributed to the effect of temperature on the algal growth rate. Also, on the same date, the model over-predicts hypolimnion and epilimnion total phosphorus concentration but under-predicts the high concentrated plume in the metalimnion. The large amount of upwelling of finer suspended solid particles, and re-suspension of the sediments laden with phosphorus, are thought to have caused high concentration in the epilimnion and hypolimnion, respectively. Nevertheless, the model well reproduced the seasonal dynamics of both chlorophyll *a* and total phosphorus concentration. Also, the model tracked the interflow of high phosphorus concentration plume brought by the turbid discharge during the Asian summer monsoon season. Two different hypothetical discharge scenarios (discharge from epilimnetic, and hypolimnetic layers) were analyzed to understand the response of total phosphorus interflow plume on the basis of differential discharge gate location. The simulated results showed that the hypolimnetic discharge gate operation (103 ~ 113 m) was the most effective reservoir structural control method in quickly discharging the total phosphorus plume (decrease of in-reservoir concentration by 219% than present level).**

**Key words : Chlorophyll *a*, Total phosphorus, CE-QUAL-W2 model, Andong Reservoir**

## INTRODUCTION

South Korea experienced the heyday of construction of large multi-purpose reservoirs in the 70s and 80s. As of 2007, there are sixteen large multi-purpose dams in operation, and further three more dams under construction. These multi-purpose dams serve the purpose of industrial, agricultural and drinking water supply, flood

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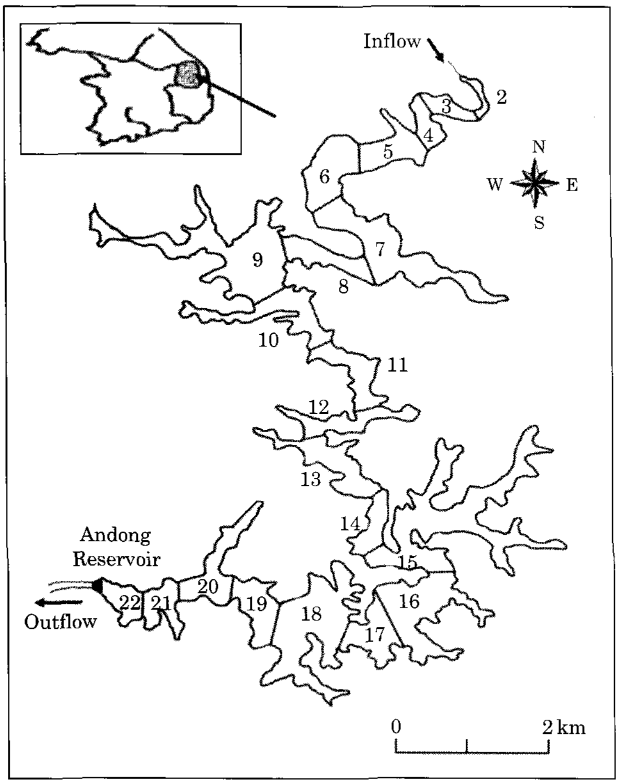


**Fig. 1.** Segments of Andong Reservoir Model superimposed on the Andong Reservoir.

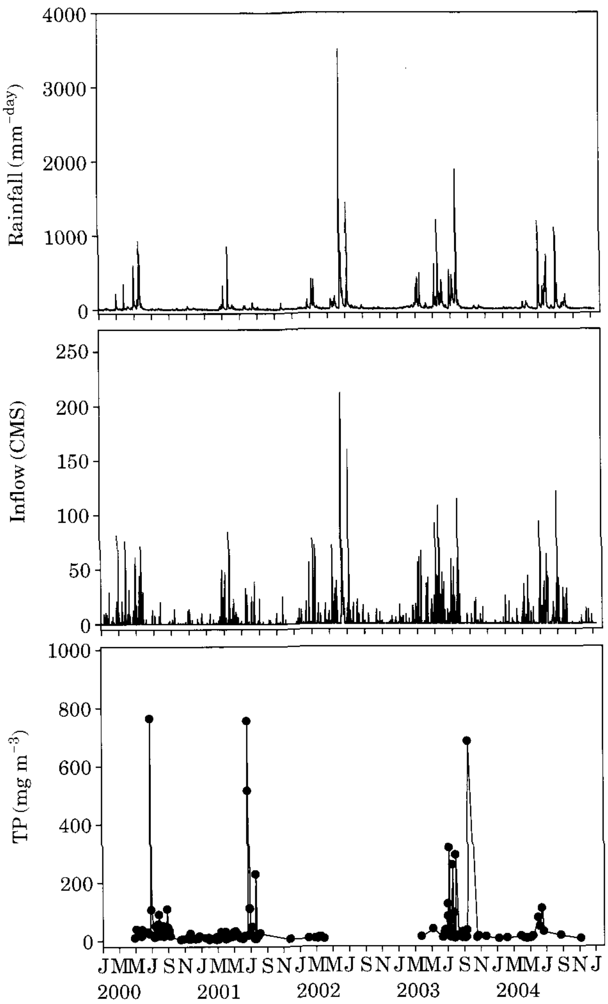


**Fig. 2.** Variations of daily average rainfall, inflow rate and total phosphorus at the main inflow site of Andong Reservoir during the study period (2000~2004).

control during rainy seasons, maintenance flow to the downstream during the drought seasons and generate hydro-electricity (KICT, 2007). However, almost all of these precious freshwater reserves are marred by various problems such as reduction of hypolimnetic and metalimnetic dissolved oxygen, large spate of algal blooms, and cultural eutrophication set off mostly by anthropogenic discharges (Kim *et al.*, 2001; Hwang *et al.*, 2003). Also, during the Asian monsoon season, most of these dams are subject to highly turbid inflow laden with high concentrations of suspended solids and phosphorus. This not only poses a challenge in the compliance and restoration of in-reservoir water quality after the monsoon season but also heightens the risk of eutrophication.

