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Remotely-Sensed DTMs for Hydrogeomorphic Applications I Posters

Investigating the spatial variability of hillslope flow velocities

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NEW MEXICO TECH
Surface Hydrology Research Group

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Abstract

The width function (WF), measuring the number of channel links or the portion of contributing area at the same hydrologic distance (i.e. the distance measured along the downhill flow path) to the outlet, is an important river basin and stream network parameter for hydrogeomorphic applications. The rescaled WF, obtained weighting the hydrologic travel distances with the corresponding surface flow velocity, is commonly used in the so-called WF-based Instantaneous Unit Hydrograph or simply WFIUH. The basic assumption of assigning two different constant flow velocities respectively to the hillslope and to channel network has already proven to improve the ability of the WFIUH in characterizing the runoff timing formation and the behaviour of the river basin hydrologic response. Nevertheless, a complete spatially variability of hydraulic conditions at the river basin scale has never been broadly investigated. Aim of this work is to investigate the impact of WF rescaled using a fully spatially distributed field of flow velocities as related to the different terrain morphologic (slope) and land cover properties (vegetation, soil type).

Aim

Aim of this work is to investigate performances when applying a fully spatially distributed hillslope flow velocity field to weight the Width Function as respect to the standard approach which considers a constant runoff velocity.

The Manning Law
applied to each hillslope cell

$$V = \frac{1.49}{n} h^{\frac{2}{3}} \sqrt{S}$$

h = depth of flow
n = Manning's roughness coefficient
S = cell steepest slope
V = hillslope cell velocity

Table 1
The 'n' Manning coefficient
(USDA-SCS, 1986; Ponce, 1989; Kilgore, 1997; McCuen, 1998)

Corine Land Cover	'n' Manning
1.1.1. Continuous urban fabric	0.03
1.1.2. Discontinuous urban fabric	0.05
2.1.1. Non-irrigated arable land	0.12
2.2.1. Vineyards	0.12
2.2.2. Fruit trees and berry plantations	0.12
2.2.3. Olive groves	0.12
2.3.1. Pastures	0.30
2.4.2. Complex cultivation	0.20
2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	0.15
3.1.1. Broad-leaved forest	0.60
3.2.1. Natural grassland	0.25
3.2.3. Sclerophyllous vegetation	0.30
3.2.4. Transitional woodland shrub	0.40
3.3.2. Bare rock	0.10
3.3.3. Sparsely vegetated areas	0.13
3.3.4. Burnt areas	0.10

Methodology

The WF is obtained applying the following procedure to 20 different river basins (*)

1) Artificial depressions are removed from the DEM using the Garbrecht and Martz (1997) procedure, flow directions are characterized using the D8 method (O'Callaghan & Mark, 1984; Jenson & Domingue, 1988) and the stream network is extracted using the automated drop analysis combined with the curvature based method (Tarboton et al., 1991; Tarboton and Ames, 2001).

2) Determination of the Width Function based on the estimation of hydrologic distances measured along the D8-based steepest slope path for the river network and using the D∞ method (Tarboton, 1997; Bogaart & Troch, 2006) for the hillslopes.

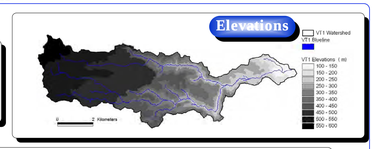
3) Channel cells are assigned a flow velocity of 2 m / s. Hillslope runoff velocities are estimated implementing the uniform flow resistance equation in the Manning form, calculating the local slope 'S' as the steepest slope, and hypothesizing that every cell behaves like a large rectangular section with flow depth equal to 0.01 m; the 'n' Manning coefficient is estimated as function of land cover as shown in Table 1, using the CORINE (Coordination of information on the environment - programme of the Commission European) land cover classification system; a velocity value of 0.05 m / s has been added to formula result to avoid null velocities in correspondence of zero slope.

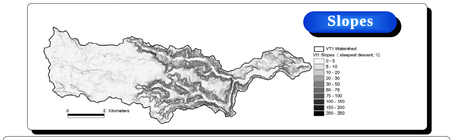
4) Rescaled WFs are determined weighting the WF with the corresponding flow velocity in two conditions: a) a fully spatially distributed hillslope flow velocity field; b) a spatially invariant hillslope flow velocity estimated as the mean of the heterogeneous flow velocity field.

