Using JULES to simulate infiltration and surface runoff in situations of intense rainfall

JULES Conference
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Overview of talk:

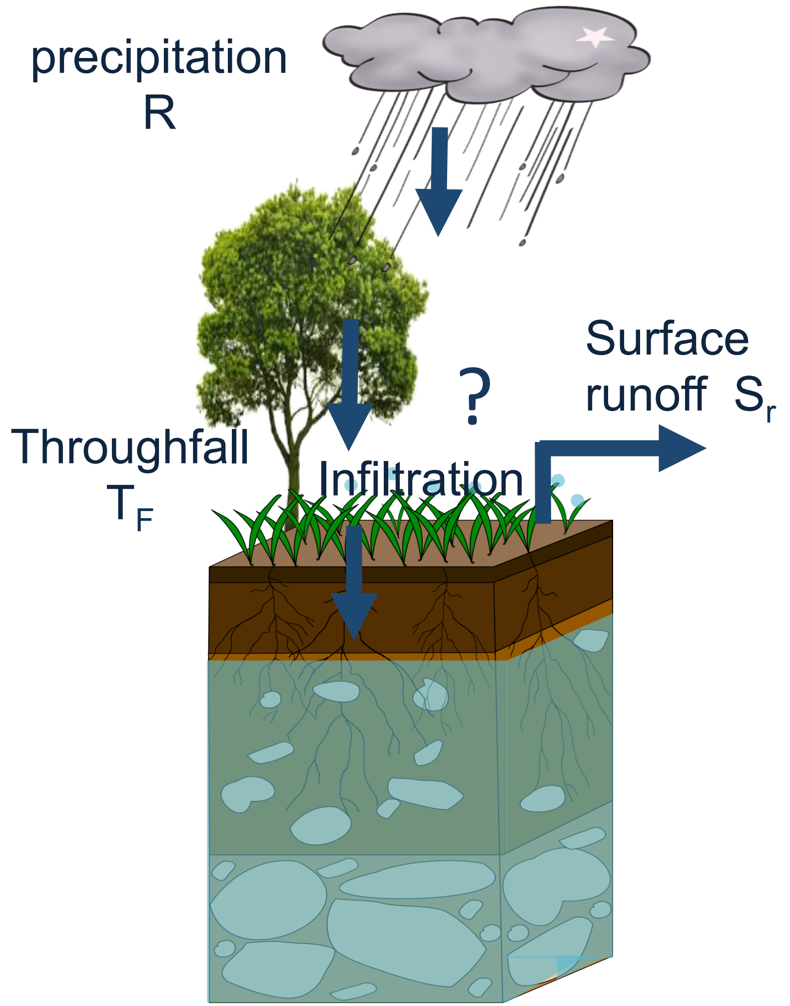
1. Infiltration theory

2. Methods:
   1. Methods of infiltration used in Land surface models
   2. New scheme of infiltration in JULES

3. Results: Comparison of observed and modelled river flow for a UK catchment (Ure)

4. Conclusions and Outlooks

Schematic of infiltration processes:



Actual infiltration depends on value of T_F and maximum infiltration I_{max}

If $T_F > I_{max}$: Surface runoff $= T_F - I_{max}$
If $T_F < I_{max}$: Infiltration $= T_F$

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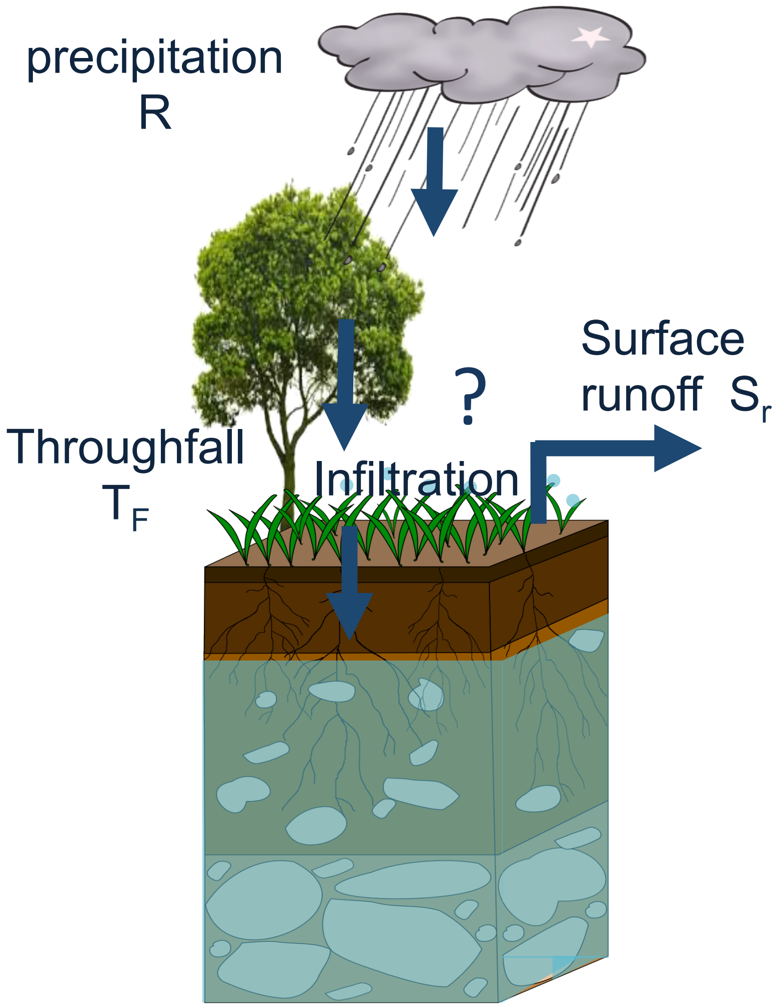
Schematic of infiltration processes:



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Standard version of JULES: $I_{max} = \beta \ K_{sat}$

20 mm/d < K_{sat} = f(soil) < 1200 mm/d

PFT Number	default value
Broadleaf tree	4.00
Needleleaf tree	4.00
C3 grass	2.00
C4 grass	2.00
Shrubs	2.00
Urban	0.10
Open water	0.00
Bare soil	0.50
Ice	0.00