Andong Reservoir (Fig. 1), completed in 1977, is not an exception to these common characteristics of large multi-purpose dam in South Korea. Andong Reservoir is located in the Asian summer monsoon region and it receives almost 2/3$^{rd}$ of its yearly precipitation from late June to August. Even though the watershed is sparsely populated, the major activities carried out are: intensive agricultural practices and higher stock keeping of farm animals (KWATER, 2006). The highly episodic, hydrological event-driven runoff transports and delivers 70~80% of the total yearly loading to Andong Reservoir from those various non-point and diffuse sources (Kim *et al.*, 1997; Heo *et al.*, 1998). Sediments, particulate organic matters, and adsorbed constituents (especially particulate phosphorus adsorbed to clay particles) are primarily transported during the elevated flows or storm events (Johnson *et al.*, 1976; Verhoff and Melfi, 1978; Bilby and Likens, 1979; Sharply and Seyers, 1979; Kennedy *et al.*, 1981). The variation in total phosphorus concentration of the inflow highly corresponds to increase in

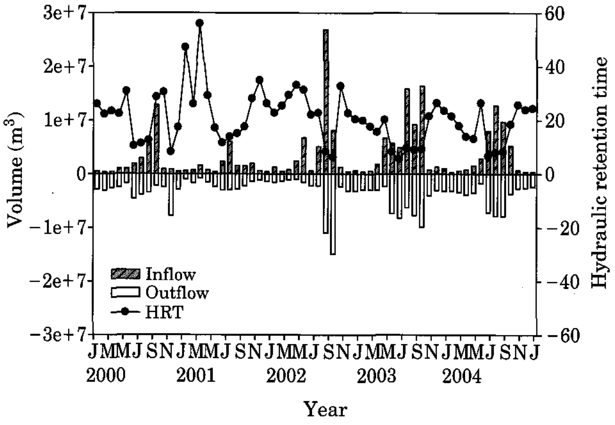


**Fig. 3.** Monthly inflow and outflow water volumes and water retention time for Andong Reservoir (2000~2004).

precipitation (Fig. 2). In addition, the graph also tells us that total phosphorus loading to Andong Reservoir is an intermitted occurring phenomenon rather than a continuous phenomenon.

The monsoon derived runoff enters the warm-monomictic, deep watered (maximum depth 60 m) Andong Reservoir, it forms an interflow as it moves towards the main dam site. The longer residence time (Fig. 3) means that a large part of such phosphorus-loss events driven by the Asian summer monsoon will remain in the reservoir system for sufficient time to contribute to spring/fall biological phosphorus demand (Kim 1998; Kim *et al.*, 2001; Hwang *et al.*, 2003). Algal blooms are almost the yearly occurring phenomenon in the upstream section of Andong Reservoir (KWATER, 2006) and they have also been related to metalimnion dissolved oxygen minima at the main dam site (Park *et al.*, 2006). The seasonal distribution of temperature, turbidity, total phosphorus, and chlorophyll *a* for the year 2003, in Andong Reservoir, is shown in Fig. 4.

In this part of our study, we examine the application of two dimensional (2-D) laterally averaged hydrodynamic and water quality model, CE-QUAL-W2 model [v3.2] in Andong Reservoir by simulating the dynamics of two most important water quality parameters: total phosphorus and chlorophyll *a* concentration. Further, a hypothetical scenario of differential discharge gate location is performed to examine the response of in-reservoir total phosphorus concentration. We hope that this application of CE-QUAL-W2 model in Andong Reservoir would not only help in making better decisions regarding the water quality restoration after monsoon season but also help in the optimum operation of the reservoir.

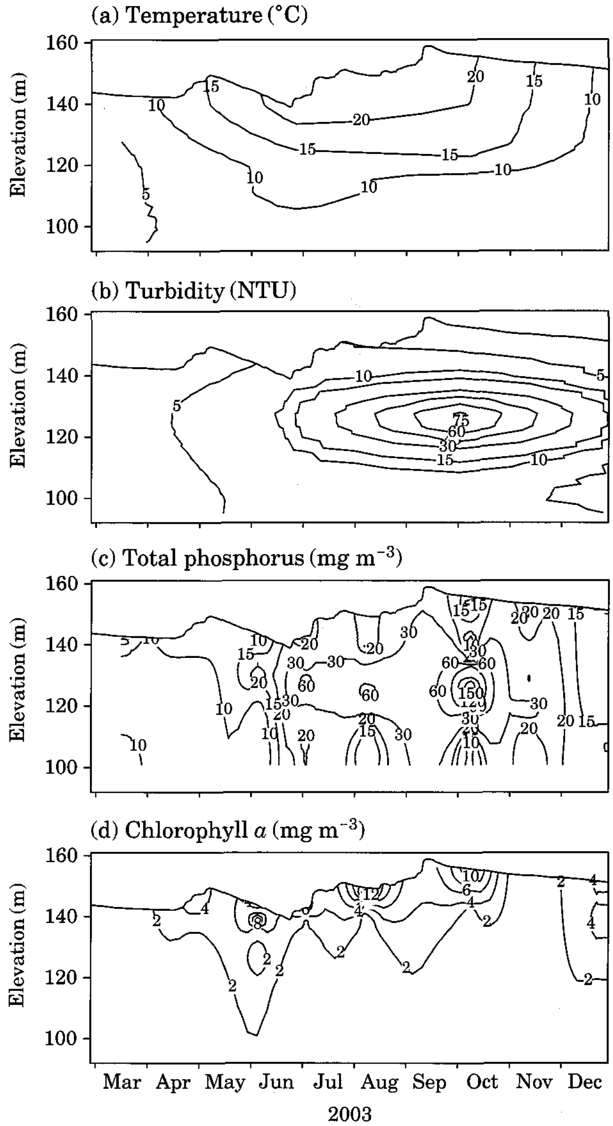


**Fig. 4.** Distribution of (a) Temperature (°C), (b) Turbidity (NTU), (c) Total Phosphorus (mg $m^{-3}$), and (d) chlorophyll *a* (mg $m^{-3}$) for the year of 2003 at the dam site of Andong Reservoir.

