# Development of VFDM: a Riparian Vegetated Filter Dimensioning Model


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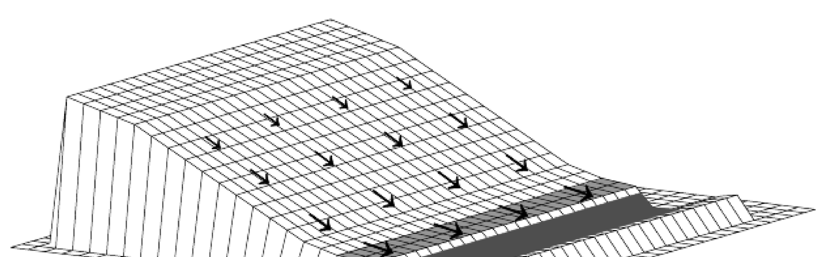
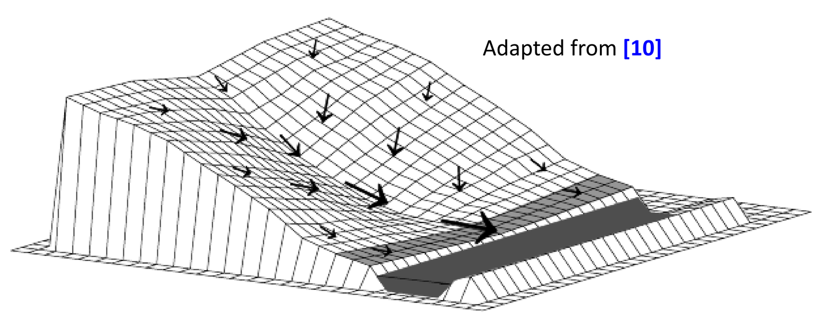
## Abstract


*Riparian buffer zones are considered as one of the best beneficial management practices (BMPs) to improve surface water quality. In most cases they are assumed to be responsible for large reductions in sediment and agricultural chemical losses from cropland to water bodies. Filtration, deposition, infiltration, adsorption, absorption, decomposition, and volatilization are thought to be the biophysical processes governing the reduction of agricultural contaminants transported by surface runoff. Vegetation at the downstream edge of disturbed areas may effectively reduce runoff volume and velocity; initially because of increasing hydraulic roughness, and subsequently by enhancing water infiltration. Decreasing flow volume and velocity lead to sediment deposition in the vegetative filter (VF) as a result of reducing the transport capacity of runoff. Dimensioning and positioning these structural BMPs represents a "real life" challenge for soil conservation engineers, managers, planners and policy-makers. Different factors, such as trapping efficiency; implementation, management, and opportunity costs (resulting from cropland surface reduction); and government policies and regulations need to be weighed to meet this challenge. Trapping efficiency depends on many parameters, including: (i) VF characteristics such as width and slope, vegetation height, vegetation density, species composition; (ii) flow characteristics such as runoff velocity, discharge volume, water height; and (iii) sediment characteristics such as particle size, aggregation, and concentration. Government policies and regulations may include dimension and location of VFs and/or a cropland percentage that needs to be converted into VF areas. The main objective of this paper is to describe the development of a mathematical model to determine the optimal dimensions of riparian vegetated filter strips (RVFSs) in agricultural watersheds. The model calculates the optimal width with respect to vegetation, topographical, hydrological and sedimentological characteristics. Future work will involve linking the model to an economics model in order to evaluate the effectiveness of RVFSs with respect to both water quality and economic objectives.*