Infiltration scheme used in Land Surface models:

Model	Institution	Reference	Maximum infiltration method	Actual infiltration method
JULES	Met Office	(Best et al., 2011)	Fixed Imax rate	SWB
VIC	Princeton Uni.	(Gao et al., 2010) (Liang et al., 1996)	VIC scheme	SWB
ISBA	Meteo-France	(Decharme and Douville, 2006) (Noilhan and Mahfouf, 1996)	VIC scheme	SWB
ORCHIDEE	IPSL	(Krinner et al., 2005)	VIC $I_{max}=f(\theta)$	probability distrib.
CLM	NCAR	(Oleson et al., 2010)	VIC $I_{max}=f(\text{texture},\theta)$	SWB
HTESSEL	ECMWF	(Balsamo et al., 2009)	VIC $I_{max}=f(\theta,\text{orog.})$	SWB
NOAH	NCEP	(Schaake et al., 1996)	VIC $I_{max}=f(\theta,K_{sat})$	SWB
CLASS	Canada	(Verseghy, 1991)	Green-Ampt	Green-Ampt $I=f(K,\Psi)$
CABLE	Australia	(Haverd and Cuntz, 2010)	No I_{max}	SWB
MATSIRO	Japan	(Takata et al., 2003)	No I_{max}	SWB
G2G	CEH	(Bell et al., 2007, 2009)	VIC $I_{max}=f(\theta)$	probability distrib.

Adaptation from the work of H.Ashton

VIC: Variable Infiltration Capacity
SWB: Surface Water Balance

$$I = \Sigma_{i=1}^{nPFT}(T_{fall} + M - S_{\text{runoff}})$$

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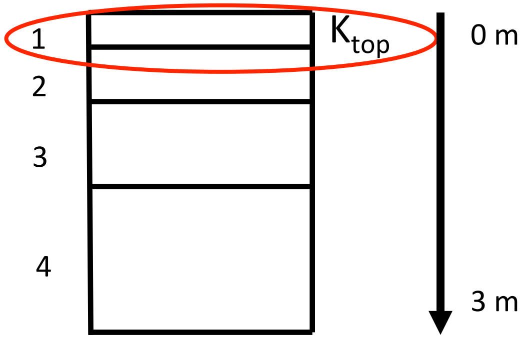
Variable maximum infiltration schemes:

- Standard Scheme $$I_{max} = \beta K_{sat}$$
- New scheme of infiltration $$I_{max} = \beta K_{top}$$



Comparison of river flow in a small catchment:

- Standard Scheme $I_{max} = \beta K_{sat}$ (CTL)
- New scheme of infiltration $I_{max} = \beta K_{top}$ (β K)

- Scheme PDM activated (PDM)
- Scheme PDM deactivated (NO PDM)

- Observation (National River Flow Archive)

PDM scheme :

- Calculation of the fraction of the grid which is saturated F_{sat}
- Generate surface runoff from saturation excess

$$F_{sat} = 1 - \left(\frac{S - S_0}{S_{max} - S_0} \right)^{\frac{b}{b+1}}$$

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Evaluation of the model : Kling-Gupta Efficiency

$$KGE = 1 - \sqrt{(\underbrace{\frac{Cov_{sim,obs}}{\sigma_{simu}\sigma_{obs}}}_{\rho} - 1)^2 + (\underbrace{\frac{\sigma_{sim}}{\sigma_{obs}}}_{a} - 1)^2 + (\underbrace{\frac{\mu_{sim}}{\mu_{obs}}}_{b} - 1)^2}$$

Comparison of river flow in a small catchment:

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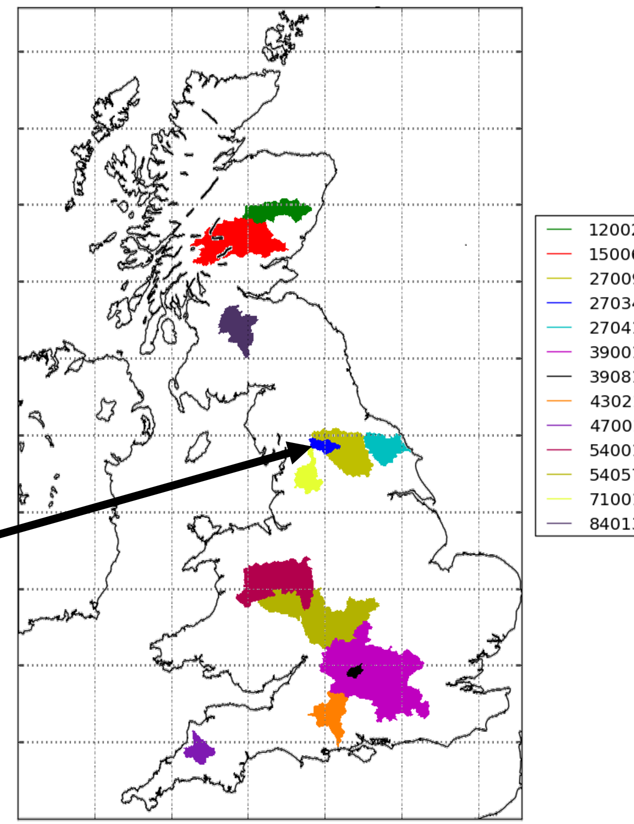
- Scheme PDM activated (PDM)
- Scheme PDM deactivated (NO PDM)
- Observation (National River Flow Archive)

Ure catchment area: 510 km^2
10 years period: 1991-2000

meteorological forcing used: CHESS (CEH)
- 1 km^2 spatial resolution
- daily precipitation
- using RFM for each simulation