## MATERIALS AND METHODS

### 1. Model description

The CE-QUAL-W2 model for Andong Reservoir was developed in several steps. A single main branch model grid consisting 22 segments and 69 layers was constructed based on available lake bathymetry data. Each model cell had an assigned cell width. Segments ranged from 2 km in length to less than 500 meters. A height of 1.0 meter was specified for all the layers. The model domain covers a total distance of about 44.7 km from the dam site up to the riverine zone. The bathymetry data had the error of just 0.3% when compared with the sediment survey storage-capacity curve for the year 1996. The model was calibrated for year 2003, and then verified with the data of remaining years from 2000~2004. Daily input data were specified for upstream inflows, downstream outflows, withdrawals, and climato-meteorological conditions, while data for water quality at the inflow and at the deepest part of the dam site were done at different intervals and frequency throughout the study period.

The CE-QUAL-W2 model, a two dimensional laterally averaged hydrodynamic water quality model, uses a numerical scheme for a direct coupling between hydrodynamic and water quality simulations. In the CE-QUAL-W2 model, the hydrological module drives the water quality module. Thus, the readers are referred to the PART I (Bhattarai *et al.*, 2008) of this study for the further description of the hydrodynamic modules that includes the simulation of hydro-thermal dynamics, dissolved oxygen regime and characteristics of density current in Andong Reservoir.

The water quality module of CE-QUAL-W2 model can simulate 21 constituents. However, as, they are highly inter-connected, and any small changes to one can have a large effect on others. Below is the brief description on phosphate-phosphorus and algae compartments, and for the description of other constituents the reader is referred to Cole and Buchak (1995).

In the CE-QUAL-W2 model, the total phosphorus is treated as pseudo-conservative, even though it's not a conservative constituent. The measurement of total phosphorus includes phosphorus that is contained in dissolved organic matter and algae as well as dissolved orthophosphate. Thus, the total phosphorus concentration computation in the CE-QUAL-W2 model is unaffected by algal uptake, respiration, and other various decomposition processes taking place in the water column.

In the CE-QUAL-W2 model, the algal community is typically represented as a single assemblage or is broken down into diatoms, greens, and blue-greens. The current model formulation now gives the user complete freedom in how many and what kinds of algal groups can be included in the simulation through careful specification of the kinetic rate parameters that define the characteristics of each algal group. However, this version [v 3.2] of the model doesn't explicitly include zooplankton and their effects on phytoplankton or recycling of nutrients.

## 2. Water quality data

The water quality data for concentration of total phosphorus and chlorophyll *a* were recorded at different frequencies and intervals throughout the study period. The inflow was measured for its total phosphorus concentration only. Due to the high flow velocity, the phytoplankton weren't measured. Both the total phosphorus and chlorophyll *a* concentration were measured at various depths from 0~45 m of the main dam section of Andong Reservoir.

The CE-QUAL-W2 model uses algal biomass (mg $L^{-1}$) as carbon as the algal response variable. To convert chlorophyll *a* into algal biomass, measured chlorophyll *a* concentrations (μg $L^{-1}$) were multiplied by a factor of 0.067 (Brown and Barnwell, 1987; Cole and Buchak, 1995) to provide an estimate of algal biomass (mg $L^{-1}$). Literature values were referred to obtain the ranges of values for growth, respiration, excretion, settling, and mortality rates as well as the half-saturation constants in the algal compartment (e.g. Holm and Armstrong, 1981; Bowie *et al.*, 1985; Grover *et al.*, 1999; Rounds *et al.*, 1999; Wallace and Hamilton, 1999; Cole and Wells, 2003; Park *et al.*, 2005; Jung *et al.*, 2007).

The filtered water was used to determine the dissolved phosphorus concentration. Total phosphorus was calculated according to Standard methods (APHA, 1992), using persulfate digestion and ascorbic method. The CE-QUAL-W2 model doesn't directly predict total phosphorus, so a conversion is needed to predict this quantity. First the total organic carbon (TOC) was estimated from the BOD concentration. Then, the arrived TOC was used to estimate concentrations of labile and refractory portions of both dissolved and particulate organic using the following equations (Cole *et al.*, 1999):

$$\text{L-DOM} = \{\text{TOC} \times 0.75\} \times 0.30$$
$$\text{R-DOM} = \{\text{TOC} \times 0.75\} \times 0.70$$

