Exercise in application of System Thinking in the water purification system

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1. The background

There is a lake named “WEIMING” in our school, however, this lake, an important interest place in school, has been polluted seriously, especially in summer, when students often suffer from the effluvium of the lake. As members of System Thinking Club, we hope to improve the terrible situation of the lake by using System Thinking and STELLA. We need to explore the causes affecting the water quality and model the real situation in the lab, and then find the efficient way to purify the water in the lake.

2. The theme and the goal

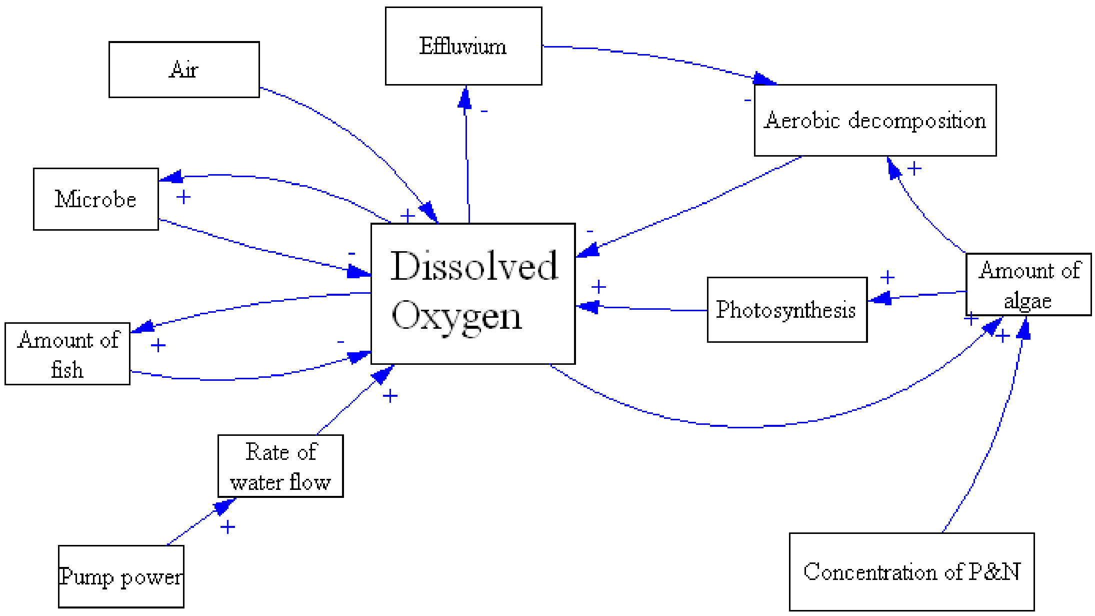


Fig.1

In the lab, we built the sewage treatment procedure to simulate the artificial wetland, and we utilize the method of System Thinking to research the operating mechanism of wetland and modify the water quality. With the help of System Thinking, we would build the eco-machine model. This method can be applied widely to different fields in the industry. Our research goal is to improve the water quality through a series of analysis and processing. We found two elements that affect water quality: one is the amount of dissolved oxygen; the other is the amount of phosphorus (P) and nitrogen (N). Therefore, we set the goal of water modification as follows: to increase the amount of dissolved oxygen and to reduce the amount of P and N.

3. The explanation of model

Because our research object is a complicated ecosystem, we didn't build the model in our first step, but listed all of elements affecting the amount of DO and P&N and we found the relationship between elements, which is described in detail when you read on.

In fig.1, the rate of water flow, photosynthesis effect, and oxygen in the air are positively related to the amount of DO. When the rate of water flow is increasing through the raise of pump power, the amount of DO is increased. Otherwise, the increase in the amount of algae inside the system would increase the amount of DO through photosynthesis. In the meantime, DO is consumed by microbe, fish and algae in the water. The aerobic decomposition leads to the decrease of the amount of DO. Furthermore, the amount of algae determines the photosynthesis and aerobic decomposition. The DO and P&N also lead algae to grow. Let us assume that the amount of DO is the dominant factor which influences the degree of effluvium and they are negatively related, then effluvium is negatively related to the aerobic decomposition. These relationships constitute the system.

