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Hydrology and Earth System Sciences Discussions

Interactive comment on "Diffuse hydrological mass transport through catchments: scenario analysis of physical and biogeochemical uncertainty effects" *by* K. Persson et al.

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The paper presents a modeling exercise to illustrate the effect of different assumptions to compute the advective travel time distributions on the total solute mass delivered to surface waters. In particular the authors analyze a single catchment in Sweden and compute the travel time distribution under two possible scenarios: 1) flow follows primarily preferential pathways, in this case the encountered hydraulic conductivity is relatively constant, 2) the flow occurs through different soil types thus encountering high variable hydraulic conductivity. The manuscript then analyze for the two different scenarios the potential mass delivered in the case of a unit injection over the whole basin surface and a first order decaying solute.

The paper is well written, the methods are sound and clear. However, in the present form, the new scientific contribution is not clear and it appears as a marginal incremental step with respect to *Darracq et al.* 2010a,b. In their revision the authors should explain more clearly the scientific advance contained in the paper. The generality of the results is also somewhat questionable, as I will detail in the following, and I believe it should be properly discussed. Finally I will propose some changes on the presentation and interpretation of the results.

I believe that the authors misinterpreted the result shown in Figure 3 when they say that *"For $\lambda\tau_g$ in the order of 1 or greater, larger travel time variability increases the total mass delivery $\overline{\alpha_C}$. Scenario 2 then yields the largest $\overline{\alpha_C}$ because it has the largest fraction of transport pathways with advective travel times much longer than τ_g, along which a significant mass fraction can reach the recipient, even for large characteristic attenuation product $\lambda\tau_g$"*. Intuitively, however, for large values of $\lambda\tau_g$ the solute mass attenuates rapidly during the transport pathway and therefore only cells with short travel time can deliver significant amount of mass. In this specific case therefore, $\overline{\alpha_C}$ is higher in the second scenario because it has a larger fraction of very fast transport pathways, as stated by the same authors at the beginning of page 4732. This is better highlighted if we look at the probability density function of the travel times $pdf(\tau)$ for the two scenarios reported in the figure below. They have been obtained by digitalizing and differentiating the cumulative distribution reported in Figure 2. They are not smooth because of the digitalization procedure but I trust that they are quite close to the real ones.

To better quantify this effect it is useful to introduce the function:

$$\alpha_C(<\tau) = \int_0^{\tau} pdf(\tau)e^{-\lambda\tau}d\tau,$$

which expresses the mass fraction delivered from cells that have a transport pathway with advective travel time shorter than τ. Consistently, the quantity $\overline{\alpha_C}$ used in the manuscript for the whole catchment can be computed as $\alpha_C(<\infty)$.

The second figure reported below shows the function $\alpha_C(< \tau)$ for $\lambda\tau_g = 100$ for the two scenarios. As expected, almost all the mass delivered in the second scenarios comes form cells with travel time shorter than $\tau_g = 6.1$ year. This is the opposite of what stated in the text. Therefore the fact that the second scenario can lead to larger mass delivered depends on the peculiar characteristic of the catchment studied that has a relative large proportion of short travel times due to, as stated by the authors, very permeable soils near surface waters. The generality of this results, which is highlighted in the abstract as one of the main conclusion, is therefore questionable. Can the authors argue that this patterns is generally expected in river basins? In principle one can observe, in the absence of this very permeable soils, that scenario 2 has relative less short travel times with respect to scenario 1, thus obtaining opposite results.

Moreover I think that the presentation of the results Figure 3 and the consequent discussion are misleading. In fact it may seem that under certain conditions (e.g. $\lambda\tau_g > 1$) scenario 2 exports more solute mass than scenario 1. However the authors are comparing different solutes with different attenuation rates λ, because the analysis keep constant the product $\lambda\tau_g > 1$ and the two scenarios have different τ_g. As far as I have understood, the two different scenarios represent two different possible flow pathways, or better they represent two extreme scenario that envelope all the possible intermediate ones. Therefore it would be interesting to compare the mass of a specific solute exported in the two flow-path scenarios, keeping therefore the same λ. The differences in the two ways to illustrate the result are shown in the last Figure attached here. From the second panel it is clear that for $\lambda < 100$ the scenario 2 always exports less solute mass. Only for very fast decaying rate scenario 2 export more mass, but this is due, as discussed before for the peculiar characteristic of this catchment. I would suggest to rework the presentation and the discussion in this terms.