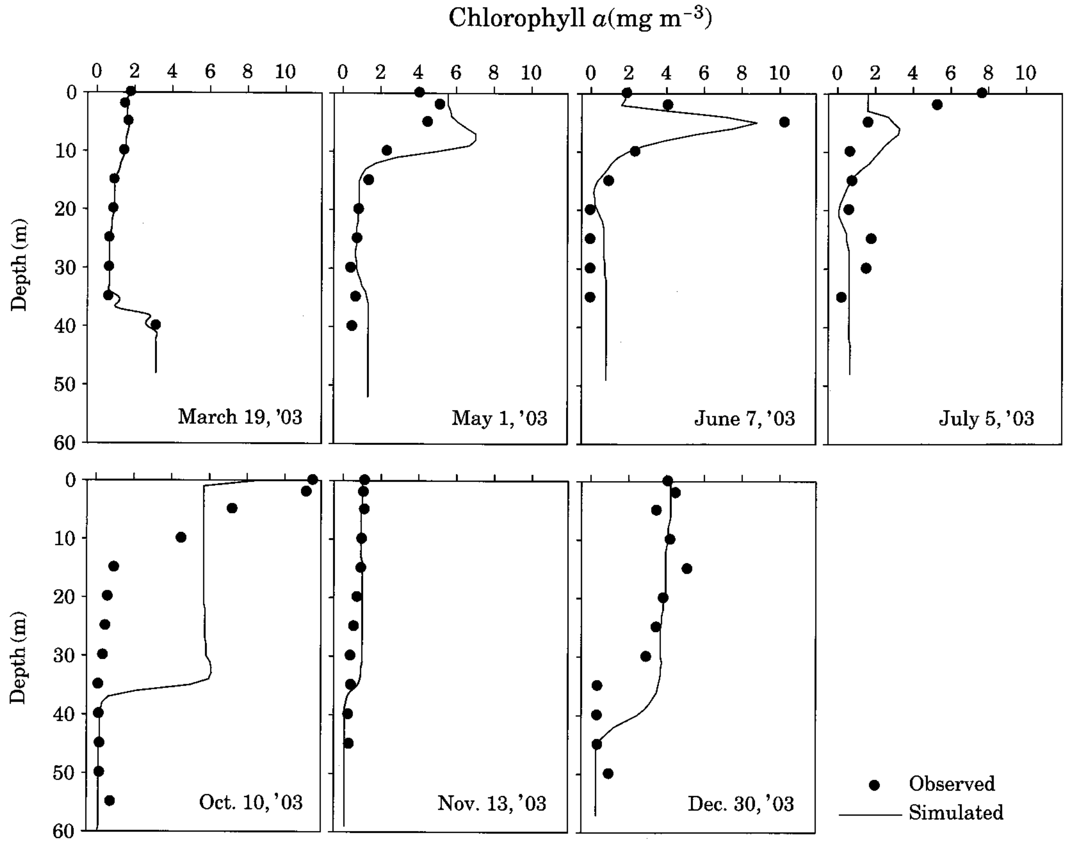


**Fig. 5.** Calibration results of vertical chlorophyll *a* profiles at the main dam site of Andong Reservoir in different seasons.

L-POM={TOC × 0.25} × 0.30
R-POM={TOC × 0.25} × 0.70

## RESULTS AND DISCUSSION

### 1. Chlorophyll *a* dynamics

We started our calibration just with initial condition of algal values originating only at the main dam site and assessed the model's ability to reproduce the general spatial and temporal variation along with size of the algal population. In the Andong Reservoir model, all the present algal species were represented as a single conglomerate by considering that all the species generally obtain most of their nutrients from the water column in a similar manner. Ideally, a comprehensive ecological model could be incorporated into the system to study inter-species competition and co-evolution, but this is precluded by data, time, and resource constraints.

Despite the lack of proper and extensive data regarding the concentration and succession of algae, the model well calibrated the general dynamics of chlorophyll *a* concentration (Fig. 5). The annual algal bloom trend in Andong Reservoir usually starts in late spring and disappears around late fall (KWATER, 2006). However, during the calibration year 2003, just the increase in algal biomass from late April till mid of June was observed and didn't reach the bloom. Slight deviation is seen on the lower epilimnion on 1$^{st}$ May and 7$^{th}$ June. Some of the differences between simulated and measured data can be explained by the variability in the measured concentrations because of the uneven vertical distribution of phytoplankton in the water column. However, the surface algal concentration on 5$^{th}$ July was under-predicted by approximately 6 mg m$^{-3}$. In the CE-QUAL-W2 model, the algal growth rate is computed by modifying the maximum growth rate which in turn is affected by temperature, light, and nutrient availability. Around this time of the year, the reservoir water levels are

**Table 1.** Model parameters used for calibration of chlorophyll *a* concentration.

| Parameters | Variable unit | | Default | calibrated |
|---|---|---|---|---|
| Algae | | | | |
| Growth rate | AG | $day^{-1}$ | 2.0 | 1.8 |
| Mortality rate | AM | $day^{-1}$ | 0.1 | 0.05 |
| Excretion rate | AE | $day^{-1}$ | 0.04 | 0.02 |
| Respiration rate | AR | $day^{-1}$ | 0.04 | 0.06 |
| Settling rate | AS | $mday^{-1}$ | 0.1 | 0.24 |
| Phosphorus half-saturation for algal growth | AHSP | $gday^{-3}$ | 0.003 | 0.005 |
| Nitrogen half-saturation for algal growth | AHSN | $gday^{-3}$ | 0.014 | 0.30 |
| Light saturation intensity | ASAT | $Wm^{-2}$ | 75 | 55 |
| Fraction of algae to POM | APOM | – | 0.8 | 0.8 |
| Lower temperature for minimum algal rates | AT1 | °C | 5 | 6 |
| Upper temperature for minimum algal rates | AT2 | °C | 25 | 16 |
| Lower temperature for maximum algal rates | AT3 | °C | 35 | 25 |
| Upper temperature for maximum algal rates | AT4 | °C | 40 | 30 |
| Lower temperature rate multiplier for minimum algal rates | AK1 | – | 0.1 | 0.1 |
| Upper temperature rate multiplier for minimum algal rates | AK2 | – | 0.99 | 0.99 |
| Lower temperature rate multiplier for maximum algal rates | AK3 | – | 0.99 | 0.99 |
| Upper temperature rate multiplier for maximum algal rates | AK4 | – | 0.1 | 0.1 |
| Phosphorus to biomass ratio | BIOP | – | 0.005 | 0.005 |
| Nitrogen to biomass ratio | BION | – | 0.08 | 0.08 |
| Carbon to biomass ratio | BIOC | – | 0.45 | 0.45 |
| Algae to chlorophyll *a* ratio | ACHLA | – | 45.0 | 67 |

lowered to harness the incoming monsoon runoff. This provides lower volume available for dilution and the overall concentration of nutrients is therefore greater. This might result to rapid growth of algae. Further, the exclusion of chlorophyll *a* concentration data originating in the tributaries as well as in the longitudinal segments could be the main reason for deviation during the growing season, as additional biomass could have been transported from those sources. On $10^{th}$ October, the surface algal concentration was under-predicted by approximately 4 mg $m^{-3}$, but from the layer immediately below it the modeled output showed a constant concentration of about 4 mg $m^{-3}$ up to the depth of 35 m and then finally decreased below it.

