

## Response to Reviewer #1

Thank you very much for your elaborative review for our manuscript entitled “An optimisation approach for shallow lake restoration through macrophyte management”. We have carefully considered the comments and revised the manuscript accordingly. All the responses to the comments are summarized as showing below.

**1. Comment:** The overall conciseness of this manuscript should be improved. Certain sentences need to be rewritten because of their misleading meanings, e.g.: Line 25-26, Page 809, ‘*Phytoremediation can remove nutrients although the macrophyte community also leads to high evapotranspiration, which results in significant loss of water in lakes*’.

**Response:**

We have revised the English language again to improve the conciseness of the paper. Certain sentences, which may lead to misleading meanings, have been rewritten. Take the sentence in the comment as an example. This sentence has been replaced by “*Phytoremediation can remove nutrients, while the macrophyte community also leads to high evapotranspiration. The huge evapotranspiration results in significant loss of water in lakes.*”

**2. Comment:** Line 13-17, Page 810. The authors should explain more on the reason why optimization of plant density is not enough for lake restoration. Also, since both plant density and plant area are both key parameters for lake restoration, the authors should explain why only the plant area was discussed in this paragraph and the whole manuscript.

**Response:**

Macrophytes can remove nutrients from the lake to improve lake water quality, while huge loss of water caused by plant evapotranspiration is disadvantageous for water quality. Thus it is significant to regulate macrophyte populations considering these two opposite effects of macrophytes on water quality restoration. Macrophyte population is affected by two factors. One is plant density and another is plant area. Previous research has proposed the optimal plant density, but no research offered a method for determining the optimal plant area in lakes. Plant area also has a direct relationship with plant population, so only optimising plant density is not enough for water quality restoration.

Plant density and plant area are both key parameters for lake restoration, but only plant area was discussed in this study. The plant density of this study was set as the same as the current plant density in the lake. Plant density was not optimised because reed density is hard to be controlled in the real condition of the lake. If we want to control the plant density to a certain level, we need to harvest parts of them in the whole growing zone, which is more than 80 km<sup>2</sup>. This is a really heavy task for lake managers. Besides this, reed rhizome system has high reproductive capacity (Laverigne and Molofsky, 2004). Although we could control reed density to the optimal level through harvesting, high reproductive capacity of reed rhizome would break the optimal level quickly. It is nearly impossible to control reed density at a certain level throughout its growing season. Thus plant density was not discussed in this manuscript. I have explained this problem in Line 7-10, Page 817.

After this explanation, people may wonder whether plant area is also hard to be controlled. Actually, plant area is much easier to be controlled than plant density. Various measures have been proposed to control growing area of reeds (*Schönerklee, M., Koch, F., Profilers, R., Haberl, R., & Labor, J. (1997). Tertiary treatment in a vertical flow reed bed system-a full scale pilot plant for 200–600 pe. Water Science and Technology, 35(5), 223-230*). For example, Geomembrane barrier is one kind of effective productions to control reed area, which can prevent rhizome penetrating and spreading out. Thus, we don't need to worry about the feasibility of this management regime proposed in this manuscript.

In order to make the explanation clearer, one sentence has been added into the new manuscript. *“In actual conditions, plant density is very difficult to quantify and control. The reed rhizome system has high reproductive capacity (Laverigne and Molofsky, 2004), so it is almost impossible to artificially control reed density throughout the reed growing season.”*

**3. Comment:** Line 22, P810 to Line 6, P811. There is no need for the authors to discuss the effect of harvest on the water quality after Sep. For the time after Sep, the two systems are the same, since no evaporation or absorption will be occurred.

**Response:**

The highest nutrient storage of reed aboveground tissues occurred in September, so harvest of aboveground part should be finished no later than this month. If they are not harvested, reeds will release nutrients to the lake after September. Although evaporation and nutrient absorption are not occurred after September, it is still

essential to discuss the effect of phytoremediation on water quality in the following months, because harvest time will determine the water quantity and nutrient amounts remaining in the lake and then affect the water quality of next months.

For example, the water quantity remaining in the lake affects the tolerance of nutrient inflows in following months. If water quantity of the lake is very small, the nutrient concentration will be very sensitive to nutrient increasing, even a small increment. Or if water quantity of the lake is really large, the nutrient concentration will be very tolerant to nutrient increasing. Thus, water quantity remaining in the lake deeply affects the water quality in the following months after September. We need to analyse the effect of harvest on water quality in both plant growing season and plant non-growing season, so we think that this content should be retained in the manuscript.