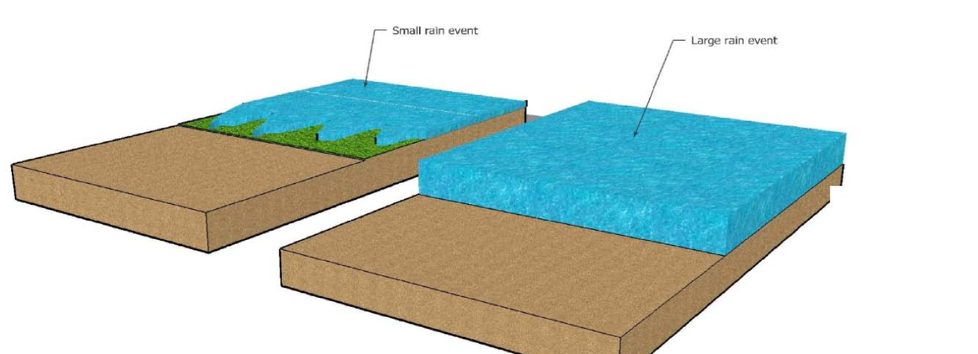

## Introduction

- Vegetated filters (VFs)reduce losses of sediments, pesticides, and nutrients from cropland to surface water bodies
- Vegetation at the downstream edge of disturbed areas may effectively reduce runoff volume and velocity, initially because of the increasing hydraulic roughness of the VFs, and subsequently by improving the infiltration rate over vegetation
- VFs may affect sedimentological connectivity both at the local scale between two adjacent fields and in a distributed way at the watershed scale
- Government policies and regulations dictate VF dimensions without taking into account flow, topographical and sediment characteristics.





Adapted from [10]




Flow characteristics

Potential types of flow: either sheet (uniform), converging or diverging flow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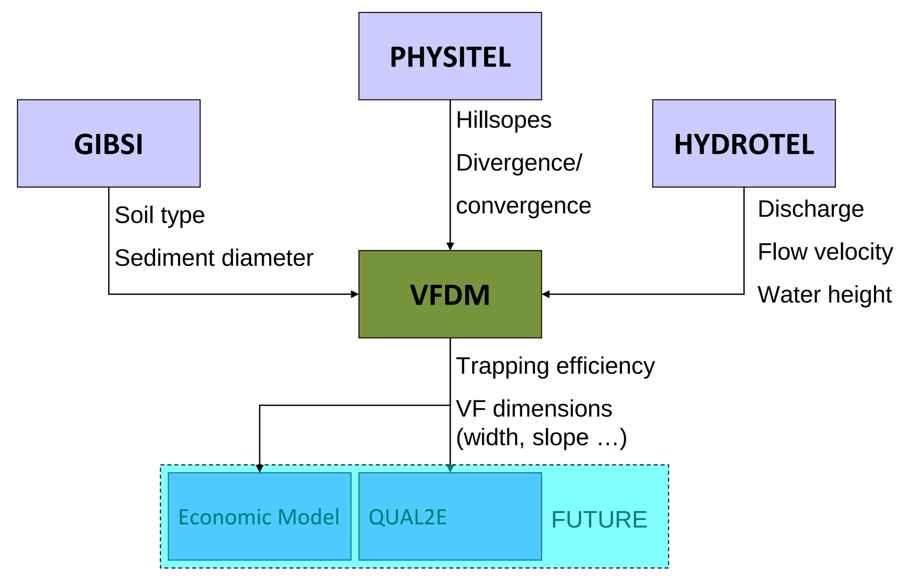
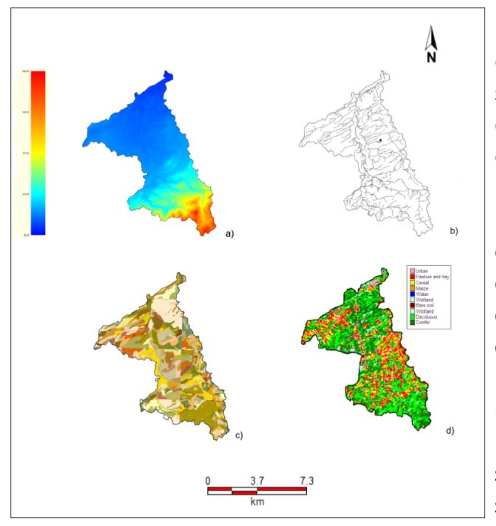
## Model Theory and Concepts

