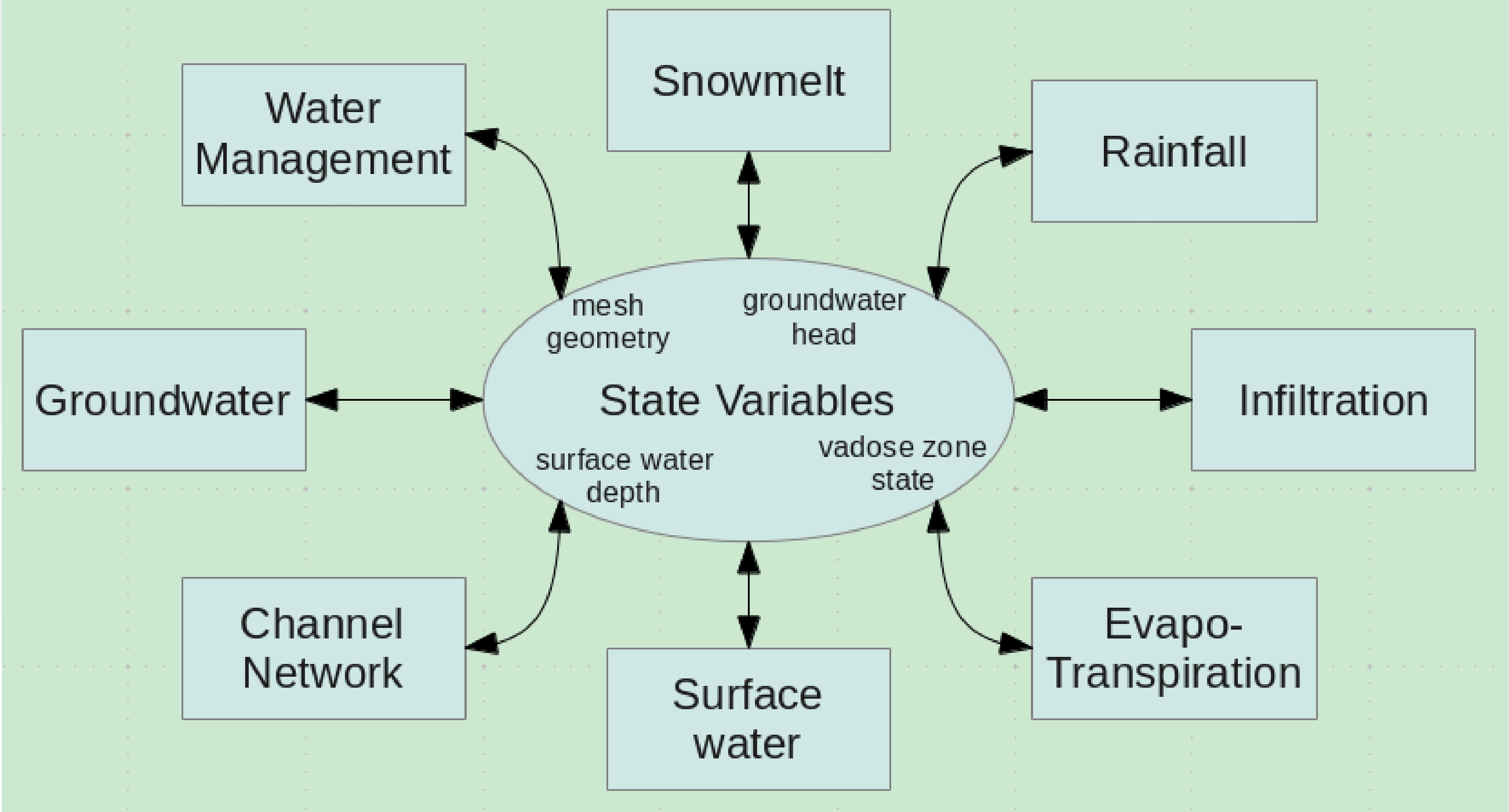
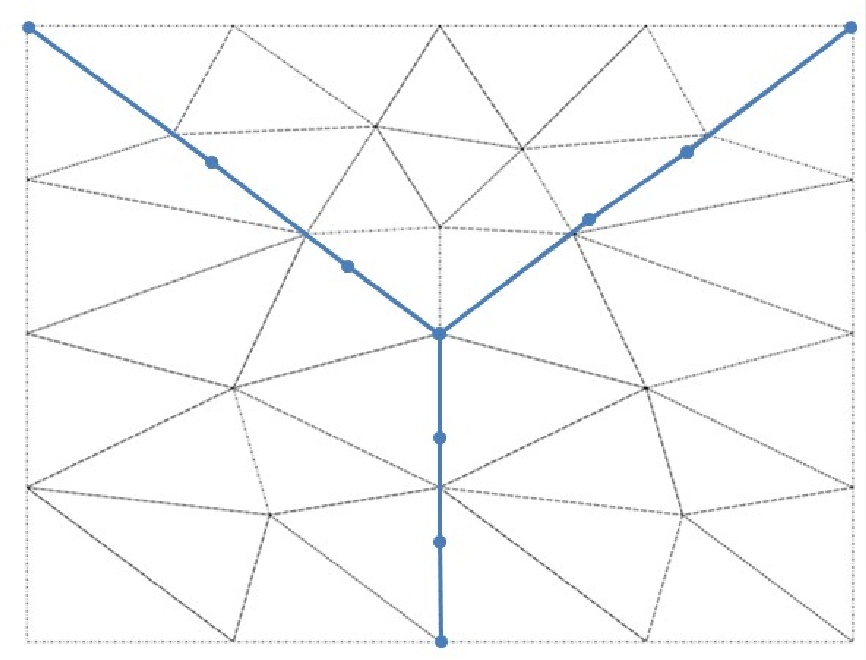
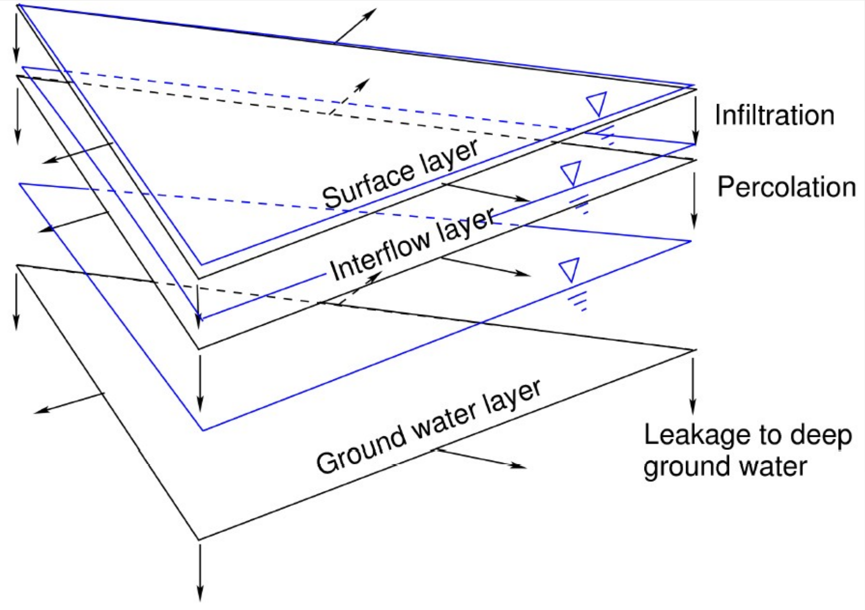
AdHydro model