3.1“Water- Oxygen” circulation in the system:

3.1.1 The following figure is constructed by aquarium, physical treatment tank, emerged aquatic plant tank and submerged plant tank. The essence of water purification system is a water circulation. The flow of water accelerates the exchange of DO and P&N between different parts of water body, also the speed of water flow influences the rate of exchange. In addition, because the time of reaching equilibrium is short in the system, we assume the speed of the siphon is negligible, and we believe the rate of the water circulation after equilibrium is determined by the pump power. If the amount of DO in the input water is more than that of the output, the amount of DO in this part will increase, vice versa.

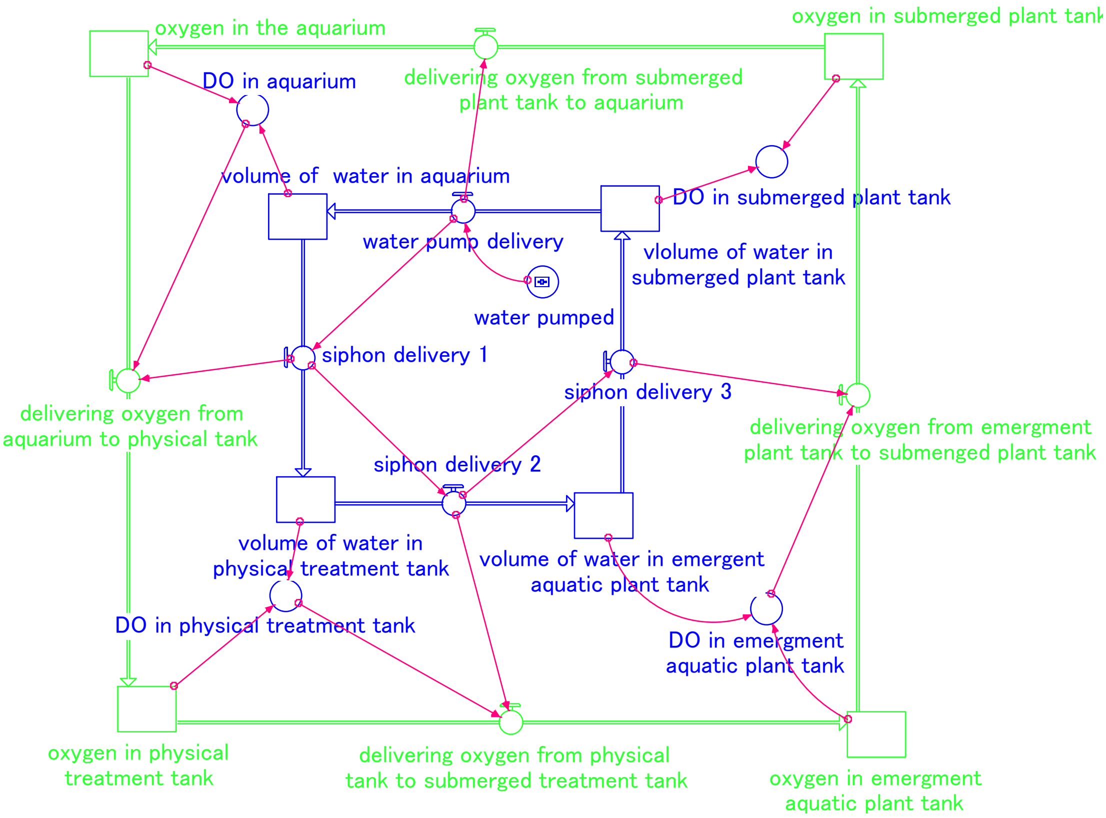


Fig.2

3.1.2 After building the basic water and oxygen circulation, we found many paths to input and output the oxygen in different parts of water. To make the system more practical, we attach the primary subsystems such as oxygen consumed by microbe, fish and aerobic decomposition, oxygen produced in the process of photosynthesis, and oxygen produced by pump aeration. The last step is to control the working time of pump, then we can quantify the amount of DO. Fig.3 is the final version of

“Water-Oxygen” circulation in the system.