Res. Note UKEP A.Martinez

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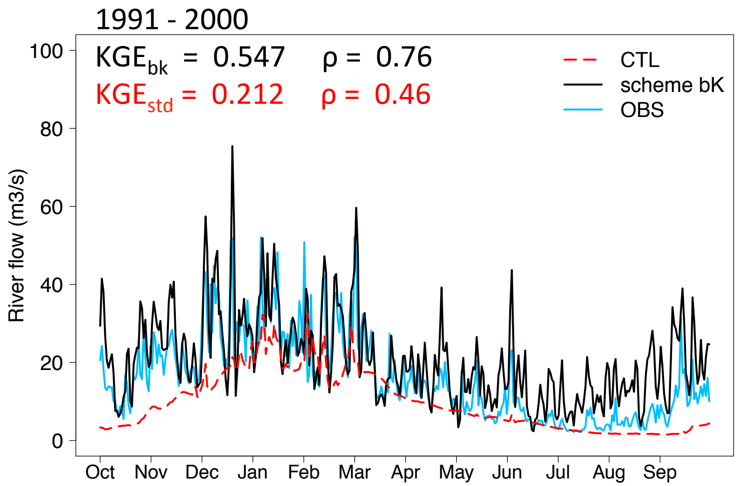
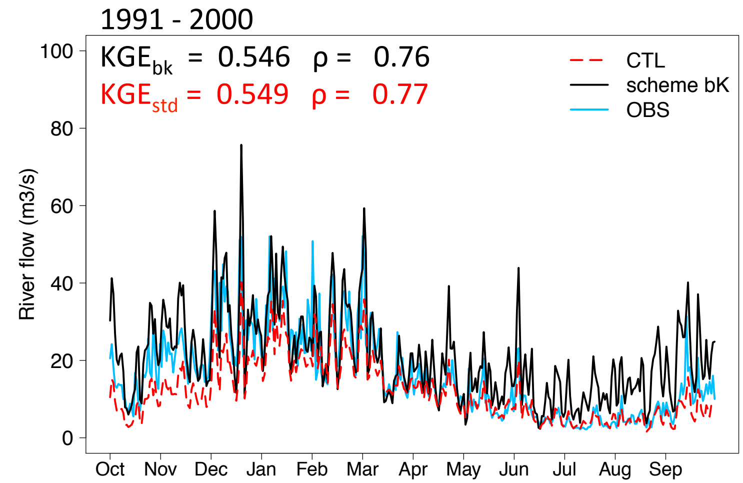
New scheme (scheme bK)
Standard scheme (CTL)

Comparison of river flow in a small catchment:

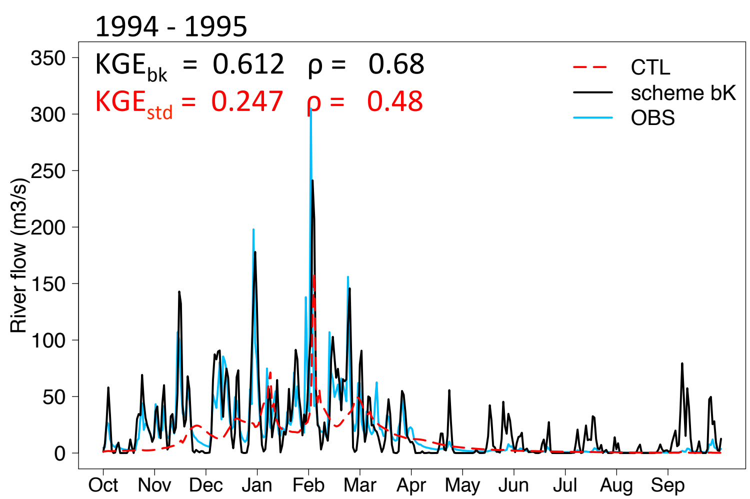
PDM deactivated (NO PDM) | **PDM activated (PDM)**

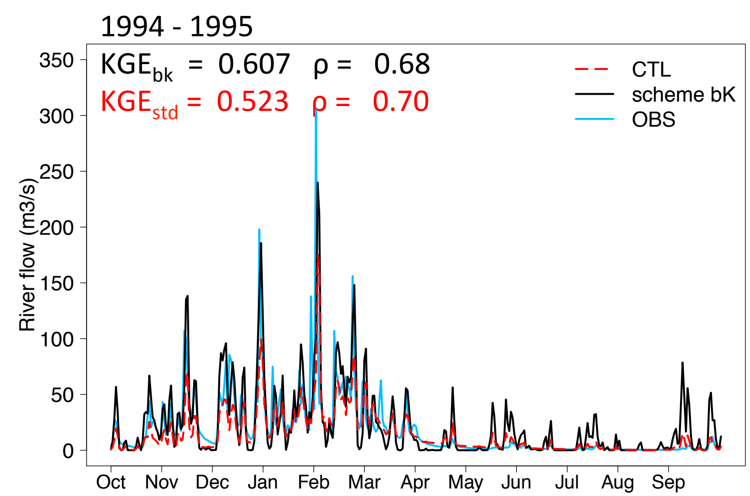
Daily annual mean 1991 - 2000





Oct. 1994–1995 Peak river flow period





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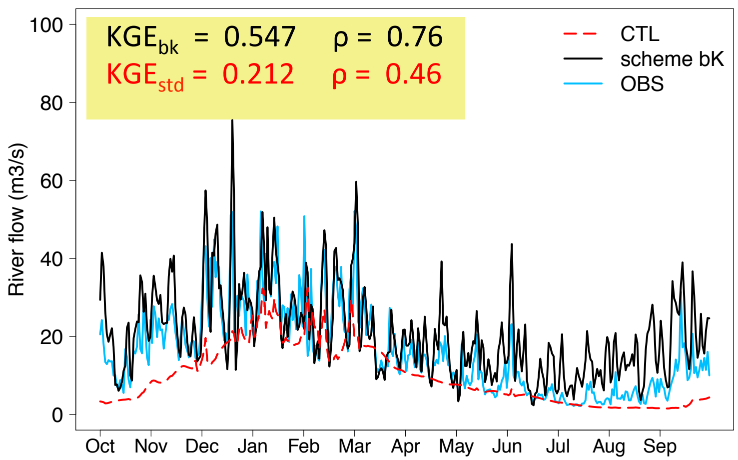
New scheme (scheme bK)
Standard scheme (CTL)

Comparison of river flow in a small catchment:

PDM deactivated (NO PDM)

1991 - 2000



ρ = 0.76	ρ = 0.46
b = 1.28	b = 0.63
a = 1.26	a = 0.55

$$KGE = 1 - \sqrt{\underbrace{\left(\frac{Cov_{sim,obs}}{\sigma_{simu}\sigma_{obs}} - 1\right)^2}_{\rho} + \underbrace{\left(\frac{\sigma_{sim}}{\sigma_{obs}} - 1\right)^2}_{a} + \underbrace{\left(\frac{\mu_{sim}}{\mu_{obs}} - 1\right)^2}_{b}}$$

New scheme (scheme bK)
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Comparison of river flow in a small catchment:

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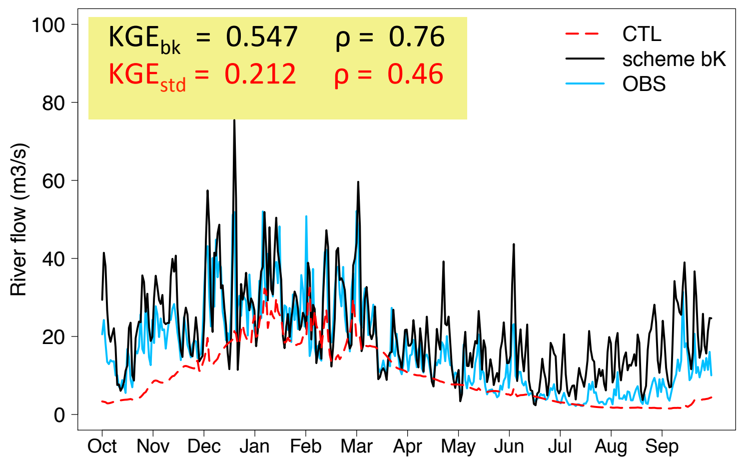

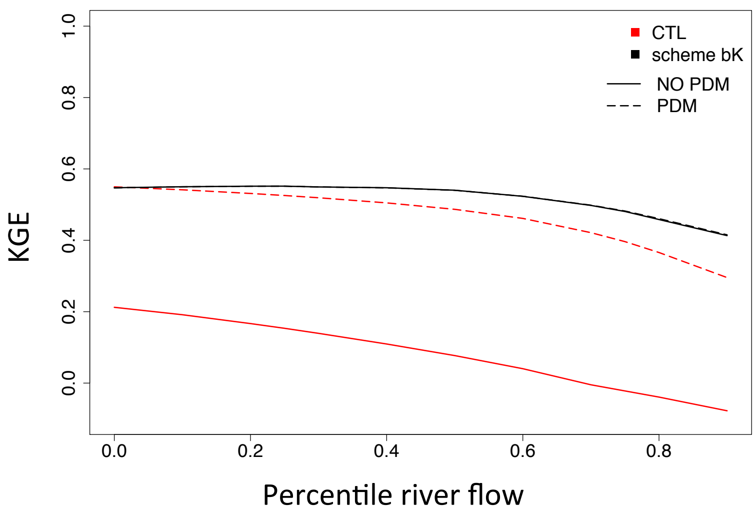

scheme bK	CTL
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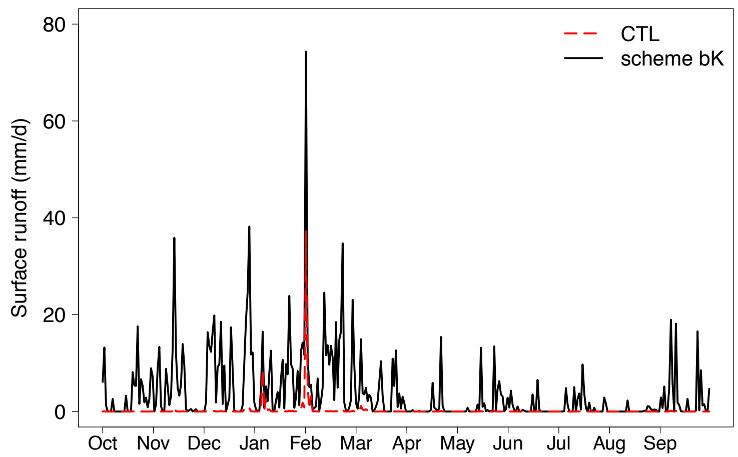
Comparison of surface runoff in a small catchment:

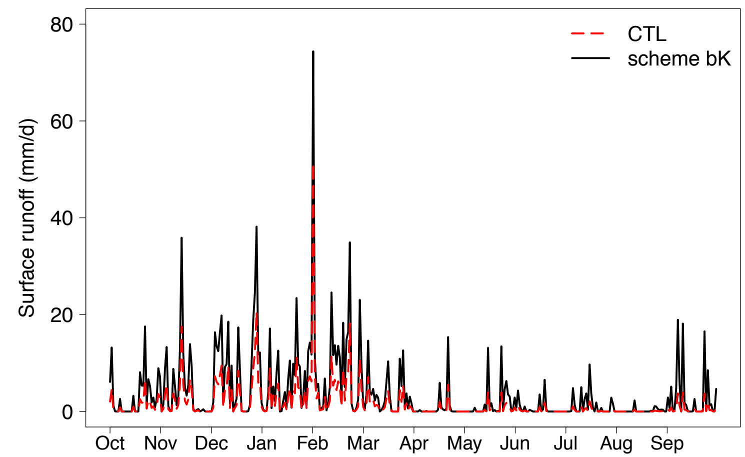
New scheme (scheme bK)
Standard scheme (CTL)