AdHydro model mesh structure





1D channel routing

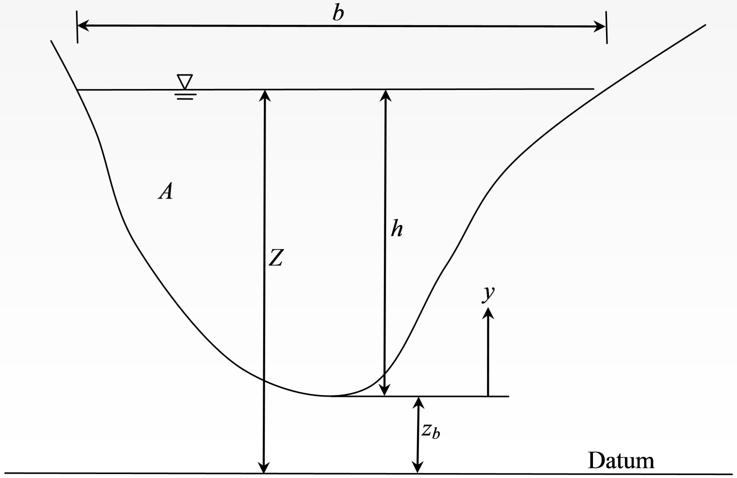
Dynamic wave equations:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=S$$

$$\frac{\partial Q}{\partial t}+\frac{\partial Q^2/A}{\partial x}=-gA\frac{\partial Z}{\partial x}-gAS_f$$

