```
clear
clc
% cell model 15 cells (Bellebeek watershed from Diskin et al., 1984) with concentration

% %number of cells in the basin
 N=15;

% cell parameters
a=[8.23 8.23 8.23 8.23 8.23 6.45 6.45 7.6 7.6 7.6 5.52 5.52 5.52 5.52 5.52]; %cell area
l=[2.53 2.53 2.53 2.53 2.53 2.9 2.9 3.16 3.16 3.16 3.01 3.01 3.01 3.01 3.01]; %channel length
TA=1.31;
KA=3.73;
DA=0;

%rain, time step and d from Ostfeld and Pries (2002)
I=[0 4 1 3 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0]; %rain data example
t=[0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20]; %time step
d=I/1;

%rainfall graph
bar(t,I,1)
title("Rain intensity for storm event")
ylabel("I [mm/hr]")
xlabel("t [hr]")
ylim([0 5])
xlim([0 10])

% model parameters

tdif=t(2)-t(1);
n=length(d);
A=mean(a);
L=mean(l);
KC=KA*sqrt(a/A);
DC=DA*(l/L);
TC=TA*(l/L);

%water quality
k=0.2;
C0=[0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5];

% %runoff from rainfall excess Qr[m3/sec]
h=zeros(N,n);
dh=zeros(n,n,N);

for j=1:N
 h(j,:)=(exp(-t/KC(j))-exp((-10*t)/KC(j)))/(0.9*KC(j));
 dh(:,:,j)=d'*h(j,:);
 qr(:,j)=sum(spdiags(rot90(dh(:,:,j))));
end
```

```
qr=qr(1:n-1,:);
Qr=zeros(n,N);
for j=1:N
Qr(2:n,j)=(a(j)/3.6)*qr(1:n-1,j);
end
Qr;

% %Concentration from rainfall excess Cr[mg/l]

Cr=zeros(n,N);
for j=1:N
for i=1:n
    Cr(i,j)=C0(j)*exp(-k*t(i));
end
end
Cr;
Nr_mass=Qr.*Cr ;

% %shock reaction (gt) flow from nearby cells [1/hr]
gt=zeros(n-1,1);
 for i=1:n-1
    for j=1:N
if t(i)>=DC
gt(i,j)=(exp(-(t(i)-DC(j))/TC(j)))/TC(j);
else
    gt(i,j)=0
end
    end
 end
gt;
gt=gt';

% initial volume (Vt) flow from nearby cells [m3]
Vt=zeros(n-1,N);
for j=1:n-1
    for i=1:N
    Vt(j,i)=3600*tdif*0.5*(Qr(j,i)+Qr(j+1,i));
    end
end
Vt;


%% runoff and concentration phase 1 (exterior cells)
% cell 1->3
% Q
Vg=Vt(:,1)*gt(3,:);
Vg;
Q13=(sum(spdiags(rot90(Vg))))';
Q13=(1/3600)*Q13(1:n-1);
% C
```

```
Cf13=zeros(n-1,N);
for i=1:n-1
    Cf13(i,3)=Cr(i,1)-(exp((-Q13(i)/Vt(i,1))*t(i))*(Cr(i,1)-C0(1)));
end
Cf13;
Nf_mass13=Q13.*Cf13 ;

% cell 2->3
% Q
Vg=Vt(:,2)*gt(3,:);
Vg;
Q23=(sum(spdiags(rot90(Vg))))';
Q23=(1/3600)*Q23(1:n-1);
% C
Cf23=zeros(n-1,N);
for i=1:n-1
    Cf23(i,3)=Cr(i,2)-(exp((-Q23(i)/Vt(i,2))*t(i))*(Cr(i,2)-C0(2)));
end
Cf23;
Nf_mass23=Q23.*Cf23 ;

% Q and C cell 3
Q3tot=zeros(n,1) ;
Q3tot(2:n)=Q13+Q23+Qr(2:n,3) ;
N3_mass=zeros(n,1) ;
N3_mass(2:n)=Nf_mass23(:,3)+Nf_mass13(:,3)+Nr_mass(2:n,3) ;