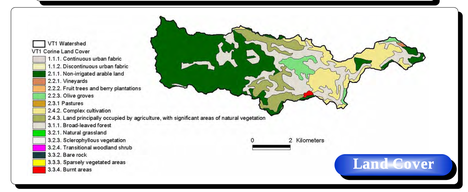
(*) The statistical parameters of all DEMs are reported in the Summary Report; of those 20 DEMs, the first 6 are reported in Figures

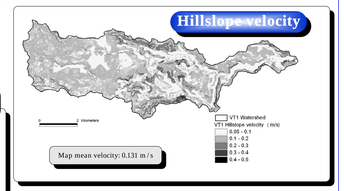
Dem 1

VT1, Italy, Lazio Region; Integer data; Cellsize = 20 m; A = 36.87 Km²



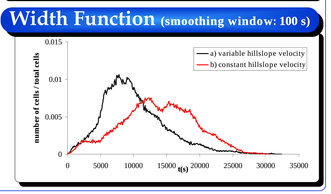






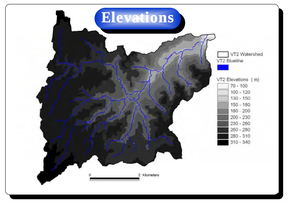
Width Function Statistics

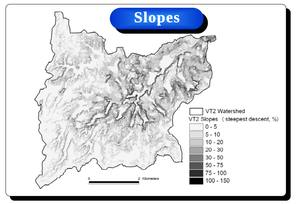
VT1	
<L> (m)	11038
Lmax (m)	20023
a) variable hillslope velocity	
<T> (s)	10100
Tmode (s)	7750
Tmax (s)	32350
Fmode (-)	0.010
M1 = <T> cv / <L>	1.83
M2 = var(T) / <T>²	0.23
M3 = <(T-<T>)³> / var(T)^1/2	0.88
b) constant hillslope velocity	
<T> (s)	13688
Tmode (s)	12250
Tmax (s)	30450
Fmode (-)	0.007
M1 = <T> cv / <L>	2.48
M2 = var(T) / <T>²	0.16
M3 = <(T-<T>)³> / var(T)^1/2	-0.02

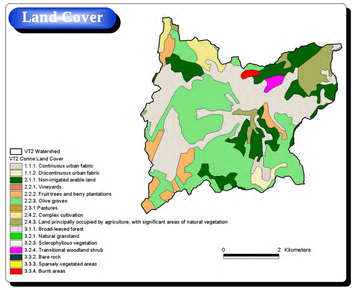


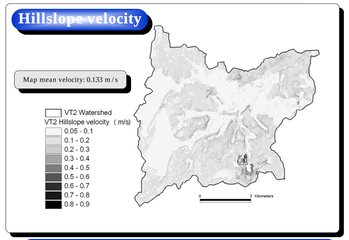
Dem 2

VT2, Italy, Lazio Region; Integer data; Cellsize = 20 m; A = 29.87 Km²



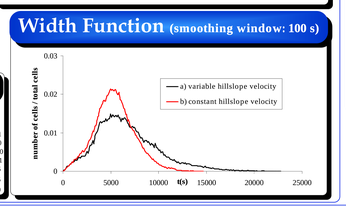






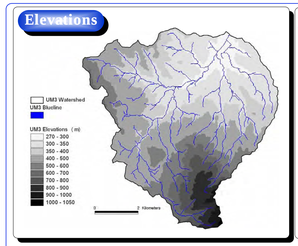
Width Function Statistics

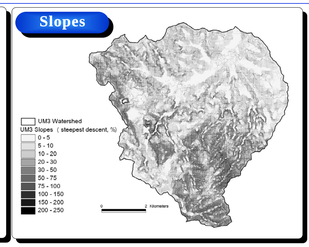
VT2	
<L> (m)	6945
Lmax (m)	11997
a) variable hillslope velocity	
<T> (s)	6710
Tmode (s)	4950
Tmax (s)	22750
Fmode (-)	0.015
M1 = <T> cv / <L>	1.93
M2 = var(T) / <T>²	0.23
M3 = <(T-<T>)³> / var(T)^1/2	0.83
b) constant hillslope velocity	
<T> (s)	5411
Tmode (s)	4950
Tmax (s)	14650
Fmode (-)	0.021
M1 = <T> cv / <L>	1.56
M2 = var(T) / <T>²	0.15
M3 = <(T-<T>)³> / var(T)^1/2	0.29