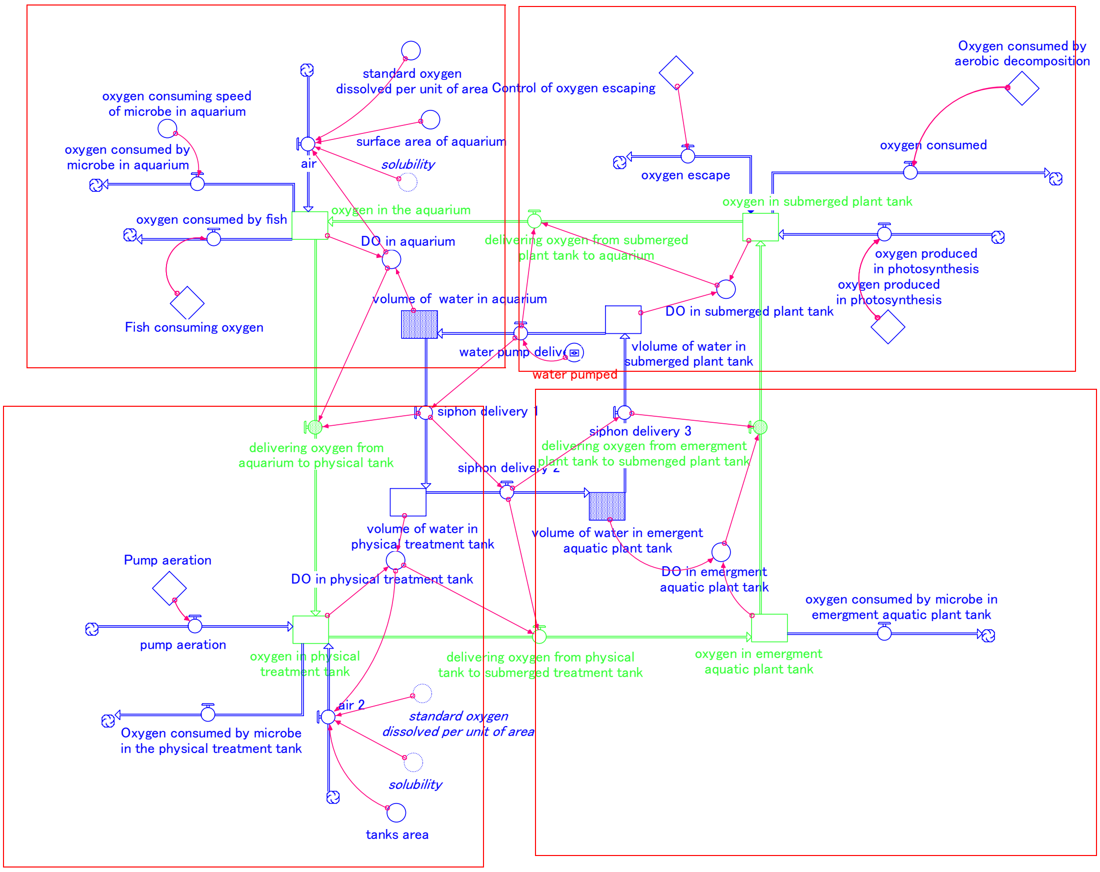
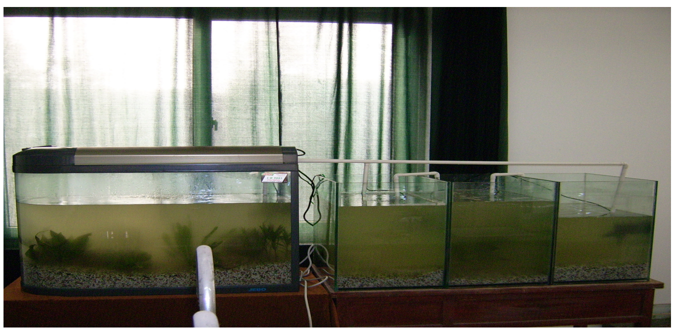