For the same day, the temperature distribution also showed iso-therm of 20°C up to the same depth of 35 m (Fig. 6). As, water temperature strongly affects the maximum algal growth rate, the deviation of algal concentrations from the measured values should be viewed as a natural consistent reflection of water temperature. The model well captures the collapse of algal bloom in November, and the subsequent increase in biomass with depth as winter sets in from December onwards and the overturn starts to occur in Andong Reservoir. The RMSE value for the calibration of the year of 2003 was 1.516 mg $m^{-3}$. Selected model parameters related to chlorophyll *a* and their values used in the calibrated model are listed in Table 1. The verification result from the remaining data set, from 2000~2004 (Fig. 7) shows the RMSE value of 2.166 mg $m^{-3}$.

Necessarily models of algae are a gross simplification of what actually occurs in nature. Their concentration in aquatic systems are highly dynamic and depend on number of variables such as nutrients, light, temperature, chemical composition of the water, grazing pressure, etc., and show large variation among and within sites (Wetzel, 2001; Håkanson and Boulion, 2002; Kalff, 2002). Also, different populations of phytoplankton grow depending on the tolerance of each species to these factors. The present modeling effort captures the general algal dynamics in Andong Reservoir. However, the study wants to point out the need of further refinement in algal modeling in Andong Reservoir and any such future efforts should include: a) the quantitative information on chlorophyll *a* concentrations arising from the tributaries; b) diverse composition and concentration of algal species, and c) zooplankton compartment.

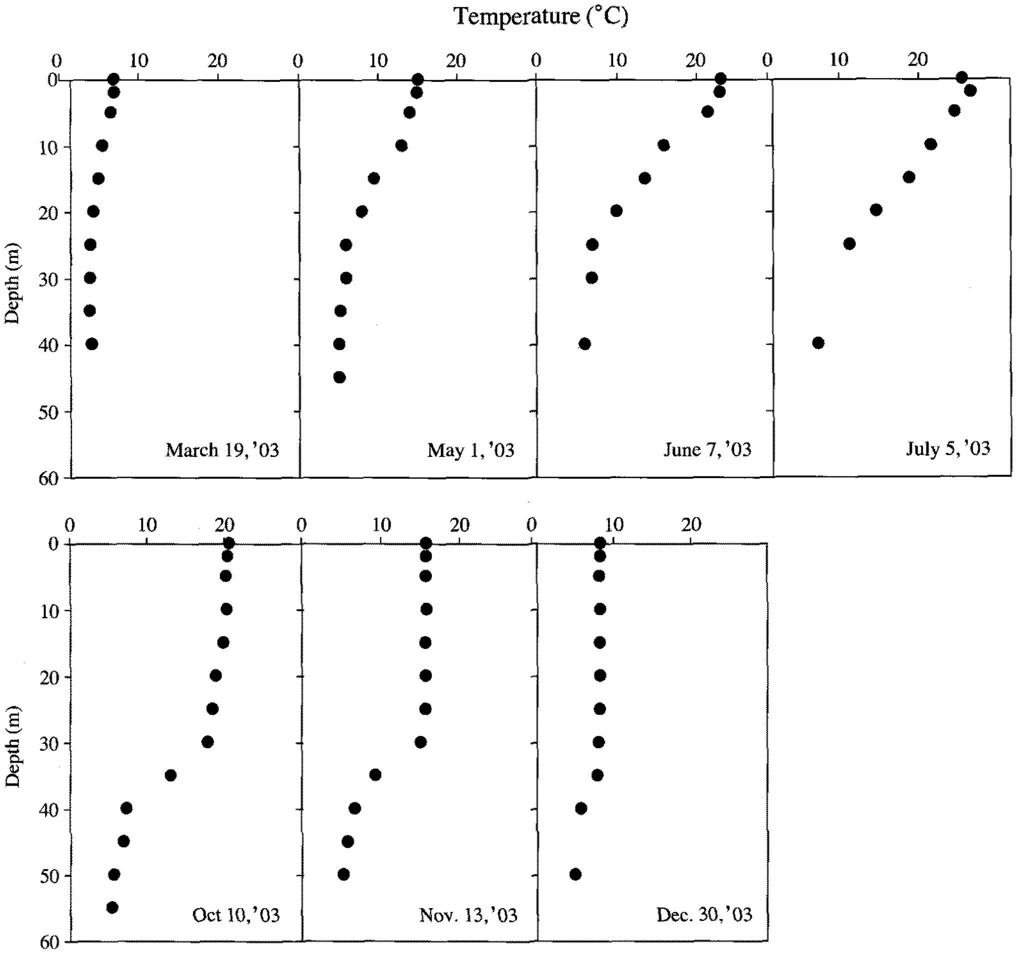


**Fig. 6.** Vertical water temperature profiles at the main dam site of Andong Reservoir in different seasons.

## 2. Total phosphorus dynamics

The calibration data matches well with observed data of total phosphorus as seen in Fig. 8. The months of March and May showed lower concentrations of total phosphorus in Andong Reservoir. With the starting of formation of stratification and occasional rainfall, we can see the slightly increasing trend of total phosphorus concentration in the metalimnion in the month of June. The model slightly under-predicts the total phosphorus concentration up to the metalimnetic depth in the month of July. The greatest deviation between modeled and measured phosphorus concentrations in Andong Reservoir model typically occurred in the fall, when the model predicted higher total phosphorus in the epilimnion than was measured. In October, the model showed higher concentration of total phosphorus concentration in the layers above the thermocline as well as in the hypolimnion region. The under-prediction of total phosphorus plume in the mid-reservoir level indicates the early discharge of water layer with high concentration of total phosphorus. Further, the diffusion of total phosphorus concentration to the epilimnion and hypolimnion of the reservoir can also be pointed out for the under-prediction in the metalimnion region. The storm water inflow of 1887.1 CMS around mid-September might have resulted in highly turbulent internal currents and thus diffusing the greater total mass of fine particles of suspended solids along the whole body of Andong Reservoir. As already explained in the PART I (Bhattarai *et al.*, 2008), the finer particles of less than 1 μm in size remained in suspension and were longitudinally transported to the main section of the dam. Due to their very low settling rate, the turbulent currents can easily transport them to the epilimnion. Also, during such high flows, the sediments can also re-suspend and increase the hypolimnion total phosphorus concentration. The model well captures the remaining concentration of the plume containing high phosphorus concentration in November. In the month of December, the total phosphorus in almost the whole water-body was a bit over-predicted. The RMSE for the calibration year was 14.9 mg m$^{-3}$. The months of July and October had very high RMSE values of 20.42 mg m$^{-3}$ and 48.79 mg m$^{-3}$, respectively. The RMSE value of the remaining months was 6.42 mg m$^{-3}$. Selected model parameters related to phosphorus and their values used in the calibrated model are listed in Table 2.