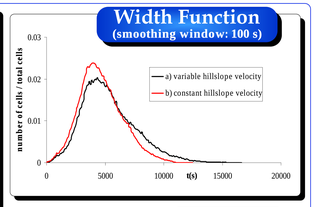


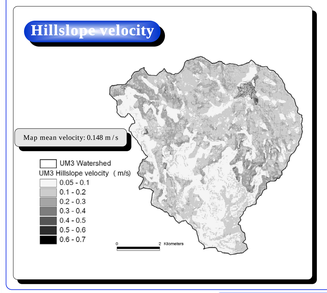
Dem 3

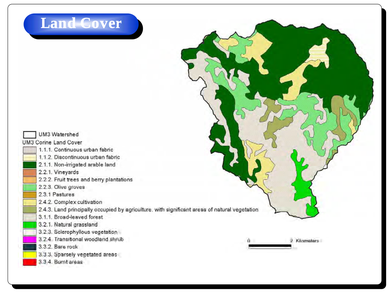
UM3, Italy, Umbria Region; Integer data; Cellsize = 20 m; A = 51.70 Km²









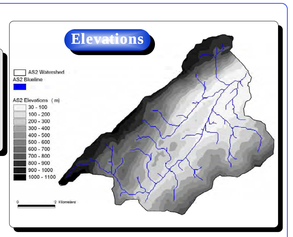


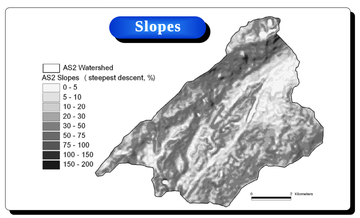
Width Function Statistics

UM3	
<L> (m)	6561
Lmax (m)	14848
a) variable hillslope velocity	
<T> (s)	5332
Tmode (s)	4350
Tmax (s)	16650
Fmode (-)	0.020
M1 = <T> cv / <L>	1.63
M2 = var(T) / <T>²	0.18
M3 = <(T-<T>)³> / var(T)^1/2	0.75
b) constant hillslope velocity	
<T> (s)	4653
Tmode (s)	3950
Tmax (s)	12450
Fmode (-)	0.024
M1 = <T> cv / <L>	1.42
M2 = var(T) / <T>²	0.15
M3 = <(T-<T>)³> / var(T)^1/2	0.45

Dem 4

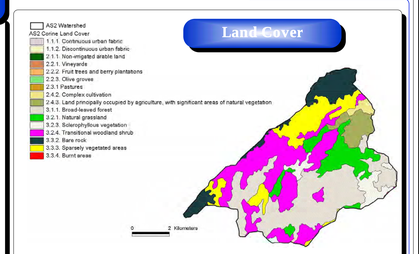
AS2, Italy, Sardinia Region; Integer data; Cellsize = 30 m; A = 53.97 Km²

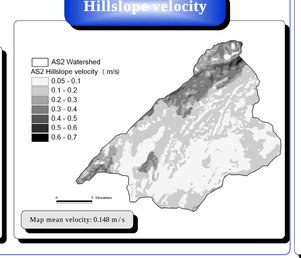


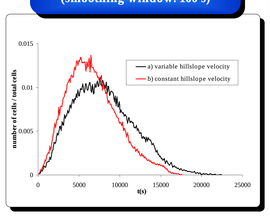


Width Function Statistics

AS2	
<L> (m)	7066
Lmax (m)	15805
a) variable hillslope velocity	
<T> (s)	8028
Tmode (s)	7550
Tmax (s)	22450
Fmode (-)	0.011
M1 = <T> cv / <L>	2.27
M2 = var(T) / <T>²	0.21
M3 = <(T-<T>)³> / var(T)^1/2	0.46
b) constant hillslope velocity	
<T> (s)	6688
Tmode (s)	6450
Tmax (s)	17650
Fmode (-)	0.013
M1 = <T> cv / <L>	1.89
M2 = var(T) / <T>²	0.22
M3 = <(T-<T>)³> / var(T)^1/2	0.55







