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Modelling Curtain Weirs and its Effects on Controlling Algal Blooms in a Subtropical Reservoir of China

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Abstract

Curtain Weirs (CWs) is a hydraulic structure which acts as a barrier to flow and diffusion of heat across the width of the water body. Algal blooms occurred frequently in Xiangxi Bay (XXB), one of the largest tributaries of the Three Gorges Reservoir (TGR). A laterally averaged two-dimensional hydrodynamic and water quality model (CE-QUAL-W2) was used to simulate the curtain weirs including hydrodynamics and chlorophyll-a concentrations in XXB. The developed model was calibrated using data collected in XXB from January to December in 2010. Results indicated that the maximum chlorophyll-a concentrations were observed 154 mg/m\textsuperscript{3} according sampling sites such as XX09, XX06 and XX01 respectively. Performance of the CWs suggests that overall chlorophyll-a concentrations were markedly reduced between 30-85\% as a function of floating curtain weirs height and locations. Therefore, the proposed curtain weirs can be a possible way to reduce algal blooms and improve water quality in XXB of TGR.

Keywords: Curtain weirs (CWs), Three Gorges Reservoir (TGR), Xiangxi Bay (XXB), Algal blooms, CE-QUAL-W2.

1. Introduction

Three Gorges Reservoir (TGR) is located at the end of the upper Yangtze River in central China (Ma et al., 2015; Yang et al., 2009). Xiangxi Bay (XXB) is one of the largest tributary in the lower reach of TGR (Figure 1 (a)) (Ji et al., 2017; Ma et al., 2015). Density currents influence over the year and algal blooms occur frequently in Xiangxi Bay (XXB) (Ma et al., 2015). Noteworthy, numerous investigations of algal blooms have been
conducted for XXB of the TGR, but previous studies haven’t discussed the exact cause and how to control algal blooms and the occurrence of density currents. Due to the deficiency of research of density currents in XXB, we discover a curtain weir method to divert density currents and control algal blooms in XXB. The curtain weir is a hydraulic structure built across a river, channel and reservoir to divert the flow and control algal blooms (Asaeda et al., 2001; H. S. Lee, 2010; Priyantha et al., 1997; Se-Woong Chung, 2008).

The objective of this paper is to control algal blooms in XXB of the TGR by the application of CWs by using a two-dimensional, laterally averaged, hydrodynamic model based on CE-QUAL-W2. We focus on curtain weirs (CWs) effects on hydrodynamics and chlorophyll-a concentrations in the XXB of the TGR. The performance of curtain weir was evaluating the reduction in chlorophyll-a predicted by the model, termed the weir efficiency.

2. Materials and methods

2.1. Study area

Xiangxi Bay (XXB) is located (from 110°25′E to 111°06″E and from 30°57′N to 31°34′N) at the lower reach of TGR and middle reach of the Yangtze River in Hubei Province, China. Xiangxi Bay (XXB) is the largest tributary in the lower reach of the (TGR) (Ma et al., 2015). Due to connect with the mainstream of the TGR, large amount of density currents intrudes to the XXB at different layers such as surface, middle and bottom (Ji et al., 2017; Ma et al., 2015; Yang et al., 2009). The XXB model was represented by 64 longitudinal segments, each 500 m in length, and 109 vertical layers, each 1 m thick (Ma et al., 2015) in Figure 1 (b).

2.2. Curtain weirs (CWs) incorporate with CE-QUAL-W2 model for XXB

The CE-QUAL-W2 is a 2D hydrodynamic and water quality model (Berger, 2008; Wells, 2012). The floating curtain weir is set at specified cell locations such as segment [I] and layer number [K], i.e., cell (K, I) as showed in Figure 1 (b). The CWs always is in the reservoir water surface during the simulation period (Figure 1 (c)). All meteorological data
were obtained from a hydrological station at Xingshan as showed in Figure 1(a) and China Three Gorges Corporation (CTGC) for the year 2010 (Ma et al., 2015).

Figure 1 Location of the sampling sites in the XXB (a) and schematic representation of curtain weirs (b) and curtain weir (CWs) illustrates for XXB (c).

2.3. Curtain weirs (CWs) mechanism

Curtain weirs (CWs) were installed at three different sites such as XX09, XX06 and XX01 of XXB having height 3m, 5m and 7m respectively as showed in Figure 1 (c). CWs effectively act as a barrier to flow and diffusion of heat across the width of the water body. Inflow formed plunge flow before the CWs and later travel as an interflow under the curtain weir (Figure 1 (c)). When inflow or intrusive, flow passing under the CWs as an interflow the mutual interaction occurred between the interflow and curtain weirs. Interflow exerts forces on the curtain weirs. Simultaneously CWs must exert an equal and opposite force on the interflow or ambient water as a result eddies will be formed which are produced heat and also effect on the thermal structure at XXB.

3. Results

3.1 Curtain weirs (CWs) effect on hydrodynamics in XXB

Curtain Weirs (CWs) have significant effects on density currents in Xiangxi Bay
Density currents are influenced by the Xiangxi Bay upstream inflow simultaneously intrusion flows from the mainstream of the TGR. Scenario S-2, S-3 and S-4 are owned by one float type curtain weir having height 3m, 5m and 7m at XX09, XX06 and XX01 respectively whereas there is no CWs as scenario S-1 (Figure 2). On June 20, the velocity increased due to the effect of curtain weir in scenario S-2 at XX09 but decreased in scenarios S-3 and S-4 at XX06 and XX01 respectively (Figure 3).

Figure 2 CWs effects on hydrodynamics at XXB.

