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NEW MODIFIED GREEN-AMPT MODELS TO CALCULATE WATER FLUX VIA UNSATURATED LAYERS, CASE OF SIDI SLIMANE RIVER (ALGERIA)

NOVEAU MODÈLE GREEN-AMPT MODIFIÉ POUR CALCULER LE FLUX D'EAU À TRAVERS LA ZONE NON SATURÉE, CAS DE OUED SIDI SLIMANE (ALGÉRIE)

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ABSTRACT

Calculation of infiltration is important to understand the water movement in soils layers for two main objectives 1) to establish the hydrological water budget for water resources planning and management 2) to study the migration of pollutants via the unsaturated zone. This study was focused on the water flux movement via the unsaturated zone based on a traditional Green-Ampt model. This experiment was realized in the river of Sidi Slimane located at 300 km south of the capital of Algeria (Algiers). Eight soils profiles was studied along the two bank of the river, however a very important results was obtained it show reduction of the water movement of water across soils layers in the direction East-West because of the soils textures variation, these results are confirmed by the chloride mass balance method.

Key words: Infiltration; Green-Ampt model; Chloride mass balance, Sidi Slimane River.

RESUME

Le calcul de l'infiltration est important pour comprendre le mouvement de l'eau dans les couches du sol pour deux principaux objectifs : 1) établir le bilan hydrologique hydrique pour la planification et la gestion des ressources en eau ; 2) étudier la vitesse de migration des polluants à travers la zone non saturée. Cette étude a été axée sur le mouvement du flux d'eau via la zone non saturée basée sur un modèle traditionnel de Green-Ampt (1911). Cette expérience a été réalisée dans la rivière de Sidi Slimane située à 300 km au sud de la capitale algérienne (Alger). Huit profils de sols ont été étudiés le long des deux rives de la rivière, des résultats obtenus montre une diminution des flux d'eau des couches de sols dans la direction Est-Ouest à cause de la variation des textures du sol ainsi la présence d'une couche de sels .les résultats sont confirmé par la méthode du bilan des chlorures

Mots clés : Infiltration ; Modèle Green-Ampt ; Bilan massique du chlorure , rivière Sidi Slimane

INTRODUCTION

The objective of this work is to study the phenomenon of infiltration of precipitation through the unsaturated zone by combining two methods (Green-Ampt model). Water movement is a focus of hydrological research because of its basic role in land-surface and subsurface hydrology (Milla and Kish, 2006). Arid and semi-arid areas are the most vulnerable to the effects of global warming for this reason understanding of water flux for water resources planning and to study the velocity of migration of a contaminant via the Vadose zone are important in the hydrological research.

Many models was used to study water flux in the unsaturated zone, we can cite the Darcy physical law, the chemical tracer method (Chloride mass balance), Green-Ampt model, Richard model and Horton model (Muzzammil and Alam, 2016)

THEORETICAL BACKGROUND

Estimation of infiltration rates is of paramount importance for estimation of groundwater recharge. Numerous infiltration models are in use for estimation of infiltration rates (Zakwan et al, 2016) as example we can cite: Green-Ampt model (1911).

Green-Ampt model (1911)

The Green-Ampt model (Green and Ampt,1911) is a simple vision of the process of the infiltration. The model assumes that a sharp wetting front separates the soil profile into an upper saturated zone and a lower unsaturated zone (Figure.1). The soil water content in the lower unsaturated zone keeps at the initial value (Ma et al, 2010).

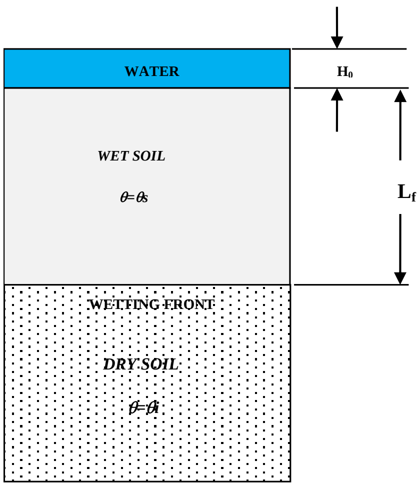

Figure 1 : Green-Ampt model: Lf Depth to wetting front, θ water content

The infiltration rate can be expressed as (Green and Ampt):

$$i = K_s \frac{L_f + H_0 + S_f}{L_f} = K_s \left(1 + \frac{H_0 + S_f}{L_f}\right) \tag{1}$$

Where i is the infiltration rate (cm/min), Ks is the hydraulic conductivity of upper saturated soil (cm/min), Lf is the wetting front depth (cm), Sf is the wetting front suction head (cm), and H_0 is the depth of pounding water (cm).