One sentence has been revised in the new manuscript. *“This harvest scheme may not be best for water quality in the following months, because in addition to nutrient removal reeds also undergo evapotranspiration. Water quantity and nutrient amounts remaining in the lake have a deep influence on water quality in next months.”*

**4. Comment:** For the ease of understanding, it would be preferential for the authors to list all the equations relating to the optimization process, e.g.: the equations to calculate  $TN_{\text{uptake}}$ ,  $TN_{\text{release}}$ , etc.

**Response:**

This manuscript offered a series of equations to help analyzing the mass balances in the water body, but we did not give these equations for calculating some parameters because we thought the calculation processes of these parameters were very clear. For example,  $TN_{\text{uptake},i}$  means the amount of TN absorbed by plants in month  $i$ , which can be calculated by multiplying plant growing acreage and the amount of TN absorbed by plants in unit area. The amount of TN absorbed by plants in unit area in each month is measured through experiments and these data are clearly showed in the manuscript.

According to your advice, we think that we should add some equations to help readers easily understand the calculation processes of these parameters about plant uptake and biological denitrification, such as  $TN_{\text{uptake},i}$ ,  $TP_{\text{uptake},i}$ ,  $TN_{\text{rhiz,deni},i}$  and  $TN_{\text{sedi,deni},i}$ . These equations are added behind equation (5).

$$TN_{\text{uptake},i} = (tn_{\text{above,upt},i} + tn_{\text{below,upt},i}) \times A_{\text{plant,sub},i} \quad (6)$$

$$TP_{uptake,i} = (tp_{above,upt,i} + tp_{below,upt,i}) \times A_{plant,sub,i} \quad (7)$$

$$TN_{rhiz,deni,i} = tn_{rhiz,deni,i} \times A_{plant,sub,i} \quad (8)$$

$$TN_{sedi,deni,i} = tn_{sedi,deni,i} \times A_{submerged,i} \quad (9)$$

where  $tn_{above,upt,i}$  and  $tn_{below,upt,i}$  are the amounts of TN absorbed by aboveground parts and belowground parts of reeds in unit area;  $tp_{above,upt,i}$  and  $tp_{below,upt,i}$  are the amounts of TP absorbed by aboveground parts and belowground parts of reeds in unit area;  $tn_{rhiz,deni,i}$  and  $tn_{sedi,deni,i}$  are the amounts of TN removed through biological denitrification at plant rhizosphere and sediment in unit area;  $A_{submerged,i}$  is the area of submerged zone in the lake;  $A_{plant,sub,i}$  is the area of plants in submerged zone of the lake.

**5. Comment:** Several basic assumptions of this manuscript should be explicitly listed, e.g.: the reviewer assumes that one of the basic assumptions of this study is that there is no spatial difference of the water quality in Baiyangdian Lake.

**Response:**

This study is based on several assumptions. We have written parts of them in the manuscript, but maybe the description is not clear enough. According to your advice, we think that it is essential to make a list of assumptions, which is added in section 2.4 of the paper. The specific content is showed as below.

*Before the model development, several basic assumptions should be listed as the base for the model.*

1. *Nutrients distribute uniformly in space. Spatial difference of the lake water quality is not considered.*
2. *The growth conditions are the same for reeds in different zones of the lake. The efficiency of nutrient removal by reeds has no spatial diversity.*
3. *The common reed is the dominant plant species in Baiyangdian Lake. The growing area of reeds is much larger than the total area of other plants. Thus common reed is the only plant species considered in this study.*

**6. Comment:** Line 19-20, page 814. The authors should explain why ‘*This value is cited in this study, although the accuracy is suspect because this value differs for different sites*’.

**Response:**

“This value” in this sentence means a parameter reflecting the relationship

between reed aboveground biomass and belowground biomass. In different zones of the world, the growth rhythms of plants have spatial differences. Even for two lakes in the same zone, the growth conditions of plants may also be different. In this study, we cited this parameter about plant growth according to the research in other lake, so the value may be not accurate to be used in our study site.

The best way to improve the accuracy is to directly measure this parameter in Baiyangdian Lake. However, the measurement of this parameter is very difficult. Reed belowground part is perennial. It is very complicated to measure the annual amounts of nutrients absorbed by the belowground part, because it is difficult to distinguish which tissues developed in the current growing season and the annual biomass increment of old tissues is also hard to measure. Thus, through short-term experiment and measurement, it is nearly impossible to determine this parameter in the lake.