Summary report: 20 Italian Case Studies

Number	DEM Name	Cellsize (m)	Area (Km²)	Acronym	Case	Fmode (-)	Tmode (s)	Tmax (s)	M1 -	M2 -	M3 -
1	Rio Chiaro	20	36.87	vt1	hv var.	0.010	7750	32350	1.83	0.23	0.88
					hv const.	0.007	12250	30450	2.48	0.16	-0.02
2	Orte	20	29.87	vt2	hv var.	0.015	4950	22750	1.93	0.23	0.83
					hv const.	0.021	4950	14650	1.56	0.15	0.29
3	Gualdo	20	51.70	um3	hv var.	0.020	4350	16650	1.63	0.18	0.75
					hv const.	0.024	3950	12450	1.42	0.15	0.45
4	Sinscola	30	53.97	as2	hv var.	0.011	7550	22450	2.27	0.21	0.46
					hv const.	0.013	6450	17650	1.89	0.22	0.55
5	Rigo	20	84.24	rig	hv var.	0.009	10850	33250	1.77	0.21	0.68
					hv const.	0.010	9150	22650	1.43	0.17	0.32
6	Montecalvello	20	7.37	mon	hv var.	0.031	3150	9750	1.76	0.16	0.54
					hv const.	0.037	3050	7650	1.51	0.14	0.38
7	Loiri	30	131.15	as1	hv var.	0.008	11650	24802	1.37	0.19	0.24
					hv const.	0.008	9150	23113	1.29	0.20	0.21
8	Dorgali	30	35.15	as3	hv var.	0.017	5750	16745	1.85	0.17	0.32
					hv const.	0.018	5250	13696	1.69	0.18	0.24
9	Irgoli	30	63.60	as4	hv var.	0.015	5750	23818	1.70	0.22	1.14
					hv const.	0.016	5650	17790	1.53	0.19	0.71
10	Lodè	30	49.48	as5	hv var.	0.015	6450	22937	1.89	0.21	0.87
					hv const.	0.017	6250	16999	1.58	0.17	0.42
11	Brenta	75	1724.52	bre	hv var.	0.003	38950	97736	1.34	0.12	0.09
					hv const.	0.004	37250	77506	1.22	0.12	-0.14
12	Graffignano	20	5.184	min	hv var.	0.033	2450	8167	1.75	0.24	0.86
					hv const.	0.035	1750	6714	1.55	0.21	0.64
13	Naja	20	12.00	na1	hv var.	0.038	2550	9323	1.63	0.20	0.66
					hv const.	0.041	2550	7473	1.47	0.19	0.52
14	Pascena	40	40.91	pas	hv var.	0.015	6150	19953	1.69	0.25	0.59
					hv const.	0.015	4050	15526	1.51	0.23	0.42
15	Rio Torbido	20	61.66	tor	hv var.	0.009	8550	30550	1.79	0.20	0.56
					hv const.	0.013	8450	21650	1.39	0.14	0.13
16	Pasicale	20	78.45	um1	hv var.	0.013	5950	23050	1.72	0.18	0.50
					hv const.	0.016	5650	18250	1.47	0.14	0.16
17	Fabro	20	12.73	um2	hv var.	0.029	2950	12750	1.40	0.24	0.87
					hv const.	0.030	2850	9750	1.29	0.22	0.55
18	Todi	20	51.69	um4	hv var.	0.014	5250	19150	1.37	0.19	0.14
					hv const.	0.015	5050	13050	1.26	0.20	0.16
19	Montecchio	20	23.94	um5	hv var.	0.027	2950	11150	1.52	0.21	0.62
					hv const.	0.025	2950	9850	1.42	0.21	0.47
20	Vezza	20	167.89	vez	hv var.	0.007	14350	53150	1.71	0.20	0.78
					hv const.	0.009	14150	39150	1.42	0.15	0.37

Legend

'**hv var.**': hillslope velocity variable; case a)

'**hv const.**': hillslope velocity constant (equal to the mean of the previous case a); case b)

'**cv**': channel velocity = 2 m / s for all basins

<L> : mean of travel distance distribution in basin; it quantifies the average distance from one cell to the basin outlet and it is the mean of the Width Function Map not rescaled

Lmax: maximum of travel distance distribution in basin; it is the maximum of the Width Function Map not rescaled

<T> : mean of travel time distribution in basin; it quantifies the average time with which flow reaches the outlet and it is the mean of the Width Function Map rescaled from space to time

Fmode: maximum frequency (number of cells / total cells) in Width Function Map rescaled from space to time

Tmode: it is the time at which it corresponds the maximum of number of contributing cells in the Width Function Map rescaled from space to time

Tmax: maximum of travel time distribution in basin; it is the maximum of the Width Function Map rescaled from space to time

var(T) : variance of travel time distribution in basin

M1 = <T> cv / <L> : first normalized moment (mean) of travel time distribution in basin

