Appendix F: Calculation of Manning's 'n' in Swales

Introduction

MUSIC includes a model for grass swales, which models the storage-discharge relationship using Manning’s equation. A review of relevant literature shows, however, that Manning’s roughness coefficient, n, varies with vegetation type and height (relative to flow depth), as well as slope. An algorithm is adopted to incorporate this variation in roughness into the modelled discharge.

Model Background

The algorithm for modelling flow through a channel with flexible vegetation is based on work described by Kouwen (1988), Kouwen and Li (1980) and Kouwen and Unny (1973). The algorithm is based on determining the roughness of flexible vegetation for a defined flow depth.

The vegetation model is based on an empirical model, which uses an empirically defined vegetation parameter MEI to model the density and stiffness characteristics of the vegetation. The aim of the model is to reproduce the bending of the vegetation at higher discharges, and the consequent reduction of the bed roughness. The algorithm presented is a trial and error procedure to calculate the depth in uniform flow in the grass-lined channel.

The following equations are used in the algorithm:

\[
    n = \left[ \frac{1}{a + b \log\left( \frac{R}{k} \right)} \right]^{\frac{1}{2}} \frac{R^{\frac{1}{6}}}{\sqrt{8g}}
\]

where:

- \( n \)  Manning roughness,
- \( R \)  Hydraulic radius of channel,
- \( g \)  Acceleration due to gravity,
- \( k \)  Deflected roughness height of vegetation, defined by Eq. 2
- \( a, b \)  Relative roughness parameters, defined in Table 1.

\[
    k = 0.14h \left[ \left( \frac{MEI}{\tau_o} \right)^{1.59} \right]^{1.59}
\]

where:

- \( M \)  Empirical vegetation stiffness parameter,
- \( h \)  Length of vegetation,
- \( \tau_o \)  Bed shear stress, defined by Eq. 3.

\[
    \tau_o = \rho g R S_o
\]

where:

- \( S_o \)  Channel bed slope.

For green growing grasses:

$$ MEI = 319h^{1.1} $$  \( (4) \)

**Table 1: Values of a and b.**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Criteria</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erect</td>
<td>$v^*/v_{crit}$ 1.0</td>
<td>0.15</td>
<td>1.85</td>
</tr>
<tr>
<td>Prone</td>
<td>$1.0 &lt; v^*/v_{crit} &gt; 1.5$</td>
<td>0.20</td>
<td>2.70</td>
</tr>
<tr>
<td>Prone</td>
<td>$1.5 &lt; v^*/v_{crit} &gt; 2.5$</td>
<td>0.28</td>
<td>3.08</td>
</tr>
<tr>
<td>Prone</td>
<td>$2.5 &lt; v^*/v_{crit}$</td>
<td>0.29</td>
<td>3.50</td>
</tr>
</tbody>
</table>

where:

$$ v^* $$ Shear velocity, defined by Eq. 5,

$$ v_{crit} $$ Critical shear velocity, defined by the minimum of Eq. 6 and Eq. 7.

$$ v_\ast = \sqrt{\frac{T_\phi}{\rho}} $$ \( (5) \)

$$ v_{crit}^\ast = 0.028 + 6.33 \cdot MEI^2 $$ \( (6) \)

$$ v_{crit}^\ast = 0.23 \cdot MEI^{0.106} $$ \( (7) \)

**Application in MUSIC**

MUSIC undertakes the following computations:

1. **Step 1** Calculate MEI for the grass based on Eq. 4.
2. **Step 2** Calculate the critical shear velocity, $v_{crit}$, from the minimum of Eq. 6 & Eq. 7.
3. **Step 3** Estimates an initial depth of flow in the channel.
4. **Step 4** Calculate the cross-sectional properties of wetted perimeter, area and hydraulic radius (based on the guessed depth, and the swale design parameters provided by the user).
5. **Step 5** Calculate the bed shear stress, $\tau_\phi$, from Eq. 3.
6. **Step 6** Calculate the deflected roughness height of the vegetation, $k$, from Eq. 2. Set the deflected roughness height $k$ equal to the depth when $k$ calculated from Eq. 2, is greater than the depth.
7. **Step 7** Calculate the shear velocity, $v^*$, from Eq. 5.
8. **Step 8** Determine the parameters $a$ and $b$ from Table 1.
9. **Step 9** Calculate the Manning’s $n$ from Eq. 1.
10. **Step 10** Calculate the velocity and discharge in the channel from Manning Equation.

11. **Step 11** Compare the calculated discharge, $Q_{calc}$, with the required discharge, $Q_{req}$. Reduce the depth for $Q_{calc} > Q_{req}$ and increase depth for $Q_{calc} < Q_{req}$. Return to Step 4 and repeat process until the calculated discharge, $Q_{calc}$ equals the required discharge, $Q_{req}$.

**References**


