9.11 Manual

9.11.1 (Rigid) 3D Vegetation model

In a detailed numerical model one may want to represent the vertical variations in the vegetation characteristics and study the effect of vegetation on the 3D flow and turbulence.

The interaction of submersed vegetation upon hydrodynamics and fysical processes has received increasing attention because of its influence on water quality in lakes and on morphological developments in salt marshes (Houwing *et al.*, 2000; WL | Delft Hydraulics, 1998).

Uittenbogaard (dec. 2000) formulated theory for incorporating the effects of vegetation upon momentum and turbulence equations and implemented this in the so called '(Rigid) 3D Vegetation model', see Winterwerp and Uittenbogaard (1997), that has extensively been tested and compared to experiments (Meijer, 1998) by Oberez (2001).

The main input parameter for this formulation is the plant geometry, see section A.2.1. The implementation of vegetation resistance can also be applied for 2DH computations.

Theoretical background

The basic input parameters are the number of stems per unit area as function of height $n(z)$, and the stem width as function of height $\phi(z)$.

The influence of the vegetation upon the momentum equations is given by the vertical distribution of the friction force as caused by cylindrical elements in oblique flow:

$$F(z) = \frac{1}{2}\rho_0 C_D \phi(z) n(z) \left|u(z)\right| u(z) \qquad [\text{N/m}^3] \tag{9.1}$$

with $u(z)$ the horizontal flow velocity profile and C_D the cylindrical resistance coefficient (default value 1.0).

The horizontal cross sectional plant area is given by:

$$A_p(z) = \frac{\pi}{4}\phi^2(z) n(z) \tag{9.2}$$

The influence of the vegetation upon vertical mixing is reflected in an extra source term T in the kinetic turbulent energy equation:

$$\frac{\partial k}{\partial t} = \frac{1}{1-A_p}\frac{\partial}{\partial z}\left\{(1-A_p)\left(\nu + \frac{\nu_t}{\sigma_k}\right)\frac{\partial k}{\partial z}\right\} + T + P_k - B_k - \varepsilon \tag{9.3}$$

with $T(z)$ the work spent by upon the fluid:

$$T(z) = F(z)u(z) \tag{9.4}$$

and an extra source term $T\tau^{-1}$ in the epsilon equation,

$$\frac{\partial \varepsilon}{\partial t} = \frac{1}{1-A_p}\frac{\partial}{\partial z}\left\{(1-A_p)\left(\nu + \frac{\nu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial z}\right\} + T\tau^{-1} + P_\varepsilon - B_\varepsilon - \varepsilon_\varepsilon \tag{9.5}$$

with τ the minimum of:

$$\tau = \min(\tau_{\text{free}}, \tau_{\text{veg}}) \tag{9.6}$$

with the dissipation time scale of free turbulence

$$\tau_{\text{free}} = \frac{1}{c_{2\varepsilon}} \frac{k}{\varepsilon} \tag{9.7}$$

and the dissipation time scale of eddies in between the plants

$$\tau_{\text{veg}} = \frac{1}{c_{2\varepsilon}\sqrt{c_\mu}} \sqrt[3]{\frac{L^2}{T}} \tag{9.8}$$

that have a typical size limited by the smallest distance in between the stems:

$$L(z) = C_l \sqrt{\frac{1 - A_p(z)}{n(z)}} \tag{9.9}$$

C_l is a coefficient reducing the geometrical length scale to the typical volume averaged turbulence length scale. Uittenbogaard presents a closure and finds that a C_l value of 0.07 is applicable for grid generated turbulence. For vegetation this coefficient may be tuned, values of 0.8 are found applicable, see Uittenbogaard (dec. 2000).

A.2 Bijlage

A.2.1 (Rigid) 3D vegetation model

To include vegetation in Delft3D-FLOW, the keyword `Filpla` may be included in the FLOW input file <∗.mdf>, e.g.:

```
Filpla=#example.pla#
```

In the FLOW-GUI this keyword-value pair can be specified in Data Group *Additional Parameters*.

File contents	Characteristics of vegetation.
Filetype	ASCII
File format	Ini formatted.
Filename	<*name*.pla>
Generated	manually offline

Record description:

Table A.1: *Vegetation input file with keywords*

Keyword	Format	Record description
VegetationFileInformation		
`FileCreatedBy`	string	program name and version
`FileCreationDate`	string	creation date and time of the <∗.pla> file
`FileVersion`	string	version number of the <∗.pla> file ('01.00')
General		
`PolygonFile`	string	name of polygon file with polylines defining vegetation areas
`ClPlant`	1 R	The overall turbulence length scale C_l between stems (Equation (9.9)).
`ItPlant`	1 I	Number of time steps between updates of plant arrays
Vegetation		
`type`	string	Type of the vegetation
		continued on next page

R = Real; I = Integer; L = Logical; C = Character

Table A.1 – continued from previous page

Keyword	Format	Record description
`Vps`	2 R, 1 I, 1 R	Specification of the vertical plant structure (Vps). For each specified plant type, there should be a block in the file containing four columns: 1 height [m] 2 stem diameter [m] 3 number of stems [-] 4 C_d coefficient [-]
Area		
`VegetationType`	string	name between # must match a vegetation group in this file.
`Polygon`	string	name between # as specified the polygon file defined by the keyword `PolygonFile`
`NPlants` or	R	Number of stems per square metre [m^2]
`NPlantsFile`	string	name between # must match an existing file in dep-format (see **??**)

R = Real; I = Integer; L = Logical; C = Character

In the plant input file, the overall turbulence length scale C_l can be specified (Equation (9.9)), using the keyword `ClPlant`.