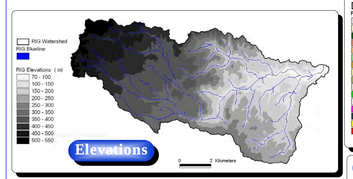
M2 = var(T) / <T>² : second normalized moment (variance) of travel time distribution in basin

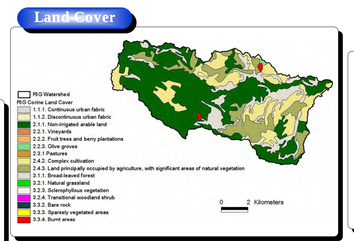
M3 = < (T - <T>)³ > / var(T)^3/2 : third normalized moment (skewness) of travel time distribution in basin

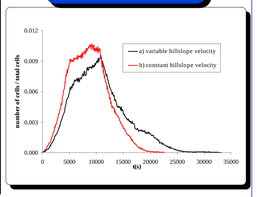
The previous three indexes (Botter and Rinaldo, 2003) allow to compare mean, variance and skewness of travel time distributions for basins with different area.

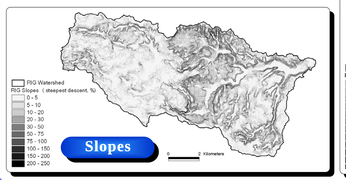
Dem 5

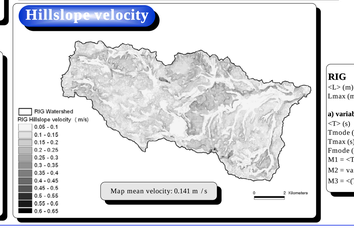
RIG, Italy, Lazio Region; Integer data; Cellsize = 20 m; A = 84.24 Km²









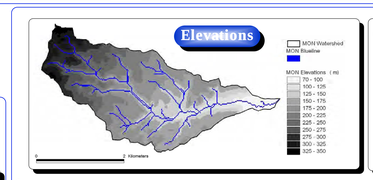


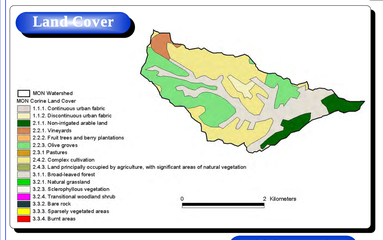
Width Function Statistics

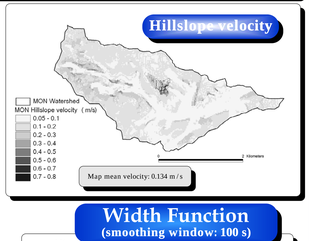
RIG	
<L> (m)	12056
Lmax (m)	23995
a) variable hillslope velocity	
<T> (s)	10669
Tmode (s)	10850
Tmax (s)	33250
Fmode (-)	0.009
M1 = <T> cv / <L>	1.77
M2 = var(T) / <T>²	0.21
M3 = <(T-<T>)³> / var(T)^1/2	0.68
b) constant hillslope velocity	
<T> (s)	8625
Tmode (s)	9150
Tmax (s)	22650
Fmode (-)	0.010
M1 = <T> cv / <L>	1.43
M2 = var(T) / <T>²	0.17
M3 = <(T-<T>)³> / var(T)^1/2	0.32

Dem 6

MON, Italy, Lazio Region; Integer data; Cellsize = 20 m; A = 7.37 Km²

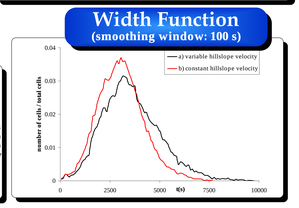






Width Function Statistics

MON	
<L> (m)	4058
Lmax (m)	7186
a) variable hillslope velocity	
<T> (s)	3573
Tmode (s)	3150
Tmax (s)	9750
Fmode (-)	0.031
M1 = <T> cv / <L>	1.76
M2 = var(T) / <T>²	0.16
M3 = <(T-<T>)³> / var(T)^1/2	0.54
b) constant hillslope velocity	
<T> (s)	3063
Tmode (s)	3050
Tmax (s)	7650
Fmode (-)	0.037
M1 = <T> cv / <L>	1.51
M2 = var(T) / <T>²	0.14
M3 = <(T-<T>)³> / var(T)^1/2	0.38



Conclusions

Case studies results show that considering the heterogeneous properties of hillslope runoff dynamics in rescaling the Width Function could significantly affect the hydrologic response in terms of time of concentration, time to peak, total duration and volume distribution.

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