Wetting front depth was expressed by the following equation:

$$Lf = \sqrt{\frac{2.K.Sf.t}{N}} \tag{2}$$

Where K is the hydraulic conductivity; Sf is the Wetting front suction depth, t is time, and N was the porosity.

Wetting front suction was calculated by the following equation:

$$Sf = \exp\begin{bmatrix} 6.53 - 7.326(\phi) + 0.00158(C^2) + 3.809(\phi^2) + 0.000344(S)(C) - \\ 0.04989(S)(\phi) + 0.0016(S^2)(\phi^2) + 0.0016(C^2)(\phi^2) - \\ 0.0000136(S^2)(C) - 0.00348(C^2)(\phi) - 0.000799(S^2)(\phi) \end{bmatrix} \quad (3)$$

Where S: percent sand; C: percent clay; ϕ: porosity

MATERIALS AND METHODS

The experiment was focused on eight soils profiles realized in the two bank of Sidi-Slimane River in the 14 February 2016; theses locations are selected to study the water flux movement in response of a storm event and in results of inter-flow phenomena.

Physical and chemical characteristics of soils samples were established in the laboratory of Natural and life sciences at the university of Khemis-Miliana (Algeria); parameters like bulk density was determinate in filed by using a specific cylinder; however the chloride concentration, ph, electrical conductivity were determinate after dilution of prepared soils samples into distilled water. Water content in soil was determinate by the difference between the initial mass of soils and the mass of soil after drying. Porosity was calculated from bulk density value (Ruth Uloma et al, 2014).

STUDY AREA

Sidi Slimane River was located in the watershed of Oued Djelfa Melah (Figure-2), at 290 km south to the capital of Algeria (Algiers). It was under Mediterranean climate with a cold and rainy winter and a hot and dry summer. Annual rainfall is around 336 mm. The inter-annual average temperature is 14.6°C. The calculation of the water balance by the method of Thornthwaite revealed that evapotranspiration gives a value of 804.66 mm and an ETR of 278.12 mm (Chibane and Ali Rahmani, 2015).