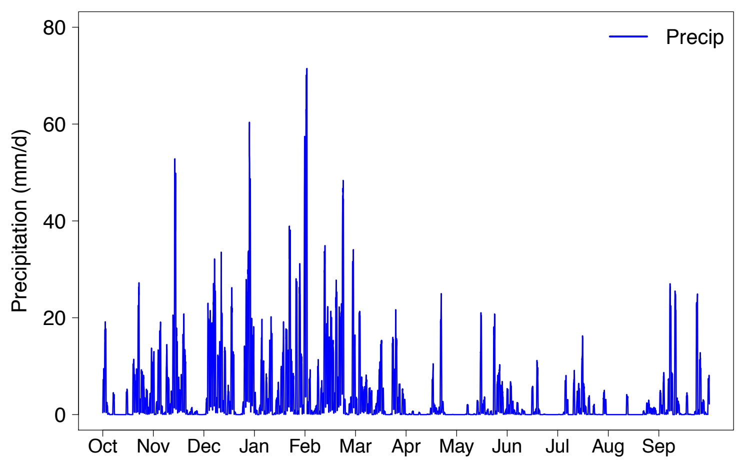
PDM deactivated (NO PDM)

PDM activated (PDM)

Surface runoff
Oct. 1994–1995
Peak river flow period







Srunoff:

ρ (bk NO PDM, bK PDM) = 0.9999

ρ (bk PDM, CTL PDM) = 0.967

Riverflow:

ρ (bk NO PDM, bK PDM) = 0.999

ρ (bk PDM, CTL PDM) = 0.92

Conclusions:

1. Land surface models used mainly : max VIC and infiltration is based on SWB

2. The scheme $I_{max} = \beta K$:

    i. Enhance an increase of the surface runoff
    ii. Improve the river flow in a small catchment when high precipitation occurs
    iii. Overestimate the mean river flow (parameter b) and the variability (parameter a)

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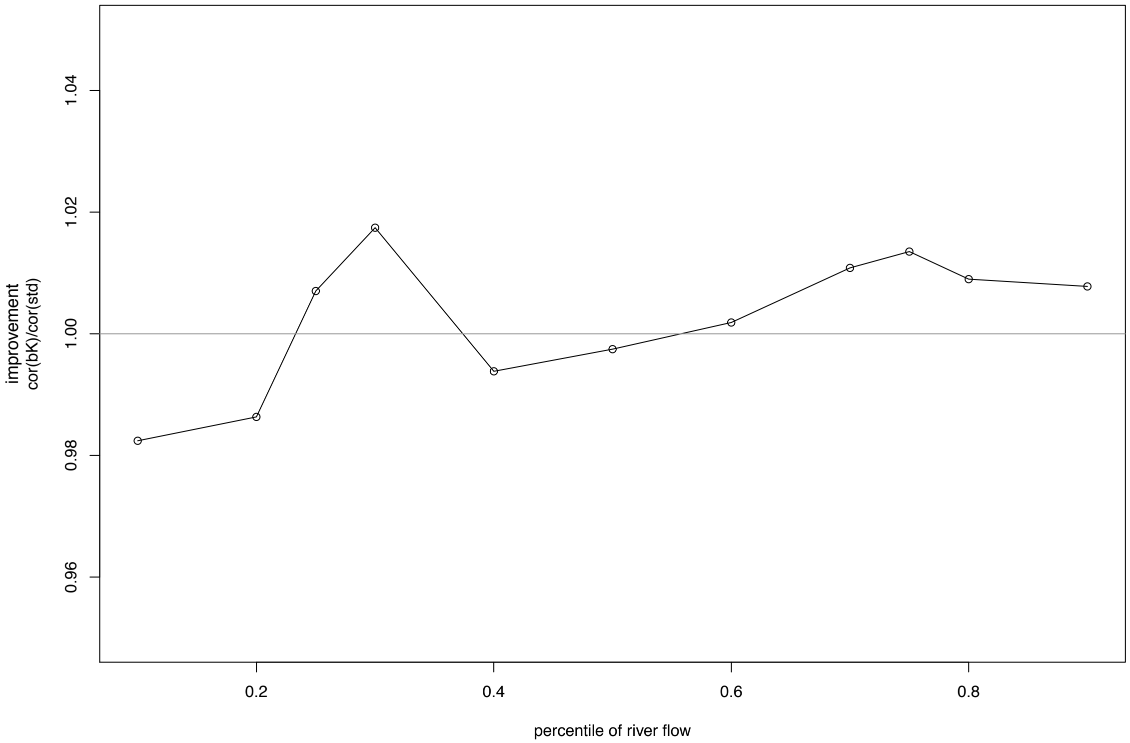
Outlooks:

1. River flow of a UK catchment :
   - Decrease the overestimation of the variation of river flow with reducing the parameter β
   - Working with other catchment

2. Study the modelled river flow with comparison of observed flash flood events

3. Study the impact on the uncertainty of modelled precipitation on the resulting surface runoff and river flow with the new/old scheme.



improvement
cor(bK)/cor(std)
0.96
0.98
1.00
1.02
1.04
0.2
0.4
0.6
0.8
percentile of river flow