For full disclosure I attached below the matlab code to generate the figures.

```
clear all
```



```
close all

scenario1=[-3 0
-2.71951 0.00045423
-2.43496 0.00145423
-2.22358 0.00245423
-2.04878 0.00345423
-1.94309 0.00777202
-1.81707 0.0146805
-1.63821 0.0241796
-1.47561 0.0362694
-1.32114 0.0518135
-1.21138 0.0759931
-1.08943 0.0932642
-0.98374 0.112263
-0.894309 0.134715
-0.813008 0.156304
-0.691057 0.187392
-0.54878 0.234888
-0.406504 0.284111
-0.288618 0.336788
-0.182927 0.389465
-0.0934959 0.446459
-0.00406504 0.502591
0.0650407 0.558722
0.142276 0.61399
0.215447 0.671848
0.272358 0.721934
0.361789 0.779793
```

```
0.447154 0.829879
0.53252 0.881693
0.650407 0.932642
0.731707 0.958549
0.845528 0.978411
0.95935 0.994819
1.10163 1];

scenario2=[-3 0.00
-2.67073 0.00318135
-2.39024 0.00677202
-2.21545 0.0128169
-2.13821 0.0146805
-2.04878 0.0172712
-1.86585 0.0259067
-1.69919 0.0328152
-1.52846 0.044905
-1.3252 0.0569948
-1.05691 0.0863558
-0.747967 0.132124
-0.49187 0.178756
-0.292683 0.220207
-0.0731707 0.272884
0.162602 0.336788
0.373984 0.397237
0.52439 0.435233
0.756098 0.468048
0.882114 0.488774
```



```
1.0122 0.515544
1.09756 0.531952
1.13415 0.552677
1.22358 0.562176
1.26829 0.573402
1.36585 0.594128
1.45528 0.61399
1.53252 0.641623
1.5935 0.658031
1.64228 0.674439
1.71545 0.696891
1.77642 0.715026
1.83333 0.727116
1.86992 0.746114
1.89837 0.764249
1.96748 0.78152
2.02439 0.800518
2.0935 0.824698
2.14228 0.839378
2.1748 0.873921
2.23171 0.892919
2.28455 0.906736
2.34553 0.917962
2.43496 0.935233
2.5122 0.946459
2.58943 0.959413
2.61382 0.982729
2.73577 0.988774
2.81301 0.992228
```

```
3  1.00];


dx=0.001;
x1=dx:dx:10^scenario1(end,1);
cdf1=interp1(10.^scenario1(:,1),scenario1(:,2),x1);
x2=dx:dx:10^scenario2(end,1);
cdf2=interp1(10.^scenario2(:,1),scenario2(:,2),x2);

pdf1=diff(cdf1)/dx;
x1=x1(2:end)-dx/2;
mean_1=sum(pdf1.*x1)*dx

pdf2=diff(cdf2)/dx;
x2=x2(2:end)-dx/2;
mean_2=sum(pdf2.*x2)*dx

figure
semilogx(x1,pdf1,x2,pdf2)
legend('scenario 1','scenario 2')
xlabel('Travel time (yr)','fontsize',12);
ylabel('pdf(\tau)','fontsize',12);


tg1=0.73;  %geometric mean scenario 1
tg2=6.1;   %geometric mean scenario 2

figure
l1=100/tg1;
```



```
l2=100/tg2;
semilogx(x1,cumsum(exp(-l1*x1).*pdf1*dx),x2,cumsum(exp(-l2*x2).*pdf2
legend('scenario 1','scenario 2')
xlabel('Travel time (yr)','fontsize',12);
ylabel('\alpha_C(<\tau)','fontsize',12);

figure
l1=0.1/tg1;
l2=0.1/tg2;
semilogx(x1,cumsum(exp(-l1*x1).*pdf1*dx),x2,cumsum(exp(-l2*x2).*pdf2
legend('Scenario 1','Scenario 2')
xlabel('Travel time (yr)','fontsize',12);
ylabel('\alpha_C(\tau)','fontsize',12);

%plot of figure 3 of the paper
ltg_vec=[0.01 0.1 1 10 100 1000];
alpha1=zeros(length(ltg_vec),1);
alpha2=zeros(length(ltg_vec),1);
for cont=1:length(ltg_vec)
    l1=ltg_vec(cont)/tg1;
    l2=ltg_vec(cont)/tg2;
    alpha1(cont)=sum(exp(-l1*x1).*pdf1)*dx;
    alpha2(cont)=sum(exp(-l2*x2).*pdf2)*dx;
end
figure
subplot(211)
semilogx(ltg_vec,alpha1,'-b.',ltg_vec,alpha2,'-g.',ltg_vec,exp(-ltg_
legend('Scenario 1','Scenario 2','Scenario 0')
xlabel('\lambda \tau_g','fontsize',12);
```

```
ylabel('\alpha_C','fontsize',12);


%"new" figure 3
l_vec=[0.01 0.1 1 10 100 1000];
alpha1=zeros(length(l_vec),1);
alpha2=zeros(length(l_vec),1);
for cont=1:length(ltg_vec)
    alpha1(cont)=sum(exp(-l_vec(cont)*x1).*pdf1)*dx;
    alpha2(cont)=sum(exp(-l_vec(cont)*x2).*pdf2)*dx;
end
subplot(212)
semilogx(l_vec,alpha1,'-b.',l_vec,alpha2,'-g.',l_vec,exp(-l_vec),'-r
legend('Scenario 1','Scenario 2','Scenario 0')
xlabel('\lambda (yr^{-1})','fontsize',12);
ylabel('\alpha_C','fontsize',12);
```