- VFDM is based on a spatial segmentation of the watershed provided by PHYSITEL [5,9]
- Watershed hydrological processes are simulated by HYDROTEL [4,7-8]
- Dimensions of VFs calculated takes into account vegetation density, flow conditions and sediment characteristics
- The model is based on Deletic's filtration equation[2]

### Model Coupling

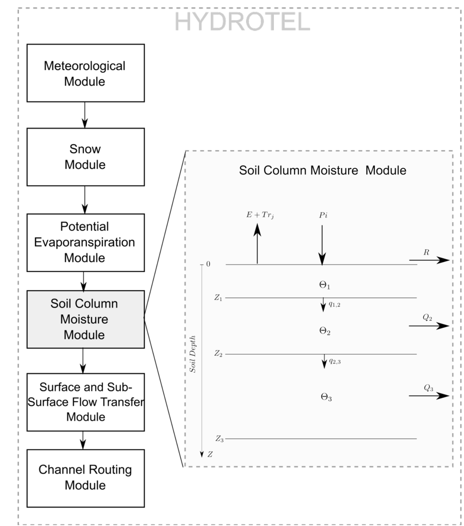



### PHYSITEL and HYDROTEL



PHYSITEL inputs

**PHYSITEL** [5,9] is a specialized GIS developed to determine the flow structure of a watershed. A digital elevation model (a) and a digitized river and lake network (b) represent the key topographic input data to PHYSITEL. Land cover (d) and soil type (c) complete the physiographic characterization of each land computational unit, the relatively homogeneous hydrological unit (RHHU), which can either be a hillslope or an elementary subwatershed (*i.e.*, drained by a single river segment).

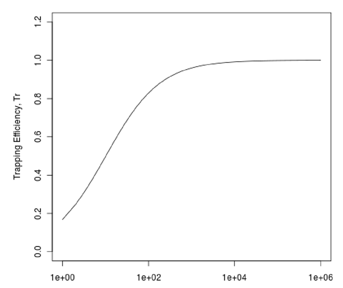



**HYDROTEL** [4,7-8] is at the heart of the hydrological forecasting systems of the Quebec Hydrological Expertise Center and one of two hydrological models currently used by Hydro-Quebec, Quebec's major power utility. HYDROTEL was designed to use available remote sensing and GIS data. The model consists of six computational modules, which are run in a cascade (decoupled manner) using a three-hour or daily time step. It can simulate inflows for the timely management of publicly owned dams and hydroelectric reservoirs, and provide spatially distributed hydrological characteristics such as stream flows along the hydrographic network and soil saturation percentages of each RHHU.

### VFDM Equations and Algorithm

#### Filtration Equation

The behavior of the vegetative filters modeled in VFDM was derived from flume experiments performed by Deletic [1]; Deletic and Fletcher [3].



$$T_r = \frac{N_f^{0.69}}{N_f^{0.69} + 4.95} \qquad N_f = \frac{l \cdot V_s}{h \cdot V}$$

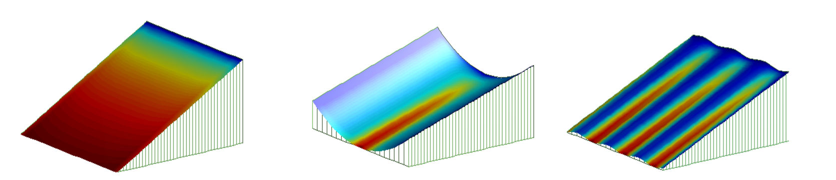
$$V = \frac{q}{B_0 \cdot h} \qquad V_s = \frac{g}{18\mu}(\rho_s - \rho) d_s^2$$

$T_r$ is the trapping efficiency; $N_f$, the particle fall number; $l$, the VF width; $V_s$, the settling velocity, $V$, the mean flow velocity, $B_0$, the vegetation density; $h$, the water height; $\mu$, the dynamic viscosity of water; $q$, the flow rate per unit of hillslope width; $\rho$, the water density; $\rho_s$, the sediment particle density; $g$, the gravitational acceleration; and $d_s$, the particle diameter.