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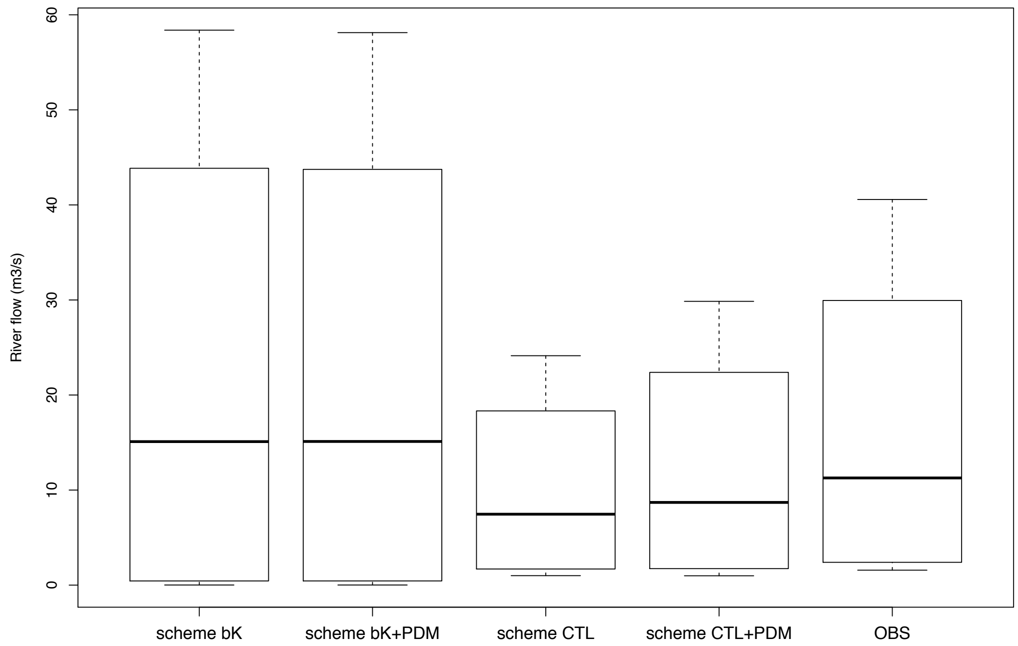
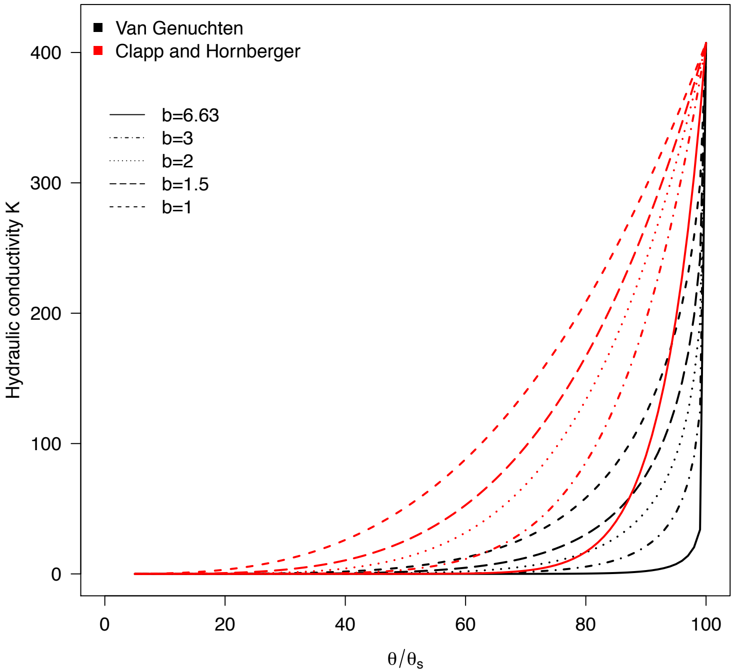
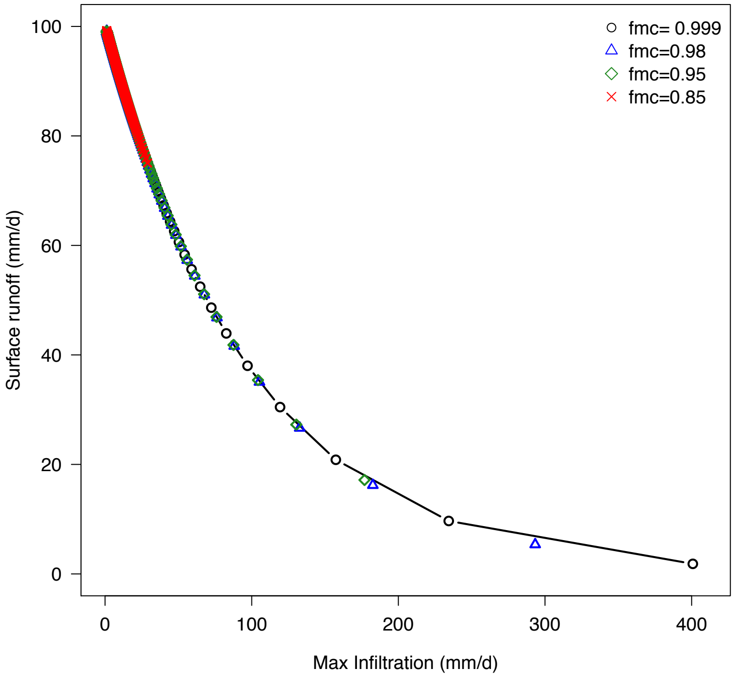
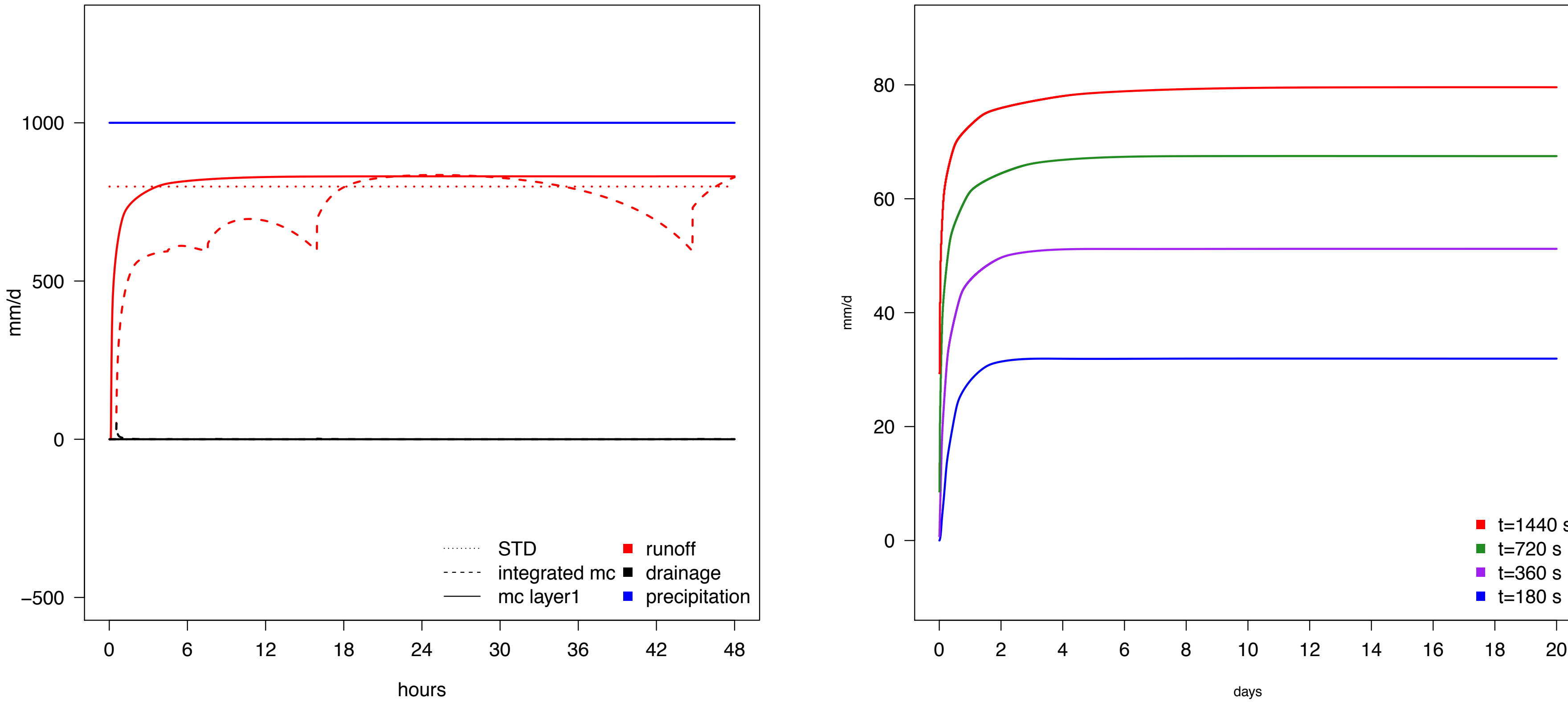
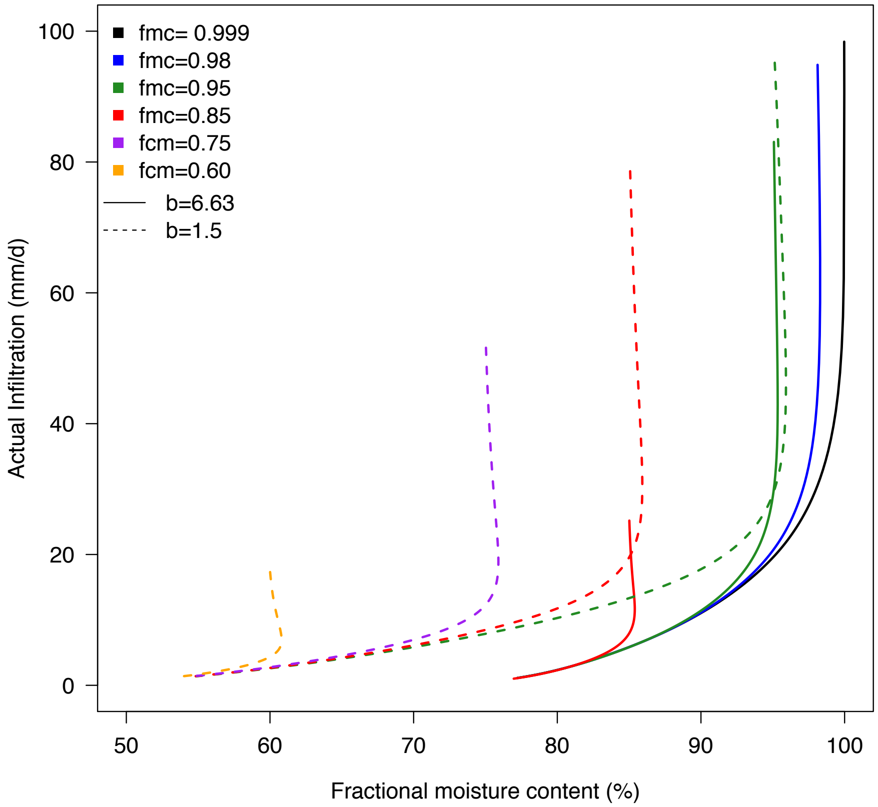