Fig.3

4. The system in the lab:



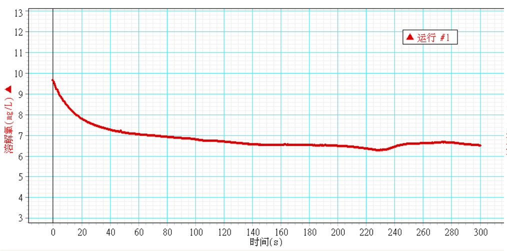
To further research with the set model, the next step is we simulate the wetland in the lab. This system is composed of 4 aquatic tanks, which prospectively include lake water, filter sand, emerged plant absorbing P&N (water spinach) and submerged plants like black algae which can increase the DO in water through photosynthesis. In order to make the man-made wetland in the lab as virtue as possible, we have to put the aquatic creatures and the "muddy bottom" modeled by sand into the first aquatic tank. And certainly the water in the whole system has to be from the Wei Ming Lake. However, how to make water in the four individual tanks flow to form a system as a whole? We got the enlightenment from the flow of the real lake, and come up with the idea of siphon. We use the pump to inject the water from the fourth tank into the first so that there's a difference of the water level which is the first condition of the siphon. Then we use plastic tubes to lead purified water from the first tank into the second, then the third, and lastly the fourth. Water will be injected into the first one again after flowing into the fourth tank. Hence the "isolated lake system" was constructed. Meanwhile, plants appropriate to live in wetland and planktons could also play their roles: planktons absorb the N, P and decompose the organics in water while those plants produce oxygen through photosynthesis.

5. The comparison of amount of DO in 4 aquatic tanks:

Firstly, we need to measure whether the amount of DO is increased after the series of circulation. And then we used DO collector to measure the values of amount of DO. Then the following charts presented the amount of DO in different aquatic tanks.

The chart of amount of DO on 7th Dec. after pumping:

No. 1



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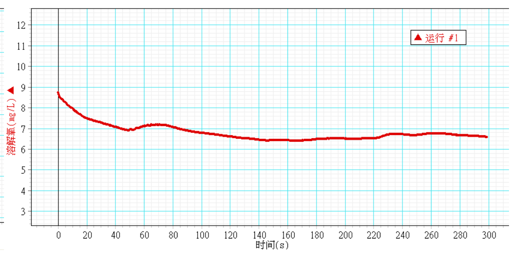
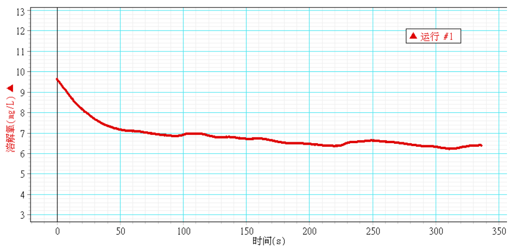
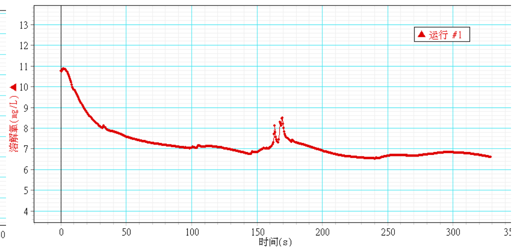


No. 3

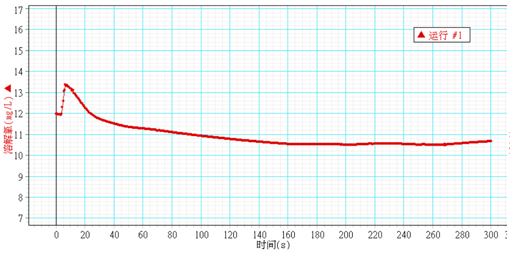
No.4





The chart of amount of DO on 10th Dec. after pumping:

No. 1



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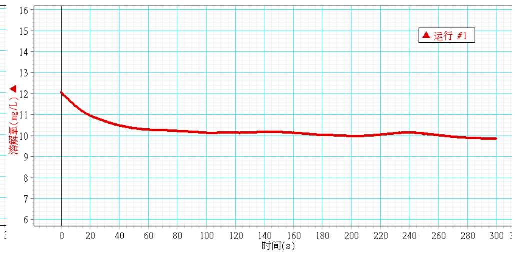
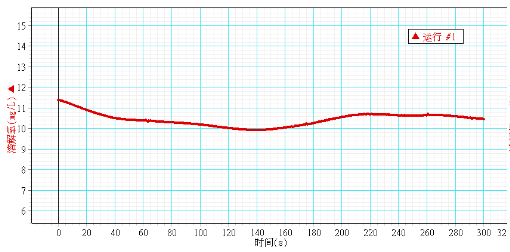
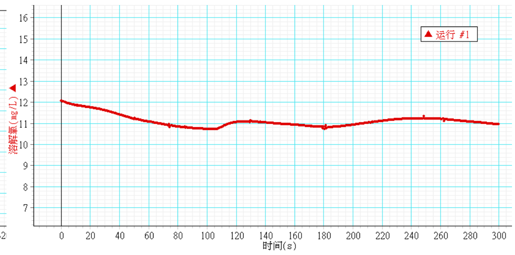