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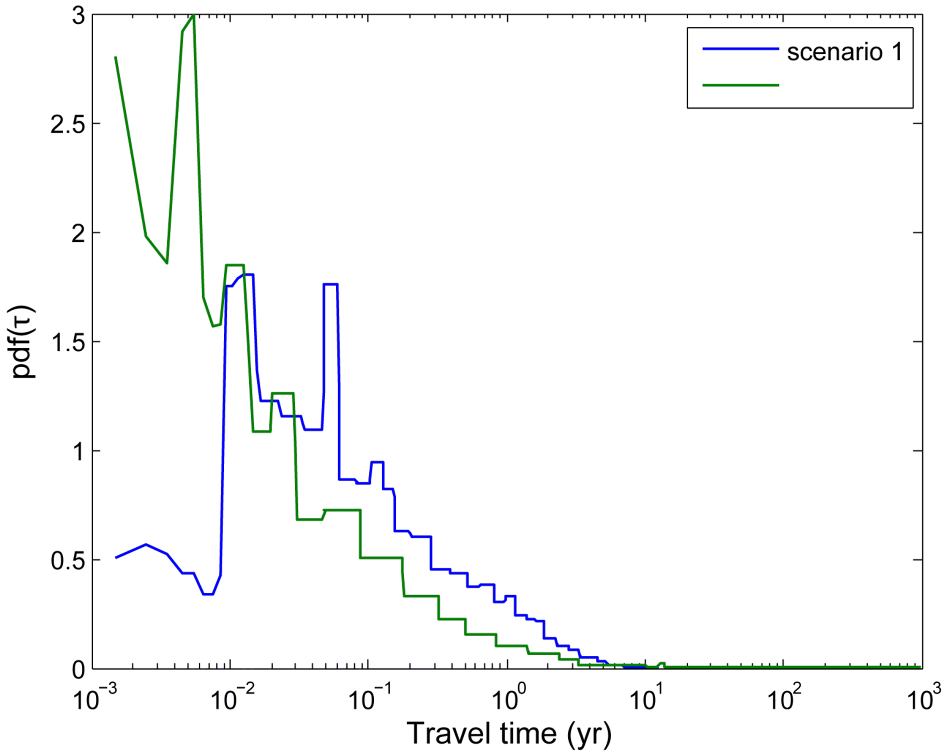
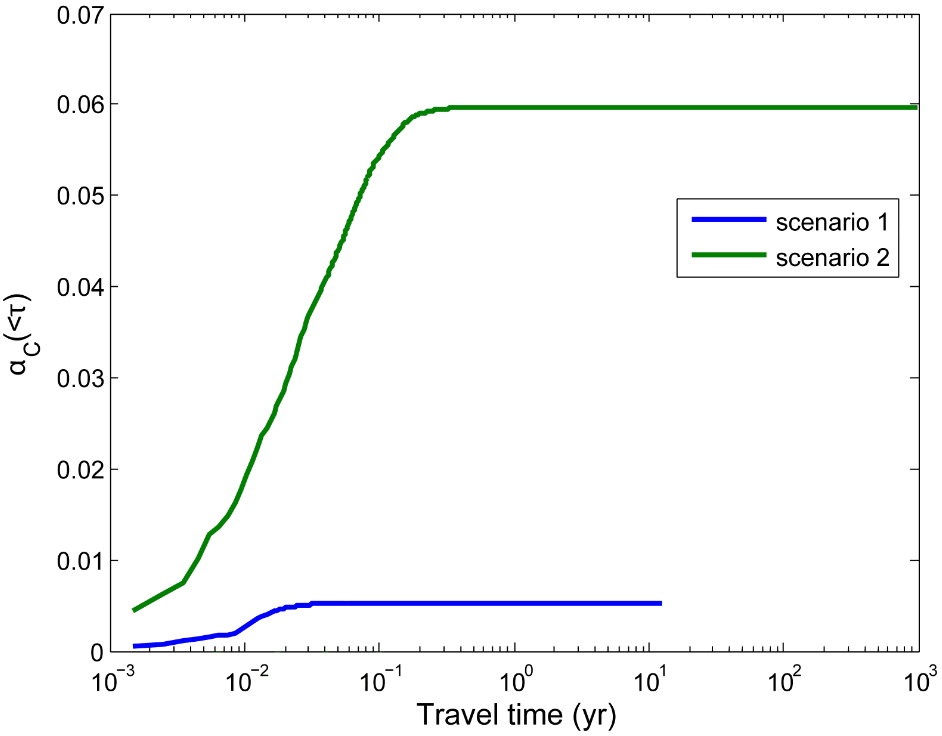
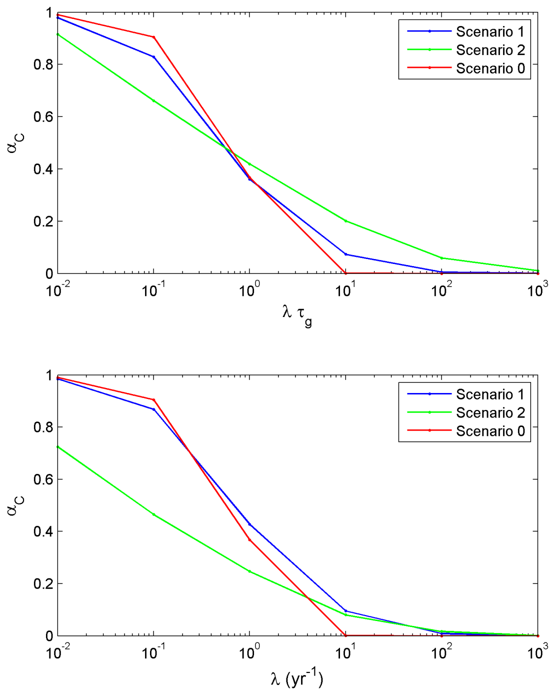


Fig. 1.



0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
$\alpha_C(<\tau)$
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Travel time (yr)
scenario 1
scenario 2

Fig. 2.



α_C
$\lambda\ \tau_g$
Scenario 1
Scenario 2
Scenario 0
α_C
$\lambda\ (yr^{-1})$
Scenario 1
Scenario 2
Scenario 0

Fig. 3.