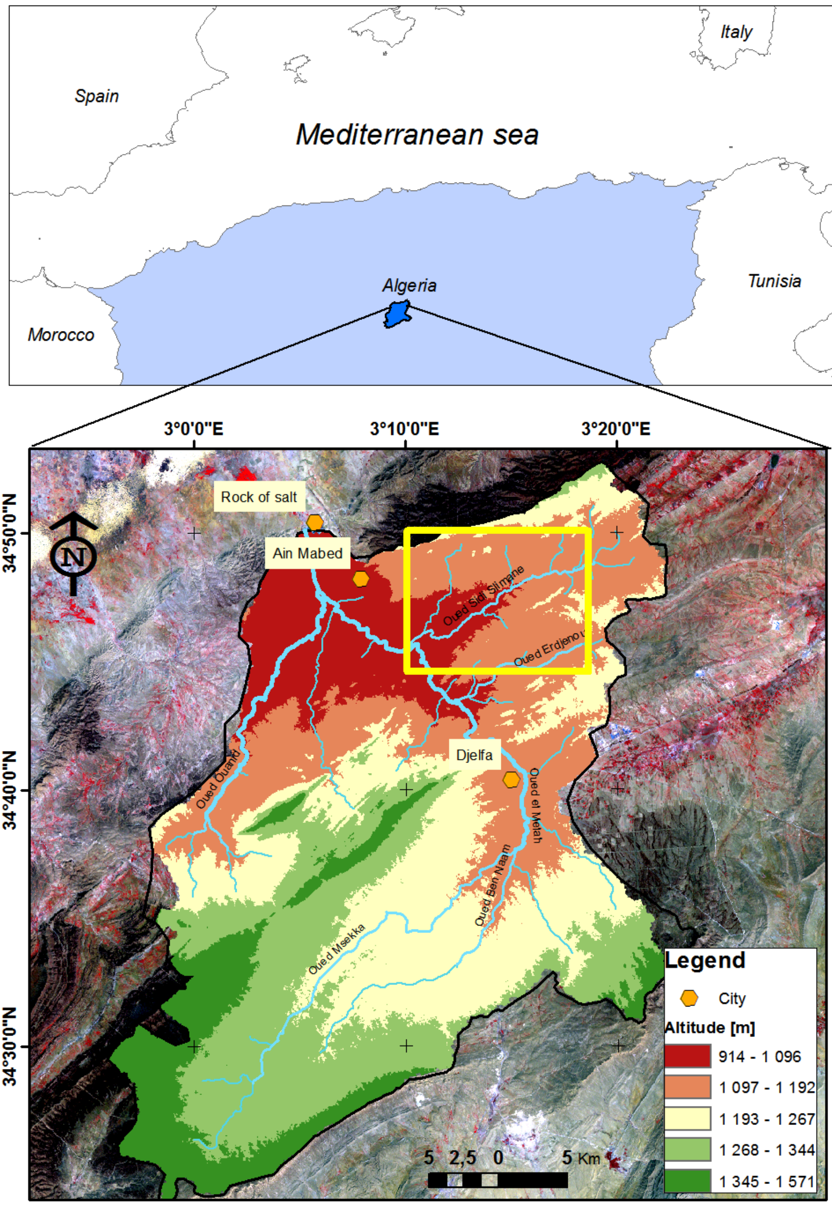

Figure 2: Study area (watershed of Djelfa-Melah River)

Figure 3: Sidi Slimane river

Figure 5: P3 soil profile location (Right river bank)

Figure 4: P5 soil profile location (Left river bank)

RESULTS AND DISCUSSION

Soils Properties and textural class:

Firstly, experimental work by using the Robinson's Pipette allows distinguishing three soils classes in the study sites (Table-1). The first class is Clay-Sandy; it was identified in five locations (P1, P2, P3, P4 and P8), theses classes were characterized by porosity that varying between 36% and 56 %. The second class is Sandy-Clay-Loam, it was identified in P5 and P6 location, in the other way the third class is Sandy-loam, it was identified in the P7 location.

Table 1: Properties of the Soils and Textural class

Id	*Profile*	B_d	Porosity	Sand (%)	Clay (%)	Silt (%)	Soils class
P1	profile P1	1,42	0,49	48,29	42,40	9,31	Clay-Sandy
P2	profile P2	1,39	0,50	44,40	39,00	16,60	Clay-Sandy
P3	profile P3	1,27	0,56	50,16	44,00	5,84	Clay-Sandy
P4	profile P-1	1,40	0,46	51,20	38,20	10,60	Clay-Sandy
P5	**profile P1'**	**1,96**	**0,24**	**68,28**	**27,00**	**4,72**	Sandy –Clay-Loam
P6	**profile P2'**	**1,42**	**0,44**	**63,45**	**33,40**	**3,15**	Sandy –Clay-Loam
P7	**profile P3'**	**1,74**	**0,33**	**72,25**	**15,80**	**11,95**	Sand-Loam
P8	profile P-1'	1,68	0,36	49,64	37,60	12,76	Clay-Sandy

The statistic summary of Soils properties is shown in the Table 2.

Table 2: Statistic of Soils properties

Parameters	B_d	Porosity	Sand (%)	Clay (%)	Silt (%)
mean	1,54	0,42	55,96	34,68	9,37
min	1,27	0,24	44,40	15,80	3,15
max	1,96	0,56	72,25	44,00	16,60
sdv	0,22	0,10	9,76	8,68	4,25
cv	0,14	0,23	0,17	0,25	0,45

The bulk density (B_d) in soils samples was vary between 1.27 g/cm3 and 1.96 g/cm with an average of 1.54 g/cm3 , the coefficient of variation is 14 % which mean that soils type across the river are homogenous.

Soil porosity are variable in the two bank of Sidi Slimane River, it vary from 24% measured in P5 and 56 % measured in P3. The variation of porosity is explained by the percentage of sand in soils layers. The percentage of sand is varying from 44.40 % in soil samples of P2 to 72.25 % in P7. In addition the Clay percentage in soils samples was range from 15.80 % measured in P7 to 44 measured in P3.