If more types of plants are specified in the same grid cell, the average stem diameter and the average number of stems per unit area are combined such that the combination gives the total resistance and total occupied plant areas. The number of stems per unit area may vary over time if a sigma layer passes a plant top. Then, the number of stems and their diameters will be redistributed over the vertical. The update may not be necessary every time step if the water level varies slowly. The update interval may be increased to save some computational effort, using the keyword `ItPlant`.

In the *(Rigid) 3D vegetation model* input file many different plant types may be specified, each type with its own vertical plant structure and horizontal spatial distribution.

The Vertical Plant Structure (VPS) describes the number of stems and their widths per plant as a function of the vertical co-ordinate. For each specified plant type, there should be a block in the file containing four columns:

1 the height of the plants,
2 number of stems,
3 stem diameter and
4 the friction coefficient

The horizontal distribution of the number of plants per m^2 can be specified for each plant type separated in two ways.

1 by means of a constant value (`NPlants`)

2 by means of reference to a file (`NPlantsFile`). The file format is according the dep-file format, see **??**

Some example input files are given in Figures A.1 to A.3

```
[VegetationFileInformation]
   FileCreatedBy    = Delft3D Support
   FileCreationDate = 29-11-2013
   FileVersion      = 01.00
[General]
   PolygonFile = plants.pol
   ClPlant     = 0.80    [ - ] Turbulence length scale coefficient between stems
   ItPlant     = 50      [ - ] Number of time steps between updates of plant arrays
[Vegetation]
   Type = reed
   *
   *    height [m]    stem diameter [m]    nr of stems [-]     cd-coefficient [-]
   *
   Vps  =  0.0           0.008                 1                      1.0
   Vps  =  0.90          0.008                 1                      1.0
   Vps  =  0.91          0.001                 1                      1.0
[Area]
   VegetationType = #reed#        [  -  ] must match a vegetation group in this file
   Polygon        = #reed#        [  -  ] must match a polygon in the PolygonFile
   NPlants        = 256           [ 1/m2 ]
```

Figure A.1: *Example of the plant input file (<name.pla>) where the areas are defined with a polygon file, see* **??**

```
[VegetationFileInformation]
   FileCreatedBy    = Delft3D Support
   FileCreationDate = 02-07-2004
   FileVersion      = 01.00
[General]
   ClPlant = 0.80    [ - ] Turbulence length scale coefficient between stems
   ItPlant = 50      [ - ] Number of time steps between updates of plant arrays
[Vegetation]
   Type = reed
   *
   *    height [m]    stem diameter [m]    nr of stems [-]     cd-coefficient [-]
   *
   Vps  =  0.0           0.008                 1                      1.0
   Vps  =  0.90          0.008                 1                      1.0
   Vps  =  0.91          0.001                 1                      1.0
[Area]
   VegetationType = #reed    #      [ - ] must match a vegetation group in this file
   NPlantsFile    = #reed.dep#      [ - ] must match an existing file in dep-format
```

Figure A.2: *Example of the plant input file (<name.pla>) where the area is defined with files according the depth-format, see* **??**

```
[VegetationFileInformation]
   FileCreatedBy    = Delft3D Support
   FileCreationDate = 29-11-2013
   FileVersion      = 01.00
[General]
   ClPlant = 0.80    [ - ] Turbulence length scale coefficient between stems
   ItPlant = 50      [ - ] Number of time steps between updates of plant arrays
[Vegetation]
   Type = wier1
   *
   * height [m]    stem diameter [m]     nr of stems [-]       cd coefficient [-]
   *
   Vps  =  0              0.003                1000              1.0
   Vps  =  0.5            0.003                1000              1.0
[Vegetation]
   Type = wier2
   *
   * height [m]    stem diameter [m]     nr of stems [-]       cd coefficient [-]
   *
   Vps  =  0              0.003                1000              1.0
   Vps  =  0.8            0.003                1000              1.0
[Area]
   VegetationType = #wier1   #
   NPlantsFile    = #vegetatiedichtheid_gemaaid_wier.dep#
[Area]
   VegetationType = #wier2   #
   NPlantsFile    = #vegetatiedichtheid_niet_gemaaid_wier.dep#
```

Figure A.3: *Example of the plant input file (<name.pla>) where two different vegetation types are defined.*

References

Houwing, E. J., I. C. Tánczos, A. Kroon and M. B. de Vries, 2000. “Interaction of submerged vegetation, hydrodynamics and turbidity; analysis of field and laboratory studies.” *Conference INTERCOH2000* .

Meijer, D., 1998. *Modelproeven overstroomde vegetatie*. Tech. rep., HKV Lijn in water. In Dutch.

Oberez, A., 2001. *Turbulence modeling of hydraulic roughness of submerged vegetation*. Master’s thesis, UNESCO IHE, Delft. H.E.100.

Uittenbogaard, R. E., dec. 2000. *Hydrodynamics of flow over plants, internal communication*. Tech. rep., WL | Delft Hydraulics, Delft, The Netherlands.

Winterwerp, J. C. and R. E. Uittenbogaard, 1997. *Sediment transport and fluid mud flow*. Tech. Rep. Z2005, WL | Delft Hydraulics, Delft, The Netherlands.

WL | Delft Hydraulics, 1998. *Interaction of submerged vegetation and physical processes; Delft, The Netherlands.* Research report, WL | Delft Hydraulics, Delft, The Netherlands. (in Dutch).