C3tot=N3_mass./Q3tot  ;

% cell 4->5
% Q
Vg=Vt(:,4)*gt(5,:);
Vg;
Q45=(sum(spdiags(rot90(Vg))))';
Q45=(1/3600)*Q45(1:n-1);
% C
Cf45=zeros(n-1,N);
for i=1:n-1
    Cf45(i,5)=Cr(i,4)-(exp((-Q45(i)/Vt(i,4))*t(i))*(Cr(i,4)-C0(4)));
end
Cf45;
Nf_mass45=Q45.*Cf45 ;

% Q and C cell 5
Q5tot=zeros(n,1) ;
Q5tot(2:n)=Q45+Qr(2:n,5) ;
N5_mass=zeros(n,1) ;
N5_mass(2:n)=Nf_mass45(:,5)+Nr_mass(2:n,5) ;
C5tot=N5_mass./Q5tot  ;

% cell 6->7
```

```
% Q
Vg=Vt(:,6)*gt(7,:);
Vg;
Q67=(sum(spdiags(rot90(Vg))))';
Q67=(1/3600)*Q67(1:n-1);
% C
Cf67=zeros(n-1,N);
for i=1:n-1
    Cf67(i,7)=Cr(i,6)-(exp((-Q67(i)/Vt(i,6))*t(i))*(Cr(i,6)-C0(6)));
end
Cf67;
Nf_mass67=Q67.*Cf67 ;

% Q and C cell 7
Q7tot=zeros(n,1) ;
Q7tot(2:n)=Q67+Qr(2:n,7) ;
N7_mass=zeros(n,1) ;
N7_mass(2:n)=Nf_mass67(:,7)+Nr_mass(2:n,7) ;
C7tot=N7_mass./Q7tot  ;

% cell 8->9
% Q
Vg=Vt(:,8)*gt(9,:);
Vg;
Q89=(sum(spdiags(rot90(Vg))))';
Q89=(1/3600)*Q89(1:n-1);
% C
Cf89=zeros(n-1,N);
for i=1:n-1
    Cf89(i,9)=Cr(i,8)-(exp((-Q89(i)/Vt(i,8))*t(i))*(Cr(i,8)-C0(8)));
end
Cf89;
Nf_mass89=Q89.*Cf89 ;

% Q and C cell 9
Q9tot=zeros(n,1) ;
Q9tot(2:n)=Q89+Qr(2:n,9) ;
N9_mass=zeros(n,1) ;
N9_mass(2:n)=Nf_mass89(:,9)+Nr_mass(2:n,9) ;
C9tot=N9_mass./Q9tot  ;

% cell 12->13
% Q
Vg=Vt(:,12)*gt(13,:);
Vg;
Q1213=(sum(spdiags(rot90(Vg))))';
Q1213=(1/3600)*Q1213(1:n-1);
% C
Cf1213=zeros(n-1,N);
for i=1:n-1
```

```
    Cf1213(i,13)=Cr(i,12)-(exp((-Q1213(i)/Vt(i,12))*t(i))*(Cr(i,12)-C0(12)));
end
Cf1213;
Nf_mass1213=Q1213.*Cf1213 ;

% Q and C cell 13
Q13tot=zeros(n,1) ;
Q13tot(2:n)=Q1213+Qr(2:n,13) ;
N13_mass=zeros(n,1) ;
N13_mass(2:n)=Nf_mass1213(:,13)+Nr_mass(2:n,13) ;
C13tot=N13_mass./Q13tot  ;

%% total Q and C after 1st phase
Qtot=Qr ;
Qtot(:,3)=Q3tot ;
Qtot(:,5)=Q5tot ;
Qtot(:,7)=Q7tot ;
Qtot(:,9)=Q9tot ;
Qtot(:,13)=Q13tot ;
Ctot=Cr ;
Ctot(:,3)=C3tot ;
Ctot(:,5)=C5tot ;
Ctot(:,7)=C7tot ;
Ctot(:,9)=C9tot ;
Ctot(:,13)=C13tot ;

% new vt after 1st phase
Vt=zeros(n-2,N);
for j=1:n-2
    for i=1:N
    Vt(j,i)=3600*tdif*0.5*(Qtot(j,i)+Qtot(j+1,i));
    end
end
Vt;

%% 2nd phase
% cell 9->10
% Q
Vg=Vt(:,9)*gt(10,1:n-2);
Vg;
Q910=(sum(spdiags(rot90(Vg))))';
Q910=(1/3600)*Q910(1:n-1);
% C
Cf910=zeros(n-2,N);
for i=1:n-2
    Cf910(i,10)=Ctot(i,9)-(exp((-Q910(i)/Vt(i,9))*t(i))*(Ctot(i,9)-C0(9)));
end
Cf910;
Nf_mass910=Q910(1:n-3).*Cf910(2:n-2,10) ;
```

```
%% total Q and C after 2nd phase
Q10tot=zeros(n,1) ;
Q10tot(2:n)=Q910+Qtot(2:n,10) ;
Qtot(:,10)=Q10tot ;
