Modeling of surface roughness effect on near bed Turbulent Kinetic Energy in a stormwater detention basin

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Outline

- Background
- Objectives
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Background

- **Turbulence kinetic energy (TKE)** is the mean kinetic energy per unit mass

\[
\begin{align*}
\bar{u} &= \bar{u} + u' \\
\bar{v} &= \bar{v} + v' \\
\bar{w} &= \bar{w} + w'
\end{align*}
\]

\[
k = \frac{1}{2} \left( u'^2 + v'^2 + w'^2 \right)
\]
Near Bed Turbulent Kinetic Energy (BTKE) can strongly impact the sediment deposition

\[ k_c = av^2 \]

\( k_c \) - critical value for deposition \((m^2/s^2)\)
\( v \) - settling velocity \((m/s)\)
\( a \) - coefficient \((=1)\)
Background

- Near bed turbulence is affected by the roughness elements
- Variable spatial roughness exists on the bed of various stormwater detention basins

Django Reinhardt Basin in Lyon, France
Problem statement

- Consider the surface roughness effect
- Hard to evaluate the surface roughness effects on turbulence in settling process
- Few studies focus on that in full scale stormwater detention basins
Objectives

- Establish, test and verify hydrodynamic modeling
- Near bed turbulence quantity (BTKE) vs. sediment deposition zone
- Analyze the sensitivity of near bed turbulence (BTKE) to surface roughness
Methodology – Experimental site

Catchment: 185 ha
Area: 1.1 ha
Volume: 32000 m³
Methodology

Strategy of modeling

- Test with different roughness sizes on the bottom according to concrete Strickler coefficient $K$ (unique $K$ for initial condition)

$$K \times k_s^{1/6} = 6.5 \times \sqrt{g}$$  \hspace{1cm} (Hager, 2010)

<table>
<thead>
<tr>
<th>cases</th>
<th>Ks1</th>
<th>Ks2</th>
<th>Ks3</th>
<th>Ks4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K(\text{m}^{1/3}/\text{s})$</td>
<td>75</td>
<td>65</td>
<td>55</td>
<td>50</td>
</tr>
<tr>
<td>$k_s (\text{m})$</td>
<td>0.00040</td>
<td>0.00094</td>
<td>0.0026</td>
<td>0.0045</td>
</tr>
</tbody>
</table>
Methodology

Model setup

- Flow regime: steady state
- Inflow: 0.35m³/s
- Fixed lid for free surface representation
- Fixed water depth: h₁ = 0.55m
- Turbulent model: RNG k-epsilon
- Roughness set: standard wall function
Geometry & mesh

- Independent mesh test (coarse-650 000, median-850 000, fine-1000 000 cells mesh)
Results: BTKE vs. deposition zones

Bed turbulent kinetic energy (BTKE)

\[ 0 < k < k_c = V_{80}^2 \]

Contours of sediment depth:

1. Sediment depth

2. \( K_s1 = 0.0004 \)

3. \( K_s2 = 0.00094 \)

4. \( K_s3 = 0.0026 \)

5. \( K_s4 = 0.0045 \)
Vertical TKE distribution

Layout of the checked points

With sediment

No sediment

sediment depth

0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 (m)
Results: vertical TKE distribution

Dey et al, 2011

Normalized tke vs. Water depth (m)

Normalized tke vs. Turbulent kinetic energy $(k)$ (m$^2$/s$^2$)
Results: Effect of roughness height

\[ K_{c} = v_{80}^{2} \]

\[ K_{s}^{+} = \rho K_{s} u_{*} / \mu \]
Conclusions

- BTKE is sensitive to surface roughness
- BTKE could be used to estimate the outer contour of the sediment zone with a critical value ($k_c=v_{80}^*v_{80}$)
- Different roughness height might be set for different zones: higher for sediment zones and lower for concrete surface
- No clear quantitative relation was found between BTKE and dimensionless roughness height