Van Genuchten
Clapp and Hornberger
b=6.63
b=3
b=2
b=1.5
b=1
Hydraulic conductivity K
θ/θs
0
100
200
300
400
0
20
40
60
80
100


fmc= 0.999
fmc=0.98
fmc=0.95
fmc=0.85
Surface runoff (mm/d)
Max Infiltration (mm/d)
0
20
40
60
80
100
0
100
200
300
400



1000
500
0
−500
mm/d
0
6
12
18
24
30
36
42
48
hours
STD
integrated mc
mc layer1
runoff
drainage
precipitation
80
60
40
20
0
mm/d
0
2
4
6
8
10
12
14
16
18
20
days
t=1440 s
t=720 s
t=360 s
t=180 s



fmc= 0.999
fmc=0.98
fmc=0.95
fmc=0.85
fcm=0.75
fcm=0.60
b=6.63
b=1.5
Actual Infiltration (mm/d)
Fractional moisture content (%)
0
20
40
60
80
100
50
60
70
80
90
100

Variable maximum infiltration schemes:

scheme 0: $I_{max} = \beta K_{sat}$ JULES

scheme 1: $I_{max} = \beta(W_{sat} - W)/\Delta t$ A. Mueller

(kg/m^2)

scheme 2: $I_{max} = \beta(W_{sat}^{top} - W^{top})/\Delta t$

scheme 3: $I_{max} = (W_{sat} - W) + max\left(0, W_{sat}\left[(1 - \frac{W}{W_{sat}})^{\frac{1}{b+1}} - (\frac{T+M}{(b+1)W_{sat}})\right]^{b+1}\right)$ CHTESSEL

(m^3/m^3)

scheme 4: $I_{max} = \beta K_{top}$

scheme 5: $I_{max} = K_{top}\frac{d\psi}{dz}$

Comparison of river flow in a small catchment:

New scheme (scheme bK)
Standard scheme (CTL)

Improvement (highlighted)