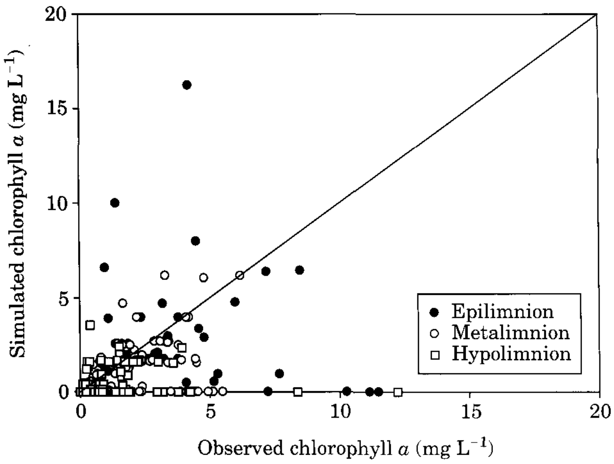


**Fig. 7.** Verification results of vertical chlorophyll *a* profiles at the dam site from 2000~2004. Diagonal line is the line of slope 1 (i.e. measured=simulated).

The verification result (Fig. 9), also shows that the model predicted higher metalimnion total phosphorus concentration at the dam site, especially during the high storm runoff on early August 2002.

Eddy coefficients are used to model turbulence in a reservoir in which vertical turbulence equa-

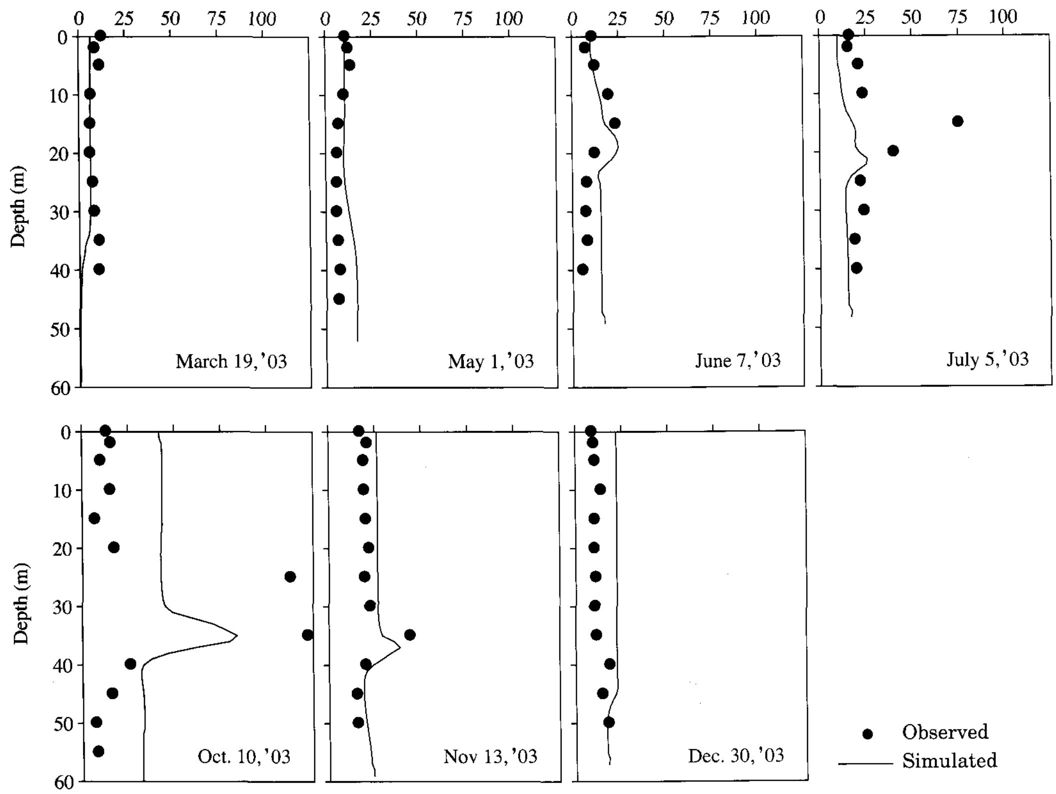


**Fig. 8.** Calibration results of vertical total phosphorus (TP) profiles at the main dam site of Andong Reservoir in different seasons.

tions are written in the conservative form using the Boussinesq and hydrostatic approximations (Cole and Wells, 2003). Since, vertical momentum is not included; the model may give inaccurate results where there is substantial vertical acceleration. Further, the settling velocity is limited by the particulate organic matter settling (POMS) rate in the model. In reality, the sediment settling velocity could be substantially different from it. The model does not have a sediment compartment that models kinetics in the sediment and at the sediment-water interface. The simplistic sediment computation in the model places a limitation on long-term predictive capabilities of the water-quality portion of the model. Further, the loadings from the upstream areas and the tributaries, which were not included in the model, might have resulted in the further deviation between the modeled and observed values.