In March, the velocities at all three segments without curtain weirs increased due to the water releasing of TGR. In April, May, June and July velocities at all three segments without curtain weirs decreased because of a stable water level at flood control level (145m) of TGR. At this time, surface intrusive flow intruded to XXB from downstream to upstream but downstream CWs diverted all intrusive flow (Figure 2). In summer (June, July and August) season cold inflow submerged the upstream and propagated to the downstream as an underflow. In July, velocities were increased without the curtain weir because of high
inflow from upstream to downstream. But due to the effects of CWs it will be decreased at all three segments because most of inflow barricaded by the curtain (Figure 3).

Figure 3 CWs spatial effects on hydrodynamics at XXB.

3.2 CWs spatial effects on chlorophyll-a concentrations in XXB

Curtain weirs (CWs) spatial effects on chlorophyll-a concentrations were analyzed according to scenarios S-1, S-2, S-3 and S-4 respectively at XX09, XX06 and XX01 of XXB. The surface chlorophyll-a concentrations are generally representative of the chlorophyll-a values throughout the vertical water column. CWs chlorophyll-a concentrations were significantly reduced in scenario S-2 at XX09 (Figure 4). It is because of the shallow nature of the XXB upstream and frequently mixing due to the effects of CWs. Sometimes, storm intrusion flow intruded to the XXB from the mainstream Yangtze River (YR) of TGR. As a result, chlorophyll-a concentration increased abruptly near the CWs and gathering one place before underneath as scenario S-3 (Figure 4). However, chlorophyll-a concentrations are distributed on horizontal with the density currents but
CWs significantly reduces these chlorophyll-a concentrations which are demonstrated by the scenarios S-2, S-3 and S-4 respectively (Figure 4). Field measurement and numerical simulation are also indicated that chlorophyll-a concentrations are higher at XX06 than XX09 and XX01 respectively of the XXB. Noteworthy upstream and downstream CWs were interrupted most of density currents having height such as 3m, 5m and 7m as scenarios S-2 and S-4 respectively (Figure 4).

![Figure 4 CWs spatial effects on chlorophyll-a at XXB.](image)

4. Discussion

4.1 Curtain weir efficiency

In this study, Curtain Weirs (CWs) have been used to control algal blooms in XXB through CE-QUAL-W2 model. Previous studies showed that floating curtain weirs were used to control algal blooms in different reservoirs (Asaeda et al., 2001; H. S. Lee, 2010; Priyantha et al., 1997; Se-Woong Chung, 2008). The performances of the curtain weirs
were determined by using normalized curtain weir efficiency ($CW_{s eff}$) which is defined in equation (1).

$$CW_{s eff} = \frac{CW - no\hspace{1em}CWs\hspace{1em}no\hspace{1em}CWs}{\ast\hspace{1em}100\%}$$

Curtain weirs efficiency showed different values at different locations such as XX09, XX06 and XX01 in XXB (Error! Not a valid bookmark self-reference.). The model also predicted the CWs efficiency overall 85%, 52% and 30% at sites for XX09, XX06 and XX01 respectively (Error! Not a valid bookmark self-reference.). The CWs performances by height more than 61% 59% and 47% for 5m, 7m and 3m respectively. Seasonally algal bloom reduction rate observed more than 62%, 54% and 50% in summer, autumn and spring respectively in 2010 (Error! Not a valid bookmark self-reference.). In winter day’s algal blooms occurred less than 30% which was not considered.

Table 1 CWs effectiveness scenarios at different locations of X XB in 2010

<table>
<thead>
<tr>
<th>X XB locations</th>
<th>CWs height</th>
<th>Scenarios</th>
<th>CWs seasonal Chl-a reduction efficiency (%)</th>
<th>Yearly Efficiency (%) per scenario</th>
<th>Average efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Summer</td>
<td>Autumn</td>
</tr>
<tr>
<td>XX09 3m</td>
<td>Seg9</td>
<td>44</td>
<td>93</td>
<td>99</td>
<td>79</td>
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<tr>
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<td>Seg9</td>
<td>79</td>
<td>97</td>
<td>99</td>
<td>92</td>
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<td>98</td>
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<td>83</td>
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<td>44</td>
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<td>46</td>
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<td>15</td>
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<tr>
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<td>35</td>
</tr>
<tr>
<td>XX01 7m</td>
<td>Seg58</td>
<td>54</td>
<td>62</td>
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<td>39</td>
</tr>
<tr>
<td>Ave*</td>
<td></td>
<td>50%</td>
<td>62%</td>
<td>54%</td>
<td></td>
</tr>
</tbody>
</table>

1. Yearly efficiency (%) per scenario means each segment and corresponds CWs height.
2. Average efficiency (%) means average algal blooms reduction percentage for locations.
3. Ave* means CWs installed sites algal blooms reduction percentage seasonally.

5. Conclusions
Curtain Weirs (CWs) have effects on hydrodynamics such as density currents which are important for nutrients, solids and other substances supply. Algal blooms occur severely in the midstream simultaneously upstream and downstream of XXB. Maximum chlorophyll-a concentrations are observed 154 mg/m³ according to scenario S-1 at XX09, XX06 and XX01 respectively. Performance of the CWs suggests that overall chlorophyll-a concentrations were markedly reduced between 30-85% as a function of CWs height and locations. Seasonally algal bloom reduction rate observed more than 62%, 54% and 50% in summer, autumn and spring respectively. The CWs performances according to height observed more than 61%, 59% and 47% for 5m, 7m and 3m respectively. During July 20-26, August 6-13 and September 3-8 the 7m CWs reduced algal blooms by up to 99% at XX09. The proposed CWs have been successfully controlled algal blooms in XXB through CE-QUAL-W2 model.

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