	PDM deactivated (NO PDM)		PDM activated (PDM)	
1991 - 2000	KGE_{bk} = 0.547	KGE_{std} = 0.212	KGE_{bk} = 0.546	KGE_{std} = 0.549
	ρ = 0.76	ρ = 0.46	ρ = 0.76	ρ = 0.77
	b = 1.28	b = 0.63	b = 1.28	b = 0.76
	a = 1.26	a = 0.55	a = 1.26	a = 0.69
Oct. 1994–1995 Peak river flow period	KGE_{bk} = 0.612	KGE_{std} = 0.247	KGE_{bk} = 0.607	KGE_{std} = 0.523
	ρ = 0.68	ρ = 0.48	ρ = 0.68	ρ = 0.70
	b = 1.20	b = 0.67	b = 1.21	b = 0.78
	a = 1.12	a = 0.57	a = 1.12	a = 0.69

$$KGE = 1 - \sqrt{(\underbrace{\frac{Cov_{sim,obs}}{\sigma_{simu}\sigma_{obs}}}_{\rho} - 1)^2 + (\underbrace{\frac{\sigma_{sim}}{\sigma_{obs}}}_{a} - 1)^2 + (\underbrace{\frac{\mu_{sim}}{\mu_{obs}}}_{b} - 1)^2}$$

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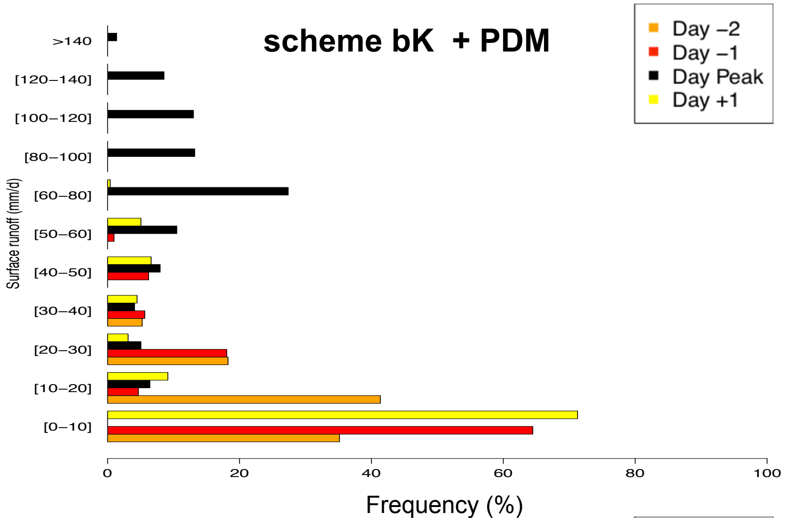
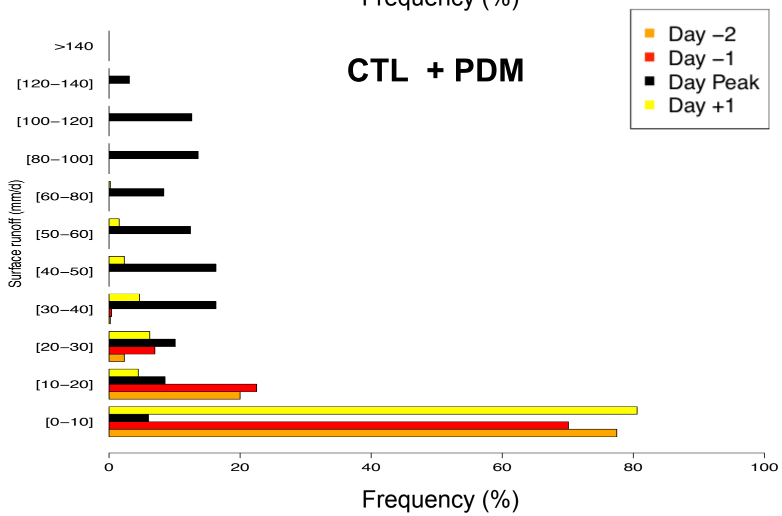
New scheme (scheme bK)
Standard scheme (CTL)

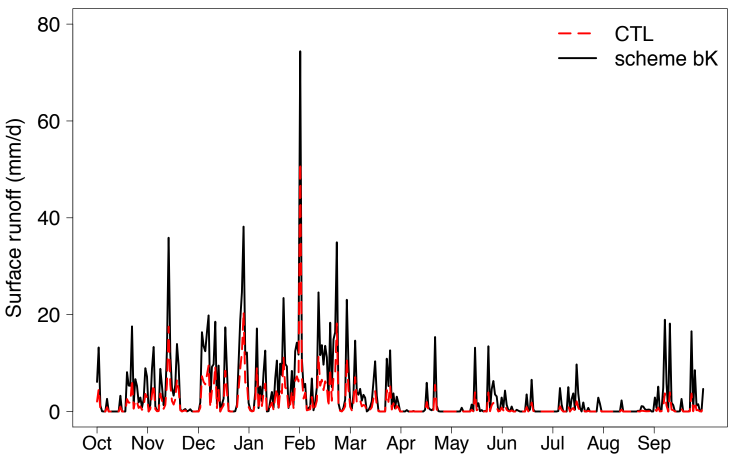
Comparison of surface runoff in a small catchment:

Spatial frequency of surface runoff over all grid cells (515)





PDM activated (PDM)



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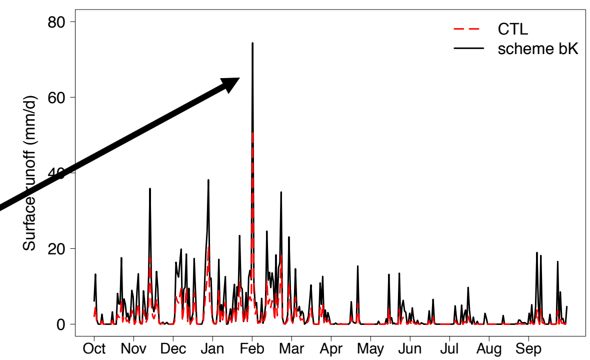
Comparison of surface runoff in a small catchment:

PDM activated (PDM)

Surface runoff Oct. 1994–1995 Peak river flow period



Spatial frequency of surface runoff over all grid cells (515)