N10_mass=zeros(n-2,1) ;
N10_mass(2:n-2)=Nf_mass910+Nr_mass(2:n-2,10) ;
C10tot=N10_mass./Q10tot(1:n-2)  ;
Ctot=Ctot(1:n-2,:);
Ctot(:,10)=C10tot ;

% new vt after 2nd phase
Vt=zeros(n-3,N);
for j=1:n-3
    for i=1:N
    Vt(j,i)=3600*tdif*0.5*(Qtot(j,i)+Qtot(j+1,i));
    end
end
Vt;

%3rd phase
% cell 3->11
% Q
Vg=Vt(:,3)*gt(11,1:n-3);
Vg;
Q311=(sum(spdiags(rot90(Vg))))';
Q311=(1/3600)*Q311(1:n-3);
% C
Cf311=zeros(n-3,N);
for i=1:n-3
    Cf311(i,11)=Ctot(i,3)-(exp((-Q311(i)/Vt(i,3))*t(i))*(Ctot(i,3)-C0(3)));
end
Cf311;
Nf_mass311=Q311.*Cf311 ;

% cell 5->11
% Q
Vg=Vt(:,5)*gt(11,1:n-3);
Vg;
Q511=(sum(spdiags(rot90(Vg))))';
Q511=(1/3600)*Q511(1:n-3);
% C
Cf511=zeros(n-3,N);
for i=1:n-3
    Cf511(i,11)=Ctot(i,5)-(exp((-Q511(i)/Vt(i,5))*t(i))*(Ctot(i,5)-C0(5)));
end
Cf511;
Nf_mass511=Q511.*Cf511 ;

% cell 7->11
% Q
```

```
Vg=Vt(:,7)*gt(11,1:n-3);
Vg;
Q711=(sum(spdiags(rot90(Vg))))';
Q711=(1/3600)*Q711(1:n-3);
% C
Cf711=zeros(n-3,N);
for i=1:n-3
    Cf711(i,11)=Ctot(i,7)-(exp((-Q711(i)/Vt(i,7))*t(i))*(Ctot(i,7)-C0(7)));
end
Cf711;
Nf_mass711=Q711.*Cf711 ;

% cell 10->11
% Q
Vg=Vt(:,10)*gt(11,1:n-3);
Vg;
Q1011=(sum(spdiags(rot90(Vg))))';
Q1011=(1/3600)*Q1011(1:n-3);
% C
Cf1011=zeros(n-3,N);
for i=1:n-3
    Cf1011(i,11)=Ctot(i,10)-(exp((-Q1011(i)/Vt(i,10))*t(i))*(Ctot(i,10)-C0(10)));
end
Cf1011;
Nf_mass1011=Q1011.*Cf1011 ;

%% total Q and C after 3rd phase

Q11tot=zeros(n-2,1) ;
Q11tot(2:n-2)=Q311+Q511+Q711+Q1011+Qtot(2:n-2,11) ;
Qtot=Qtot(1:n-2,:) ;
Qtot(:,11)=Q11tot ;
N11_mass=zeros(n-3,1) ;
N11_mass(1:n-3)=Nf_mass311(:,11)+Nf_mass511(:,11)+Nf_mass711(:,11)+Nf_mass1011(:,11)+Nr_mass(1
C11tot=N11_mass./Q11tot(1:n-3) ;
Ctot=Ctot(1:n-3,:);
Ctot(:,11)=C11tot ;

% new vt after 3rd layer
Vt=zeros(n-4,N);
for j=1:n-4
    for i=1:N
    Vt(j,i)=3600*tdif*0.5*(Qtot(j,i)+Qtot(j+1,i));
    end
end
Vt;

%4th phase
% cell 13->14
% Q
```

```
Vg=Vt(:,13)*gt(14,1:n-4);
Vg;
Q1314=(sum(spdiags(rot90(Vg))))';
Q1314=(1/3600)*Q1314(1:n-4);
% C
Cf1314=zeros(n-4,N);
for i=1:n-4
    Cf1314(i,14)=Ctot(i,13)-(exp((-Q1314(i)/Vt(i,13))*t(i))*(Ctot(i,13)-C0(13)));
end
Cf1314;
Nf_mass1314=Q1314.*Cf1314 ;

% cell 11->14
% Q
Vg=Vt(:,11)*gt(14,1:n-4);
Vg;
Q1114=(sum(spdiags(rot90(Vg))))';
Q1114=(1/3600)*Q1114(1:n-4);
% C
Cf1114=zeros(n-4,N);
for i=1:n-4
    Cf1114(i,14)=Ctot(i,11)-(exp((-Q1114(i)/Vt(i,11))*t(i))*(Ctot(i,11)-C0(11)));
end
Cf1114;
Nf_mass1114=Q1114.*Cf1114 ;

%% total Q and C after 4th phase