The research by Valk and Bliss (1971) and Fiala (1976) did wonderful work to study the growth rhythm of reed belowground part. Plentiful experiments and observation were conducted in lakes. Through their work, they proposed values for some parameters about reed growth rhythm. We determined the parameter of this study according to their research. Although this value is not accurate to be used here, its influence on the results of our study is negligible. Our study focuses on method for water quality restoration, rather than reflecting plant growth mechanism. Thus, citation of the value in this study is acceptable. In the future, some botanists may give a more accurate value for this parameter, and then it is easy to change the value in this study.

**7. Comment:** Line 4-7, page 821. From the current understanding of the reviewer, there is no spatial difference considering the absorption efficient or transpiration of common reed in this study. Therefore, based on the assumption of this study, the water quality restoration ability of reeds plant near the lakeshore or far away from the lakeshore should be the same. The authors should find other reasons to explain why *'the effect of reed area variation on water quality is not obvious when the area is larger than 40 %'*.

**Response:**

In this study, there is no spatial difference considering the absorption efficient or transpiration of common reed, but the water quality restoration ability of reeds near the lakeshore or far away from the lakeshore has essential difference. Reeds normally

absorb nutrients through their rhizome system (Haslam, 1972; Ailstock et al., 2001). This study divides reed growing area into two zones, one is submerged zone and another is terrestrial zone. Nutrients absorbed by reeds in submerged zone mostly come from water body, because most nutrients in the sediment is unavailable for biotic use and available nitrogen mainly occurs in soluble form in the lake water and interstitial sediment water (Wetzel, 2001). These reeds are considered effective for water quality restoration, while those growing in terrestrial zone mostly absorb nutrients from the soil and they are considered noneffective for improving water quality. Thus, water quality restoration ability of reeds plant near the lakeshore or far away from the lakeshore has obvious difference.

As monthly water level fluctuating, the area of reeds in submerged zone will vary accordingly, which is considered in this study. When reeds are planted in the lake in March, it is preferential to plant them in submerged zone. After filling the submerged zone, reeds will be planted in the terrestrial zone, which is insignificant for water quality restoration in this month. When water level rises in next months, they may be submerged and then they will be effective for water quality restoration. However, if reeds are planted far away from lakeshore, they may be not submerged during the whole growing season. These reeds are unmeaning for water quality restoration, so it can explain why *'the effect of reed area variation on water quality is not obvious when the area is larger than 40 %'*.

For ease of understanding, some sentences have been replaced by the followings in the new manuscript. *"Reeds absorb nutrients mainly through their rhizome system (Haslam, 1972; Ailstock et al., 2001). Only a small amount of nutrients is absorbed from the atmosphere by their leaves and can be ignored. This study divides reed growing area into two zones, one is submerged zone and another is terrestrial zone. Nutrients absorbed by reeds in submerged zone mostly come from water body, because most nutrients in the sediment is unavailable for biotic use and available nitrogen mainly occurs in soluble form in the lake water and interstitial sediment water (Wetzel, 2001). These reeds in submerged zone are considered effective for water quality restoration, while those growing in terrestrial zone mostly absorb nutrients from the soil and they are considered noneffective for improving water quality. As monthly water level fluctuating, the area of reeds in submerged zone will vary accordingly."*

**8. Comment:** The lake level or available area for reed plantation of each month for

each scenario should also be presented, since the available area for reed plantation may be less than the planned area at specific months of a specific scenario.

**Response:**

In section 2.3 of this study, we built the equation to calculate the water quantity balance in the lake. We used the average water level of statistical data as the initial water level and lake levels in next months should be calculated based on the water balance equation. So we can't offer the available area for reed plantation of each month before solving the model.

We set available area for reed plantation in March and reeds can be planted in the available zone. Then we need to run the model to analyze the water level variations in next months. During the optimisation process, the water volume and water level of the lake can be calculated every month, and then the solving program can recognize available zone for reed growing in each month. When the program finds that parts of reeds are planted in unavailable zone, it will acquiescently consider that these reeds should be harvested in this month, which means that the area of reeds harvested in this month should not be smaller than the area of reeds growing in unavailable zone. If they are not harvested, they may die and release nutrients to the lake. From these descriptions, we can find that the available condition for reed growing is considered during the whole growing season, although we didn't offer available area for reeds in each month.