The Silt present a small content in soils samples along the river, its percentages vary from 3.15 % measured in location P6, to 16.6 % measured in P2. With high variation coefficient about 45% which mean a considerable heterogonous in matter of composition of Silt can be distinguished along the two bank of river.

Simulation of Infiltration rate

Infiltration rate for the eight profiles was obtained by simulation of the Green-Ampt model, results are showed in curves of figure-6, and the Wetting front depth was shown in figure 7.

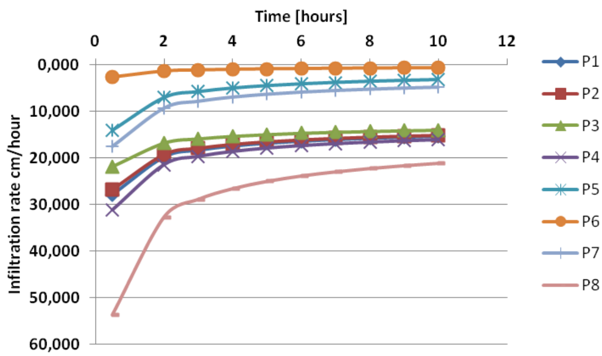

Figure 6: Infiltration rate [cm/hour] in the 8 location

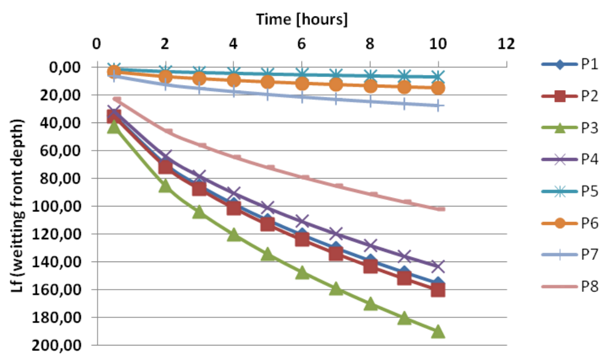

Figure 7: Wetting front depth across the two bank of the river

The duration of infiltration process was setted to 10 hours, where the infiltration rate curve for every location was obtained. From theses curves we conclude that for the profiles P1, P2, P3, P4 and P6; the infiltration rate has the same amplitude, is characterized by a small rate. The water infiltration is down until the saturation was achieved after 02 hours with a rate of 15 cm/hour.

This small rate can be explained by the hydraulic properties of theses soils which not permute rapid infiltration. The interaction between channel river and soil layers was observed in the lateral moisture in the deep of the profiles. In this region and such kind of same climate (Semi-arid), aquifer recharging is very slow across the soils layers, the high depth of soils and the irregular climatic conditions favorite the re-evaporation of soil water before its arriving at the Vadose zone. Theses complicate process make the phenomena of groundwater recharge very slow and not significant if the rain event is short with low intensity. The characteristics of the right bank of river mean that the water movement was slow and difficult because of the soils characteristics.

In the other way the high infiltration rate was recorded in the profile (P5); with 66 cm/hour, and the P7 with 30 cm/hour and the P8 was 26 cm/hour.

Theses profiles was located in the left bank of the river , theses difference can be explained by the presence of high density cover of trees in the left side of the river, the deep root of these trees create a deep hydraulic micro-channel in soils which accelerate the water velocity across the soils layers (Edwards and Webb, 2009).

The results obtained are compared to the chloride mass balance method which confirms theses explanations (Figure-8), also these high variations is due to soil texture because it influences many different characteristics as the porosity and the hydraulic conductivity

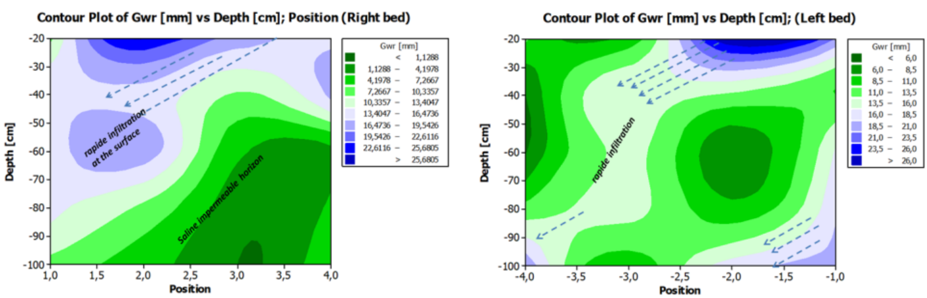

Figure 8: 2D contour plot of water flux estimated by using the chloride mass balance methods in soils profiles of the two bank of Sidi-Slimane River in function of profiles location and depth.

