CHAPTER 5

CONCLUSION

The objective of this study to solve the fish kills was met through the simulation of water quality and monitoring of phenols and other toxic chemicals. In the 1999 and 2000 monitoring data, high BOD_5 and DO were found at all aquaculture sites a week before the incident of fish kills and low DO on May 10^{th}, 1999, suggesting that there might be an algal bloom, as high BOD_5 and DO could be the results of high density of live algae and its photosynthesis, respectively. The bloom die-off resulting in low DO and the subsequent fish kills, could be due to both cellular respiration and low light extinction from continuous rainfall.

The presence of the algal bloom was proved indirectly with the use of GC/MS in conjunction with the experimental aquaculture, and modeling. The GC/MS experiment in 2002 demonstrated that cyanobacteria were associated with fish kills. During its bloom, small fish died, and when it died off, it caused severe fish kills. No other toxic chemicals were found in the river by GC/MS.

A water quality model was developed under dynamic conditions using the 1999 data for calibration and the 2000 data for validation. The results of the model calibration and validation of conventional nutrients showed good fit between the predicted and observed values, suggesting its "generality" for future prediction. Better results of calibration and validation than those reported might be difficult to achieve because, a dynamic model with undulating change could not be expected to predict the "generality" as well as the steady-state model with constant change.

Through scenario simulation, high BOD and NH_3 from both the Dam and sediment scouring were ruled out to cause low DO on May 10th. NO_2-N was also ruled out from deductive reasoning. The simulation of chlorophyll *a* illustrated that there could have been an algal bloom which peaked from May 2nd-4th, 1999 and started to die off due to cellular respiration and low light extinction from continuous rainfall (May 4th-15th, 1999). The algal die-off, in effect, could cause low DO on May 10th, 1999 which was associated with the fish kills. There could have been approximately 84 and 95 □g/L of *Chl a* at the CT aquaculture on May 3rd and May 1st, 1999, respectively. The *Chl a* simulation demonstrated that the algal die-off, low DO and fish kills occurred on the same day, suggesting that the model was accurate on a scale of days. The model's predictive capability on *Chl a* was tested by exposing the model to possible but least likely conditions such as lower temperatures in the river, and less nutrients from the reservoir. And the bloom was still predicted because it was mainly caused by the low Dam flows and agricultural runoff. The Dam flow corresponded to the residence time in the river, which affected algal growth and possibly caused more fish kills reported at the last aquaculture site.

Lignin/tannin was used as the conservative trace for runoff estimation and flow calibration because 1) the agricultural activities made the commonly-used watershed-based Rational Method inapplicable; and 2) this was a freshwater river where salinity was not possible. The RMSE of the flow calibration with lignin/tannin was within the literature values using salinity, suggesting that lignin/tannin can be used for the flow calibration. The selection of the lignin/tannin data, from the low-flow period, was crucial to the success of the flow calibration for studying the bloom because, as mentioned, low flows significantly affected the bloom. In addition to low flows, there should be no or very small amount of runoff when lignin/tannin was used for the flow calibration because lignin/tannin was also present in the runoff.

The runoff calibration yielded reasonably high R^2 values, particularly for the year 2000. It also reflected the bloom size at the aquaculture sites. Since the dynamic model was accurate on a scale of days in predicting the die-off and low DO on the same day, the flow and runoff, which affected the bloom, must have been well calibrated. Thus the use of lignin/tannin as the conservative trace for the flow and runoff calibration was justified.

The phenols analysis found only a slight amount of phenols in the river which were not suspected of killing the fish because they were found when there was no fish kills, and when there were fish kills, they were not found. This experiment proved that phenols did not play a significant role in fish kills, and there was not a significant amount of phenols from the remnants of the past spills. The trophic state analysis and algal enumeration showed that the river and areas around the Chot lagoon were under eutrophication. There was *Microcystis* sp. at a reasonably high level in May, the same month as the 1999 fish kills.

With no other toxic organic compounds found by GC/MS, it was likely that the cause of the fish kills in 1999 was due to the algal bloom. The requirements for the algal bloom were met in 1999; there were low Dam flows, high temperature and light extinction in the summer, and ample supply of runoff nutrients. After the bloom, the condition for the die-off was also met; it was the low light extinction from cloudy sky due to continuous rainfall.

Although no pesticides and other toxic organic chemicals were detected in the river by GC/MS, they could still exist at "undetectable" levels due to the large water dilution from the Dam. At these levels, they might indirectly kill fish by weakening the fish's immune system and making the fish vulnerable to low DO and susceptible to diseases. With compelling evidence of the fish-killing algal bloom in this study, it is recommended that the eutrophication problem and the possible algal bloom be controlled first; and if the fish kills persist, then it would be time to search for other possible causes.

As the conditions of Dam flows, runoff nutrients, temperature, light extinction were shown to play significant roles in determining the size of the bloom in the river, there are other important factors to be considered for algal controls, which were not discussed because they were assumed to be zero during modeling. They were the existing algal concentration in the river, algal input from the Dam, lakes and creeks, and finally algal uptake of benthic N and P. Fish kills in the isolated part of the Chot lagoon in the first year after it was dredged, might be caused by the bloom which obtained its nutrients from the remnants of the past spill. Whatever the existing algal concentration in the river might be, the final bloom in the river would always end up larger than the existing algae and algal input, if they were given enough supply of nutrients and residence time to grow. The significance of the residence time explained why the last aquaculture site in the river experienced more fish kills than other sites upstream.