**9. Comment:** The TN and TP concentration in both Fig 1 and 2 reached zero at July. The authors should explain whether the TN and TP values are calculated to be zero coincidentally or corrected to be zero manually. The authors should also explain the setting of reed growth and transpiration if the TN and TP values are manually corrected to be zero.

**Response:**

In our optimisation program, we set that the TN and TP values should not be lower than zero. When these values are lower than zero, it means that the nutrients are not enough to maintain plant growth in this month. When this condition occurs in the calculation process, the program will calculate the acceptable area for reed growing in this month. The rest of reeds should be harvested at the end of last month, which means the reeds harvested in last month should not be smaller than the area of the redundant reeds. Their nutrient removal and transpiration will not be considered in current and following months.

In order to explain this problem, several sentences have been added into the new manuscript. *“From the figure, we can find that the nutrient concentrations in the optimal situation reach zero in July, which means that nutrients in the lake are not enough to maintain all reeds growing in this month. When this condition occurs, the optimisation program can calculate the acceptable area for reed growing in this month and acquiescently consider that the redundant reeds should be harvested at the end of last month. The area of reeds harvested in last month should not be smaller than the area of redundant reeds in this month.”*

**10. Comment:** In the ‘Discussion’ part, the authors only presented the result of two different scenarios of planting area and two different schemes of harvest. Most parts of these contents could be moved to ‘Results’.

**Response:**

This study focuses on proposing an optimal management regime for reeds, including an optimal planting area and monthly harvest scheme. This regime is obtained through the optimisation model. In the “Results” part, we mainly described the optimal result and proposed the optimal management regime for reeds. A planting area of 40% of the lake surface (123 km<sup>2</sup>) and harvest of 99% at the end of June is best for the water quality of Baiyangdian Lake. In the results, we compared several scenarios of planting area. These scenarios are created in the method part based on manipulity of management.

In the “discussion” part, we also compared water qualities under different scenarios, but these scenarios are different from those in “Results” part. The scenarios in “Discussion” part are created in order to compare the optimal result with the current situation of the lake, or with what proposed by previous research. These comparisons can show the significance of reed management on water quality. We think this content is very important. These comparisons are not the direct results of this study, so we think that remaining them in the “Discussion” part is more rational.

One sentence has been added into the new manuscript. *“In order to show the significance of macrophyte management on water quality, the comparison between optimal results and current situation is conducted.”*

**11. Comment:** The authors should cite more literatures in the ‘Discussion’ part.

**Response:**

This study proposed an optimal management regime for plants in lakes. Previous



research poorly considered this issue, so the literatures cited in the ‘Discussion’ part is just a few. According to your advice, we have revised this manuscript. More contents are discussed in this part and more literatures are cited at the same time.

**12. Comment:** The authors should discuss on the potential effects of the simplification (e.g.: the lack of consideration on variations of precipitation and evaporation, etc.) process on the final result.

**Response:**

There are several simplification processes in this study, such as precipitation, evaporation and water release from upstream reservoirs. We used average values to set these parameters according to statistical data of past years. These simplifications affect the water balance in the lake system and then affect the water quality. According to your advice, we have added a part to analyze the influence of simplification on final result. The specific content is showed as below.

*Water balance calculation is an important fundament for developing the optimisation method in this study. Lake water volume is mainly affected by several factors, such as evapotranspiration, precipitation, permeation and upstream reservoir operation. In this study, average values are used to set these parameters according to statistical data of past years. It is significant to consider the influence of parameter variations on final result (Bullock and Acreman, 1999). All these parameters are about water quantity balance, so considering variation for one of them is enough to reflect the influence. Among these parameters, water release from upstream reservoirs is the most uncertain. Thus, the influence of water release from upstream on final result is discussed.*

*Through adjusting the volume of water released from upstream reservoirs, no obvious varying tendency is found for reed management regime, while the lake water quality varies obviously. When the annual volume of water released reaches  $1 \times 10^8 \text{ m}^3$ , the gap index of water quality in the year is about 0.16, which means the water quality is very close to the target. The water qualities of upstream reservoirs are relatively much better, so water release can dilute the nutrients and decrease their concentrations directly. Besides this, water volume of a lake has direct relations with its water surface area and water depth. The water surface area decides the zone where sediment denitrification occurs and the water depth affects available zone for reed growing in the lake (Ishida et al., 2006; Lawniczak et al., 2010). The influence mechanism of water release on the water quality restoration is very complicated, so*

*the influence of parameter variation on reed management regime has no obvious rule.*