No. 3



No. 4



The following is the corresponding table:

Time: 7th Dec. 2008

Aquatic Tank	No.1	No.2	No.3	No.4
Average amount of DO（mg/L）	6.8	6.8	6.8	7.2
Time Difference	0.6	0.4	0.6	0.8

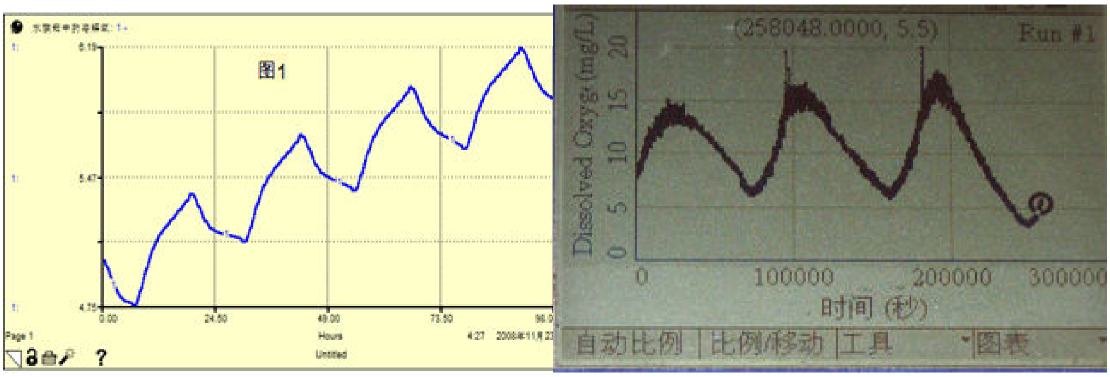
Time: 10th Dec. 2008

Aquatic Tank	No.1	No.2	No.3	No.4
Average amount of DO（mg/L）	10.9	10.2	10.4	11.1
Time Difference	0.6	0.4	0.3	0.3

With comparison we found: the amount of DO in tank No.4 is obviously more than that in the other three tanks, through the process of water circulation, the amount of DO in aquatic tanks keeps increasing. After pumping for 3 days, the amount of DO is also increasing. According to the following graph, although the values in the simulation are changing all the time but on the tendency of increase, this fit close to our collected data.

6. Experimental results analysis

From the data collected from the lab we can find that the value of DO is changing in a limited range, the period is one day. This observation results fit closely to the results of the simulator. (The left is graph of data from simulator; the right is the data from the experiment)



Therefore, we can draw a conclusion: the model we built accords with the real situation. Then through tests on the simulation results, we can get the following detailed conclusions:

1. The amount of DO is an important factor which can help us to quantify the water quality. The DO does increase due to the integrated effect of emergent plant, submerged plant, aquatic species and pumping.
2. Pumping helps increase the amount of DO, although the higher pumping rate can cause the better effect on DO. The relationship between these two factors is not linear. Besides that, cost should be taken into consideration. So we should choose

an economical method instead of operating the pump to the higher power rate.

3. Enhancing the photosynthesis by planting some black algae is an effective way to increase the amount of DO and reduce the effluvium in water. The larger the amount of black algae is, the better the effect is. In addition, the increase rate is not a constant. So that too much black algae is not a good option.
4. Simulator shows that pumping in the day time has a better effect on increasing the amount of DO compared with in the night time.
5. Judging the eco-machine from the aspect of energy consumption, we can say that eco-machine is green, economical and effective because electrical energy is the only energy source besides the aquatic species we required.
6. Our model is not a mature one so far. For the P&N modeling part, we only designed the framework (fig.4); due to the limitation of the suitable apparatus, we are not able to measure the amount of P&N continuously. So we can not find the formula involved N/P. Our job is to design a hypothetic value into the model. This inevitably brings a great uncertainty in the system.
7. In addition, according to our research, we know the influential factors include outside ones like temperature and pressure, especially the temperature is capable to affect both solubility of oxygen and the rate of metabolism. Unfortunately, we did not find a good way to involve the factor pressure, for the temperature, we chose a constant value corresponding to the situation—20℃. Because molecules move in a faster speed in higher temperature, the water pollution problem is worse in summer than in winter.