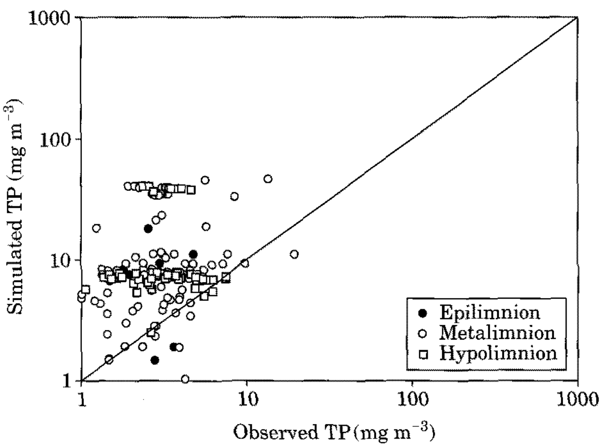


**Fig. 9.** Verification results of vertical total phosphorus (TP) profiles at the dam site from 2000~2004. Diagonal line is the line of slope 1 (i.e. measured= simulated).

### 3. Scenario of differential discharges

CE-QUAL-W2 model is capable of simulating cause-and-effect relationship between loading and reservoir response. The removal of phosphorus from a lake/reservoir occurs through two pathways: the outlet and the sediments. Most of multipurpose reservoirs are equipped with multilevel outlet structures, making it possible to release water from different depths. For the reservoir managers/operators, this feature is a highly significant tool to efficiently restore and maintain the water quality, especially in stratified lake where the vertical buoyancy forces inhibit vertical motions, and outflow zone is restricted to a horizontal layer that may be a few meters wide. In the case of Andong Reservoir, a single withdrawal structure draws water for the power plant using only one intake elevations (121 m to 129 m) and is predominantly operated throughout the year. Two different withdrawal strategies were applied to understand the impact of differential discharge gate location on the removal of highly turbid interflow containing high concentrations of total phosphorus. All the scenarios analysis was conducted for October 10$^{th}$ 2003 as, among all the sampled dates, this date had the highest concentration of total phosphorus. Also, all the parameters of the originally calibrated Andong Reservoir model as well as the coefficients arrived were kept constant, including the actual inflow,

**Table 2.** Model parameters used for calibration of total phosphorus concentration.

| Parameters | Variable | Unit | Default | Calibrated |
|---|---|---|---|---|
| Horizontal eddy viscosity | AX | $m^2s^{-1}$ | 1.0 | 1.0 |
| Horizontal eddy diffusivity | DX | $m^2s^{-1}$ | 1.0 | 1.0 |
| Chezy bottom friction factor | CHEZY | $m^{1/2}s^{-1}$ | 70 | 70 |
| Wind-sheltering | WSC | – | 0.85 | 0.5 |
| Labile DOM decay rate | LDOMDK | $day^{-1}$ | 0.10 | 0.1 |
| Refractory DOM decay rate | RDOMDK | $day^{-1}$ | 0.001 | 0.001 |
| Labile POM decay rate | LPOMDK | $day^{-1}$ | 0.08 | 0.08 |
| Refractory POM decay rate | RPOMDK | $day^{-1}$ | 0.001 | 0.001 |
| Particulate organic matter settling rate | POMS | $ms^{-1}$ | 0.1 | 1.0 |
| Oxygen limit for anaerobic processes | O2LIM | $g\ m^{-3}$ | 0.1 | 0.1 |
| Sediment release rate of phosphorus | PO4R | $day^{-1}$ | 0.001 | 0.001 |
| Fraction of phosphorus in OM | ORGP | $day^{-1}$ | 0.005 | 0.005 |
| Suspended solids settling rate: | SSS | $m\ day^{-1}$ | 1.0 | 0.1~0.9 |

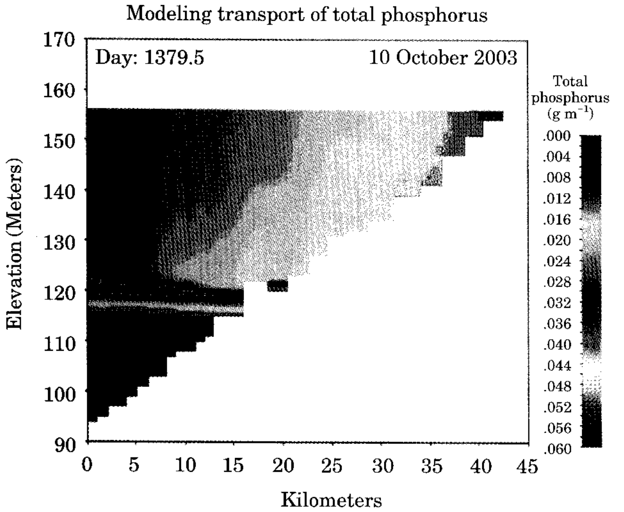


**Fig. 10.** Present discharge condition (121 ~ 129 m) elevation.

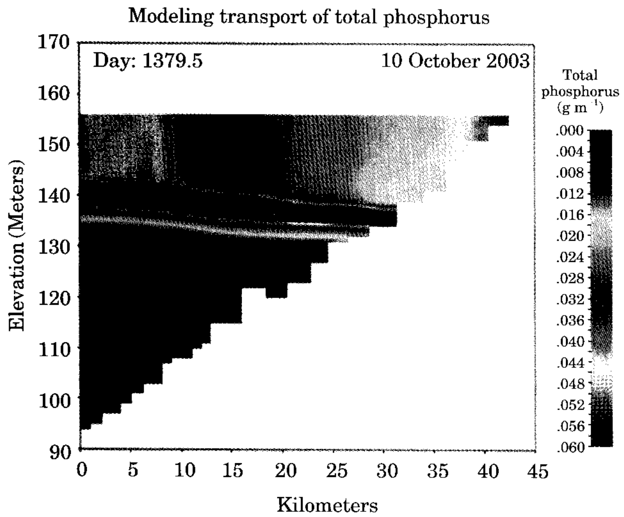


**Fig. 11.** Simulation result of horizontal and vertical distribution of Total Phosphorus (g m$^{-3}$) transport in case of upper level discharge (141 ~ 149 m elevation).