#### Converging/Diverging Flow Phenomena

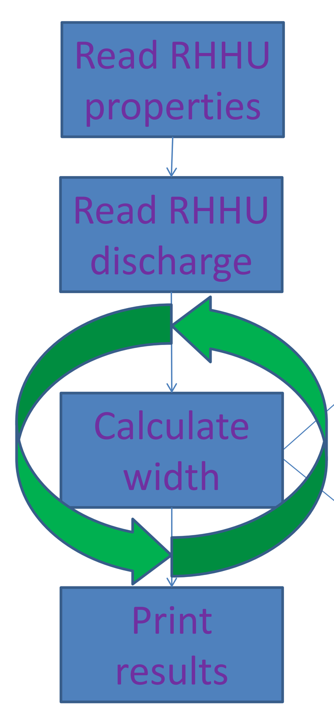
To account for converging/diverging flow phenomena, VFDM introduces virtual channels or rills in the downslope direction, routing runoff and sediments according to plan shape (convergence/divergence) and profile curvature (concave/convex) obtained from PHYSITEL. VFDM simulates flow concentration over VFs.

Flow concentration diminishes effectiveness of VFs by increasing water depth and flow velocity; hence, the width needs to be increased to maintain the same filtration efficiency.



Sheet flow — Converging flow — Semi-converging flow

#### Schematic Algorithm




Begin loop RHHU i=1 to N (RHHU)

Begin loop time j=0 to t (discharge time)

$$[V_{i,j}, h_{i,j}] = call\ Newton-Raphson\ procedure\ (discharge, Nrill, hillslope\ characteristics)$$

$$l_{i,j} = \frac{h_{i,j} \cdot V_{i,j} \cdot 4.95^{1.45} \left(\frac{T_r}{1-T_r}\right)^{1.45}}{V_s}$$