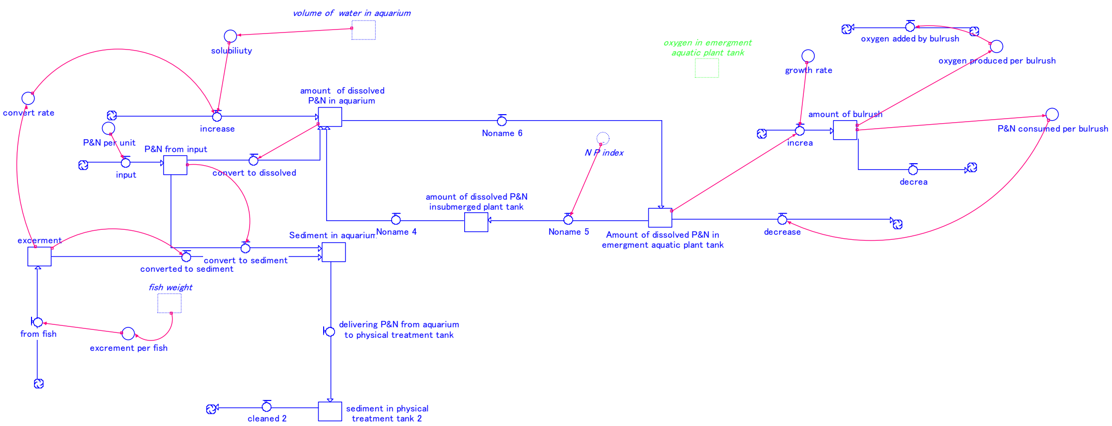
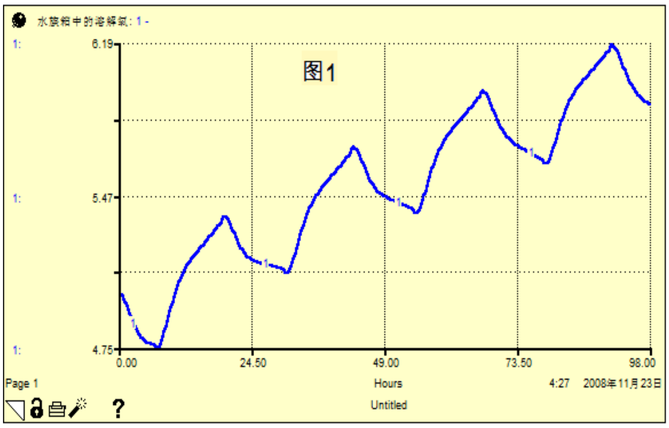


Fig.4

The corresponding charts in the conclusion part:

Chart 1:

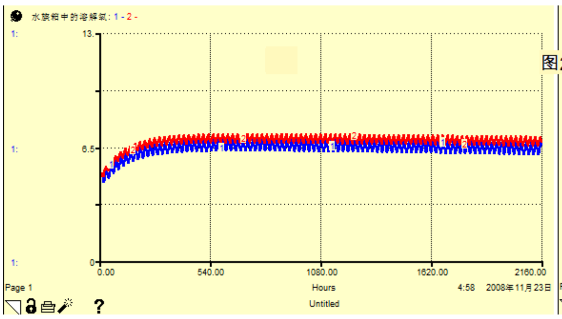


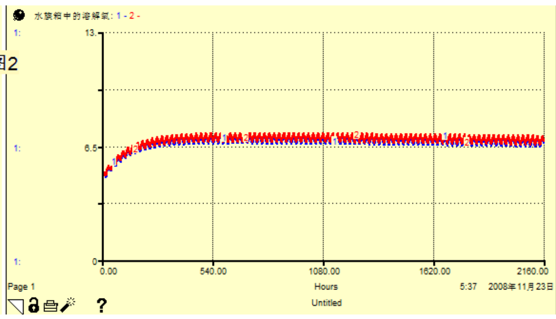
Horizontal axes: Time/s

Vertical axes: dissolved oxygen/ mg/litre

Chart 2:

(a) (b)





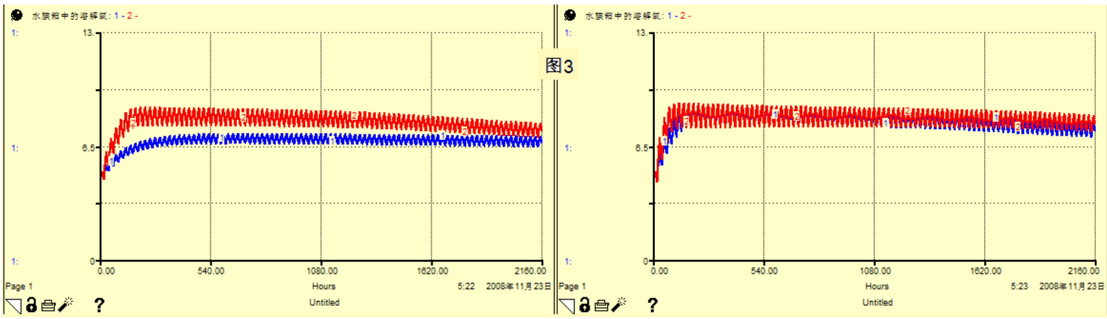
The blue ones show the situation with the slow pumping rate, while the red ones show the situation with the fast pumping rate.

Chart 2(a): both in the comparatively slow rate

Chart 2(b): both in the comparatively fast rate

Chart 3:

(a) (b)

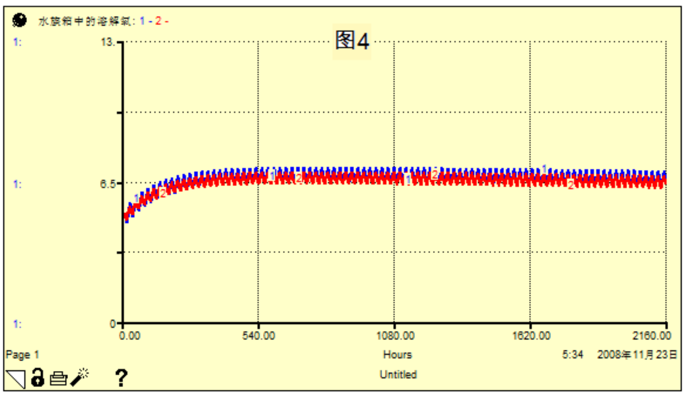


The blue ones show the situation with the small amount of black algae, while the red ones show the situation with the large amount of black algae.

Chart 3 (a): both in the comparatively small amount

Chart 3 (b): both in the comparatively large amount

Chart 4:



Blue one represents the situation in day time (6:00—18:00)

Red one represents the situation in night time (18:00—6:00)

7. Conclusion and Evaluation:

This research gave us much enlightenment, especially for learners of System Dynamics. The theme gave us a chance to improve our knowledge of the System Thinking in the real world. We still remember that we were attracted by the new thinking model, the strong complicated system analysis capability of System Thinking.

During utilizing the method of system thinking to solve real problems, we found the necessity of all-rounded thinking: the world is unbelievably complicated, there exist relationship between everything, on the contrary, the linear thinking ignores the ubiquitous relationships, so the result does not agree with the real situation.

Revising our theme, we found many problems need to be solved, our object is the ecosystem, and this is quite complicated. One simple phenomenon is related to numerous elements, and these elements are correlated to each other. Even though with the help of System Thinking, we should do lots of experiments to prove our model. As high school students, we can only us the limited resource to do research work, and our model is also on the way to simulate perfectly the reality, on this process, we should do more experiments and investigations to regulate the model. We are very pleased to get a chance to study System Dynamics and STELLA, and continue to use this tool to modify our model. We hope we can contribute our contribution to the environmental preservation.

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