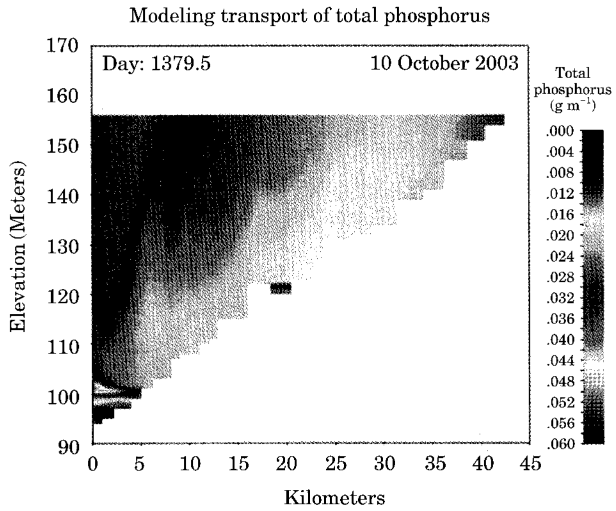


**Fig. 12.** Simulation result of horizontal and vertical distribution of Total Phosphorus (g m$^{-3}$) transport in case of lower level discharge (103 ~ 111 m elevation).

outflow quantity, meteorological parameters and water quality parameters. The present discharge condition (Fig. 10) and the visual results from the different proposed scenarios are shown in Fig. 11 and Fig. 12.

· Scenario One
→Fig. 11 Operation of discharge gate at elevations from 141 ~ 149 m

· Scenario Two
→Fig. 12 Operation of discharge gate at elevations from 103 ~ 111 m

In the first hypothetical scenario of operation of discharge gate at elevations from 141 ~ 149 m (Scenario One), the total phosphorus concentration increased by 102% when compared with the present discharge condition. But, in the second hypothetical scenario of operation of discharge gate at elevations from 103 ~ 111 m (Scenario Two), the total phosphorus concentration decreased by 219% in comparison to present discharge condition.

Hypolimnetic withdrawal has been a proven technology in lake and reservoir restoration that has been used for decades. It reduces the hypolimnetic detention time and thus the chances of development of anaerobic condition and the availability of nutrients to the epilimnion, through entrainment and diffusion, is also greatly reduced. We hope that the result of the model scenario will draw serious interest and attention of water quality manager and operator of Andong Reservoir to consider and further analyze the option of hypolimnetic withdrawal as one of the really effective and efficient method of quickly restoring the water quality of Andong Reservoir after the monsoon season.

## CONCLUSION

The CE-QUAL-W2 model [version 3.2], a two dimensional, longitudinal/vertical, hydrodynamic, and water quality model, (Cole and Wells, 2003) was applied to model the Andong Reservoir to understand the underlying hydrological and water quality issues. The CE-QUAL-W2 model uses a numerical scheme for a direct coupling between hydrodynamic and water quality simulations and the hydrodynamic module drives the water quality module.

In the PART I (Bhattarai *et al.*, 2008) of this study, the hydrodynamic module of the model was successfully employed to simulate the hydrothermal characteristics, dissolved oxygen regime (including the metalimnetic DO minima phenomenon) and interflow of density current during the Asian monsoon season in Andong Reservoir. Based on that arrived hydrodynamic module, this study further formulated the water quality module of the CE-QUAL-W2 model by modeling the two most significant water quality parameters of concern: total phosphorus and chlorophyll *a* concentration in Andong Reservoir. The model was calibrated for year 2003, and then verified with the data of remaining years from 2000~2004. In general, the model calibration reproduced the two most important water quality parameters: total phosphorus and chlorophyll *a* remarkably well throughout the calibration period. The model was able to track the interflow of highly concentrated total phosphorus plume brought by the Asian summer monsoon. This is a common phosphorus transport mode in deep reservoirs located in the Asian monsoon region. The growth of algal biomass in the spring and their disappearance in late fall, and growth of diatoms in the winter is well simulated by the model. The absence of chlorophyll *a* concentration input originating at the upper areas and tributaries might have led to the under-prediction. Also, updating the present model to the latest version which includes zooplankton compartment might also help in better calibration of chlorophyll *a* concentration. As for total phosphorus concentration, the upwelling of very fine suspended solid particles, as well as error in the calculation of internal currents at the events of huge storm runoff, lack of internal loads derived from the sediment re-suspension, and external loading derived from the tributaries might have caused the over-prediction of total phosphorus concentration in the epilimnion. Most of the simulated water-quality processes are necessarily simplified representations of complex chemical and biological reactions. The overall goal of the CE-QUAL-W2 model application to Andong Reservoir was achieved as it captures the essence of the two most important processes at their relevant spatial and temporal scales.

Further, two different hypothetical selective withdrawal scenario based on the changed discharge gate elevation (Scenario One: discharge from epilimnion, and Scenario Two: discharge from hypolimnion) were performed in order to understand the response of total phosphorus interflow plume in the reservoir. Based on the result of the hypothetical scenarios, this study proposes hypolimnetic discharge as the most effective and efficient method of effectively discharging very high, in-reservoir, total phosphorus concentration brought by the Asian monsoon derived runoff and thus quickly restoring the water quality of the reservoir after such seasons.

Some other constituents, for e.g., nitrate, pH, algal succession, were not included in the model due to the little measured data for calibration. Future modeling task should include those constituents as well, because they are important in the cycles of other constituents. As additional data are collected in the reservoir and tributaries, the calibrated model can be modified to assess the nutrient assimilative capacity of the reservoir, better simulate the algal complexities, the effect of increased in nutrient loading on reservoir trophic status, and analyze various "what-if" scenarios. Still, this study provides a sound framework for future water-quality modeling of Andong Reservoir.

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