Q14tot=zeros(n-3,1) ;
Q14tot(2:n-3)=Q1114+Q1314+Qtot(2:n-3,14) ;
Qtot=Qtot(1:n-3,:) ;
Qtot(:,14)=Q14tot ;
N14_mass=zeros(n-4,1);
N14_mass(1:n-4)=Nf_mass1114(:,14)+Nf_mass1114(:,14)+Nr_mass(1:n-4,14) ;
C14tot=N14_mass./Q14tot(1:n-4) ;
Ctot=Ctot(1:n-4,:);
Ctot(:,14)=C14tot ;

% new vt after 4th phase
Vt=zeros(n-5,N);
for j=1:n-5
    for i=1:N
    Vt(j,i)=3600*tdif*0.5*(Qtot(j,i)+Qtot(j+1,i));
    end
end
Vt;

%% 5th phase
% cell 14->15
% Q
Vg=Vt(:,14)*gt(15,1:n-5);
```

```
Vg;
Q1415=(sum(spdiags(rot90(Vg))))';
Q1415=(1/3600)*Q1415(1:n-5);
% C
Cf1415=zeros(n-5,N);
for i=1:n-5
    Cf1415(i,15)=Ctot(i,14)-(exp((-Q1415(i)/Vt(i,14))*t(i))*(Ctot(i,14)-C0(14)));
end
Cf1415;
Nf_mass1415=Q1415.*Cf1415 ;

%% total Q and C after 5th phase
Q15tot=zeros(n-4,1);
Q15tot(2:n-4)=Q1415+Qtot(2:n-4,15);
Qtot=Qtot(1:n-4,:);
Qtot(:,15)=Q15tot;
N15_mass=zeros(n-5,1) ;
N15_mass(1:n-5)=Nf_mass1415(:,15)+Nr_mass(1:n-5,15) ;
C15tot=N15_mass./Q15tot(1:n-5) ;
Ctot=Ctot(1:n-5,:);
Ctot(:,15)=C15tot;

%%%%%%%%%%%%%%%

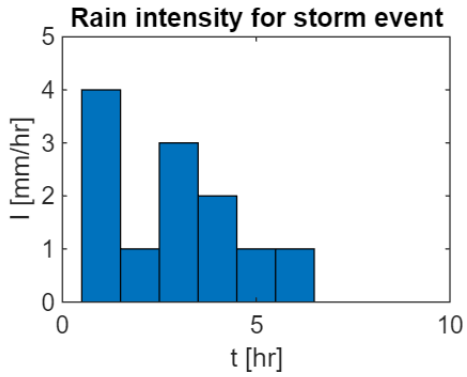
%% Total runoff and C for outlet
Qout=Q15tot %%%
```

```
Qout = 17×1
         0
    2.8705
    7.6642
   17.4309
   31.2089
   47.4474
   64.1465
   78.2659
   88.0130
   92.3443
      ⋮
```

```
Cout=C15tot %%%
```

```
Cout = 16×1
       NaN
    1.2813
    1.0608
    0.8625
    0.7440
    0.6648
    0.6044
    0.5588
    0.5225
    0.4935
      ⋮
```

```
%graphs
tiledlayout(3,2)
```




```
%runoff from cell 3
nexttile
scatter(t(1:n-5),Qtot(1:n-5,3),'filled')
title('Runoff from cell 3')
xlabel('t [hr]')
ylabel('Q [m3/s]')
ylim([0 100])

%Concentration from cell 3
nexttile
scatter(t(1:n-5),Ctot(:,3),'filled')
title('Concentration from cell 3')
xlabel('t [hr]')
ylabel('C [mg/l]')
ylim([0 1.5])

%runoff from cell 11
nexttile
scatter(t(1:n-5),Qtot(1:n-5,11),'filled')
title('Runoff from cell 11')
xlabel('t [hr]')
ylabel('Q [m3/s]')
ylim([0 100])

%Concentration from cell 11
nexttile
scatter(t(1:n-5),Ctot(:,11),'filled')
title('Concentration from cell 11')
xlabel('t [hr]')
ylabel('C [mg/l]')
ylim([0 1.5])

%runoff from cell 15
nexttile
```

```
scatter(t(1:n-5),Qtot(1:n-5,15),'filled')
title('Runoff from outlet')
xlabel('t [hr]')
ylabel('Q [m3/s]')
ylim([0 100])

%Concentration from cell 15
nexttile
scatter(t(1:n-5),Ctot(:,15),'filled')
title('Concentration from outlet')
xlabel('t [hr]')
ylabel('C [mg/l]')
ylim([0 1.5])
```