According to the results obtained by the chloride mass balance (CMB) it appear that the water flux via the unsaturated zone is not with the same rate in the two bank of river, the water movement in the soil layer of the left bank is rapid because the presence of a high percentage of sand which favorite a good movement. The water flux was evaluated from 6 mm to 26 mm against the right bank which vary from 1 mm to 25 mm.

New formulation of the Green-Ampt Model

After the experimental test, correlation between the bulk density values and the porosity of soil profiles allow us to express the variation of the Bulk density by the equation (eq.6):

$$B_d = -0.020(\phi) + 2.369 \quad (6)$$

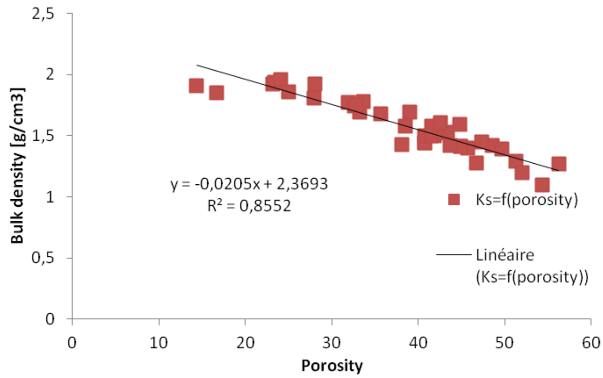

Figure 9: The bulk density expressed in function of the porosity

Where B_d is the predicted Bulk density given in g/cm3 and ϕ was the porosity of soil. The Wet front suction was expressed also in function of the porosity of soils .the results was showed in the figure 10.

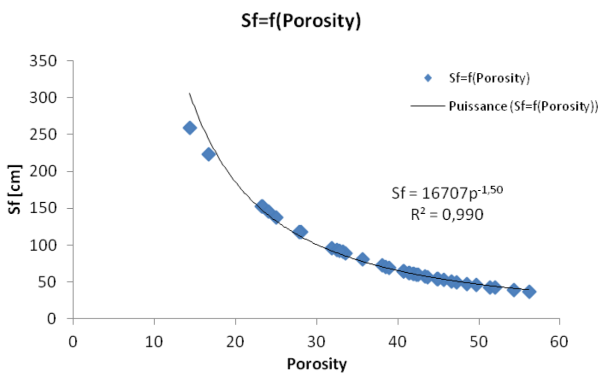

Figure 10: Suction front head expressed in function of the porosity

After the experimental test, correlation between the suction front head values and the porosity of soil profiles allow us to generate a power model which allow us to calculate theoretical the suction front in function of the porosity given in percent .

$$Sf = 16707 \times \phi^{-1.50} \quad (7)$$

Sf: suction front given in cm

Model 01

The modified Green-Ampt infiltration rate was calculated by the new equation:

$$fm1 = 0.5 \times K \times \frac{16707 \times \phi^{-1.50} + 7.1K^{0.509}}{7.1K^{0.509}} \quad (8)$$

Model 02

$$\begin{aligned} fm2 &= 1.5 \times K \times \frac{Sf^{0.9}}{\phi} = 1.5 \times K \times \frac{\left(16707 \times \phi^{-1.50}\right)^{0.9}}{\phi} \\ &= 1.5 \times K \times \frac{6318.42 \times \phi^{-1.35}}{\phi} \\ &= 1.5 \times K \times 6318.42 \times \phi^{-1.35}\phi^{-1} \\ fm2 &= K \times 9477.63 \times \phi^{-2.35} \end{aligned} \quad (9)$$

To test the performance of the two modified model, we compare the observed and simulated data, by using the Root mean square error, the mean absolute error, the Nash coefficient and the arithmetic mean error (Table-3).