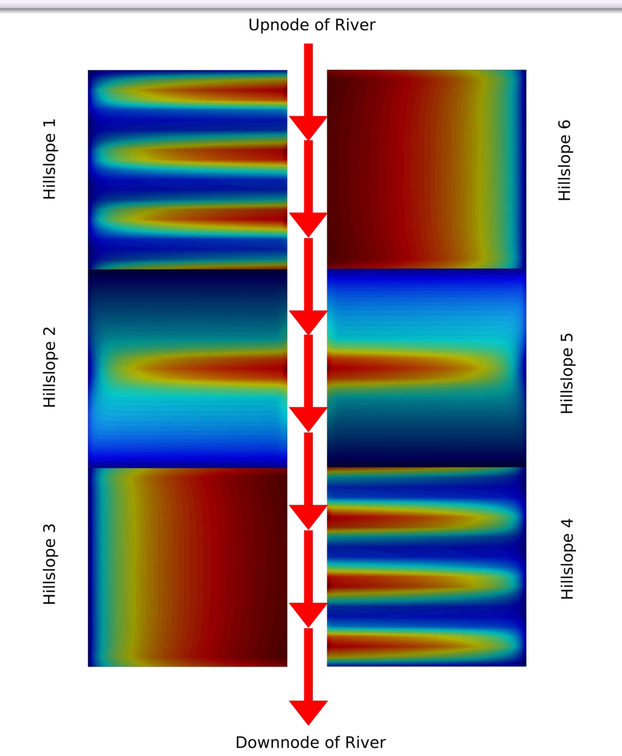
write $l_{i,j}$

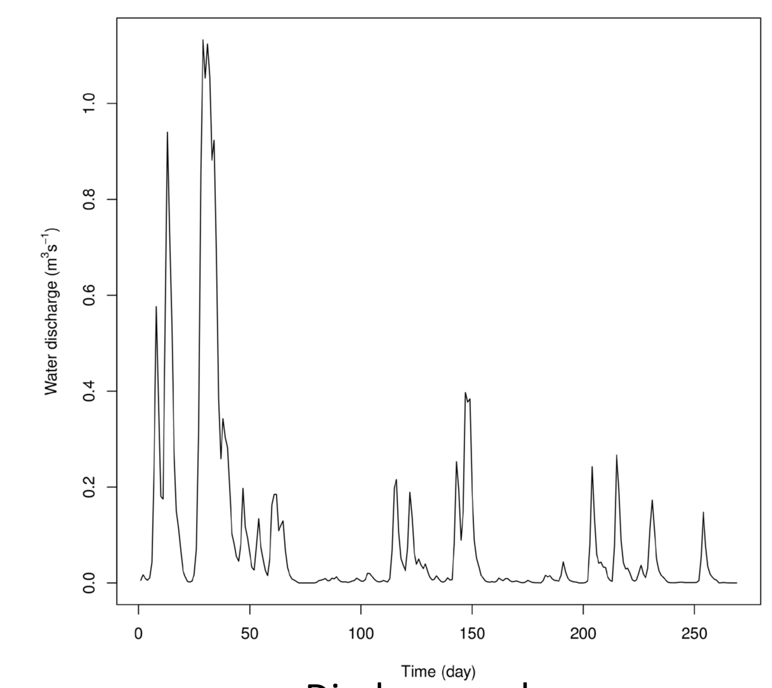
end loop time

end loop UHRH

## Model Application

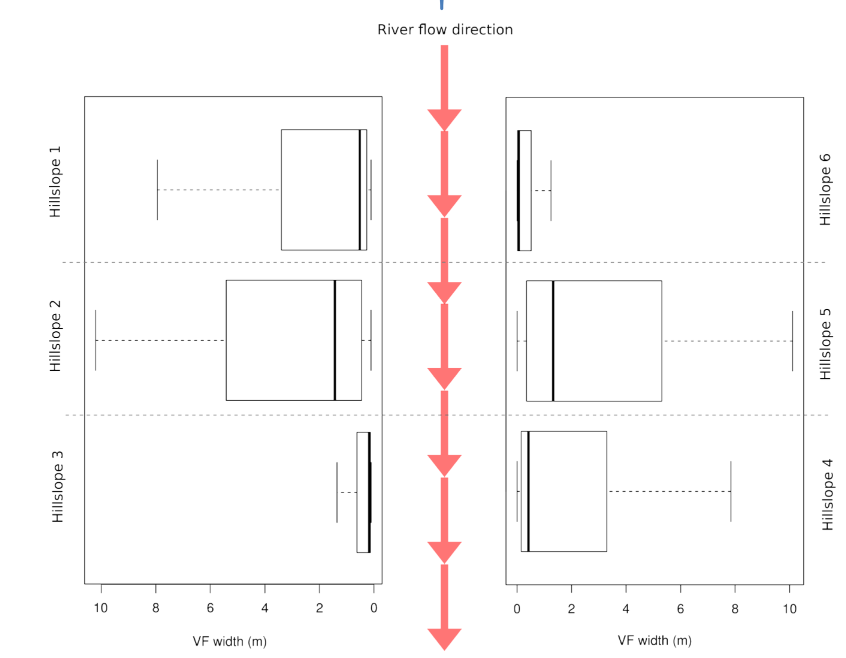
### Virtual Watershed



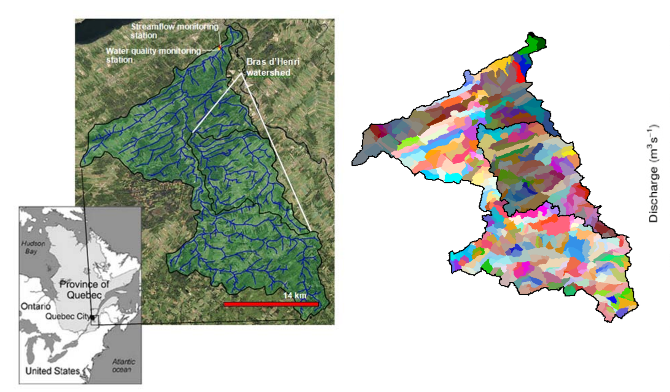



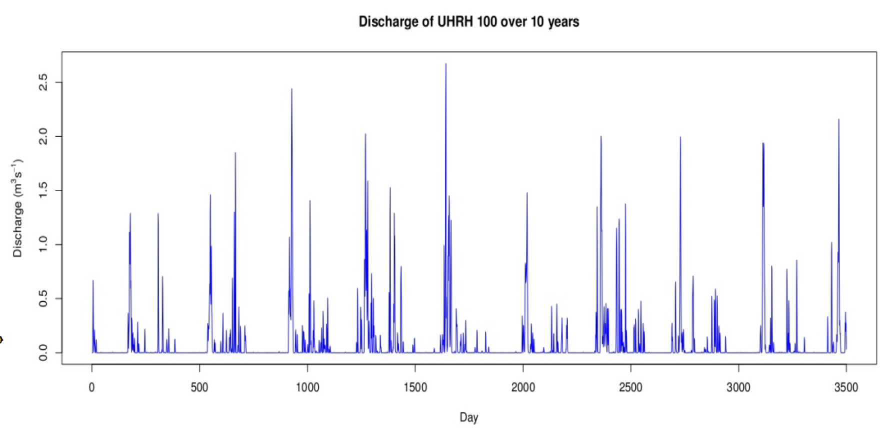

Virtual watershed (6 hillslopes) — Discharge values

VFDM




### Application Watershed: Beaurivage (Quebec, Canada)



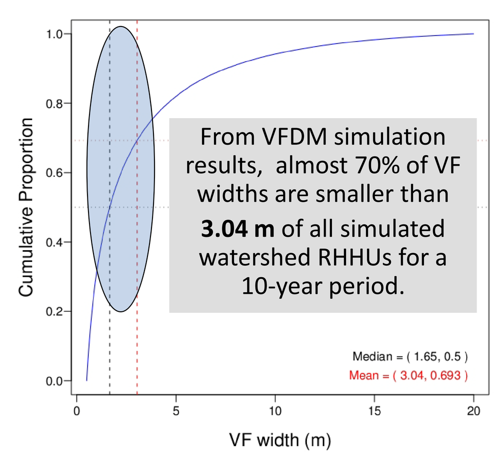

Watershed area: 718 km²

- 675 RHHUs (106 ± 100 ha)
- 34 Lakes (2.15 ± 4.19 ha)
- 609 River Segments (1.20 ± 1.09 km)
- 34 Lake Segments (0.65 km ± 0.48 km)

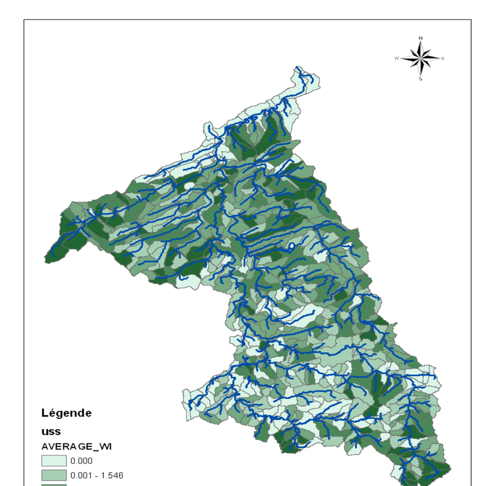
For this test, consider that vegetation is homogeneous and composed by grass, with 80% of density ($B_0$ = 0.8).

To calculate VF width, VFDM requires a threshold value for filtration. For this test, the filtration was set at 80%, in other words, VFs are able to remove 80% of the suspended sediment load in surface runoff.

A 10-year simulated flow series obtained HYDROTEL was used to perform this test.




**VFDM Results**




As VFDM is coupled with the GIBSI [6] integrated modelling platform, VF widths can be showed in a spatially distributed way.

In the map, VF widths are classified by colors going from dark green for larger widths to light green for smaller widts.

This kind of results could be useful to managers, planners and policy-makers dealing with water quality issues.

Mean width of VFs for each RHHU could be presented on either an annual basis or seasonal basis.

### References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