Table 3: Performance of the developed models:

Parameter	***Erreur***	
	Model 1	***Model 2***
Nash	0,81	0,952
MAE	4,438	4,828
RMSE	14,139	7,089
AME	24,308	26,443

It appear that the response of the second developed model is good with a Nash coefficient f 0.952 (Best = 1) and the MAE was approached to 4.828; the RMSE give a value of 7.089.

The arithmetic mean error value is approached to 26.5 % (Best < 50%) which indicate that this second developed model give a best value according to these statistic parameters.

CONCLUSION

This study presented a modified Green–Ampt model to predict infiltration through layered soils. An experimental work was down to study water movement in the unsaturated zone, in the two bank of Sidi Slimane River. Results obtained were accredited by a tracer chemical method called Chloride mass balance. The main principles results show that principles soils classes are Sandy-clay; sandy-clay-loam and sandy loam soils. The porosity of soils was varying between 24% and 56 % and the bulk density was varying between 1.27 g/cm3 to 1.96 g/cm3 in the eight profiles samples. Green-Ampt model simulation let us to determinate the infiltration rate by introducing the Wetting front depth and the suction depth was calculated in the basis of the sand-clay compositions and porosity of soil.

The infiltration rate is variable in the two bank of river which it is high in the left side against the right side. These important results obtained, let us to appreciate that the water movement in the soils layers are so slow which don’t permute a good supply of the aquifer systems. Which make the recharge via the unsaturated zone very low. The chloride mass balance method shows that the water flow via the unsaturated zone was so small, its rate is important in the left bank of the river. The developed models are depending on two parameters the hydraulic conductivity and the porosity of soil.

REFERENCES

ADINDU R.U, AKOMA C. S., IGBOKWE K.K. (2014). Estimation of Kostiakov’s Infiltration Model Parameters of Some Sandy Loam Soils of Ikwuano – Umuahia,Nigeria, Open Transactions On Geosciences, Vol. 1, n°1, pp.34-38.

ALLISON GB, HUGHES MW. (1983). The use of natural tracers as indicators of soil-water movement in a temperate semi-arid region, Journal of Hydrology, Vol.60, Issue 1, pp.157 – 173.

CHIBANE B., ALI-RAHMANI S.E. (2015). Hydrological Based Model to Estimate Groundwater Recharge, Real Evapotranspiration and Runoff in Semi-Arid Area, Larhyss journal, n°23, pp.231-242.

GREEN W.H., AMPT G. (1911). Studies of soil physics; part I-the flow of air and water through soils. J. Ag. Sci., n°4, pp.1-24.

MATTHEW E., WEBB J. (2009). The importance of unsaturated zone biogeochemical processes in determining groundwater composition, southeastern Australia, Hydrogeology Journal, September 2009, Vol. 17, Issue 6, pp.1359-1374

ZAKWAN M., MUZZAMMIL M., ALAM J. (2016). Application of spreadsheet to estimate infiltration parameters, Perspectives in Science, Vol. 8, pp.702–704, http://dx.doi.org/10.1016/j.pisc.2016.06.064

MILLA K., KISH S. (2006). A low-cost microprocessor and infrared sensor system for automating water infiltration measurements. Computers and Electronics in Agriculture, Vol.53, Issue 2, pp.122–129.

CANLON B.R. (1991). Evaluation of moisture flux from chloride data in desert soils. Journal of Hydrology, Vol.128, Issues 1-4, pp.137 – 156.

SCANLON B.R. GOLDSMITH R.S. (1997). Field study of spatial variability in unsaturated flow beneath and adjacent to playas. Water Resources Research, Vol.33, Issue 10, pp.2239 – 2252.

SHARMA M.L. (1988). Recharge estimation from the depth –distribution of environmental chloride in the unsaturated zone: Western Australia examples, In:Estimation of natural groundwater recharge, SIMMERS I.(Ed.), pp.159-173.

YING. M.A., SHAOYUAN F., DONGYUAN S., GUANGYAO G., ZAILIN H. (2010). Modeling water infiltration in a large layered soil column with a modified Green–Ampt model and HYDRUS-1D, Computers and Electronics in Agriculture, Vol.71, Supplement 1, pp.S40–S47

ROGER NORRIS H., THOMAS M.L., TOLLNER E.W. (2008). Modeling stormwater runoff from green roofs with, HYDRUS-1D, Journal of Hydrology, Vol.358, Issues 3-4, pp.288–293.