Diffusive wave equation:

$$\frac{\partial A}{\partial t}-\frac{\partial}{\partial x}\left(\frac{R^{2/3}A}{n}\frac{\partial Z/\partial x}{\sqrt{\left|\partial Z/\partial x\right|}}\right)=S$$



$A=$ cross $-$ section area ;
$Z=$ water surface elevation ;
$Q=$ flow rate ;
$S=$ source term ;

Overland 2D shallow water flow

Dynamic wave equations:

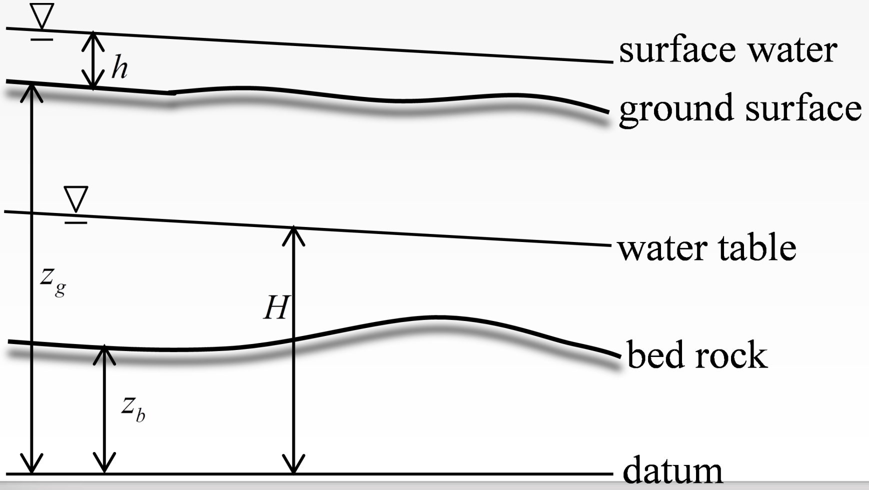
$$\frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=q_r$$

$$\frac{\partial hu}{\partial t}+\frac{\partial huu}{\partial x}+\frac{\partial huv}{\partial y}=-gh\frac{\partial z}{\partial x}-\frac{gn_x^2\,u\sqrt{u^2+v^2}}{h^{1/3}}$$

$$\frac{\partial hv}{\partial t}+\frac{\partial huv}{\partial x}+\frac{\partial hvv}{\partial y}=-gh\frac{\partial z}{\partial y}-\frac{gn_y^2\,v\sqrt{u^2+v^2}}{h^{1/3}}$$

Diffusive wave equation:

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}\left(hk_x\frac{\partial Z}{\partial x}\right)+\frac{\partial}{\partial y}\left(hk_y\frac{\partial Z}{\partial y}\right)=q_r$$

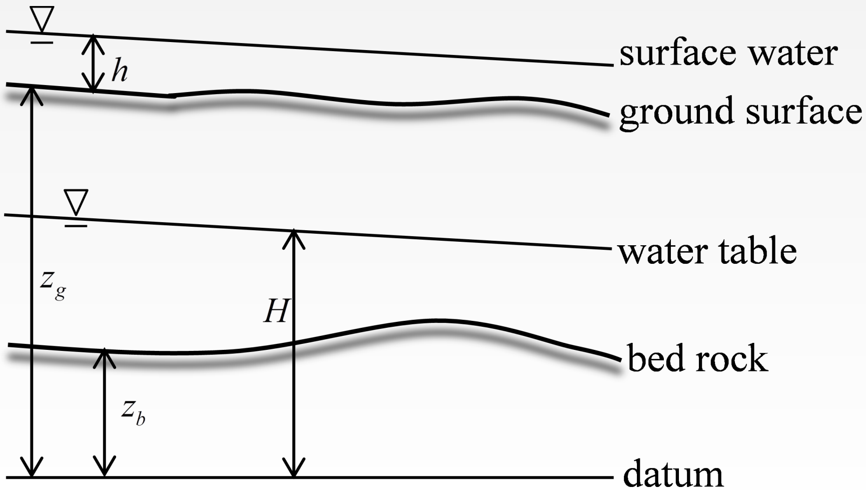


$h=$ water depth ;
$Z=$ water surface elevation ;
$u, v=$ velocities ;
$q_r=$ rainfall ;
$k_x, k_y=$ diffusion coefficients ;

Saturated 2D groundwater flow in unconfined aquifer

Boussinesq Eq: $S_y \frac{\partial H}{\partial t} = \frac{\partial}{\partial x}\left(K_x (H - z_b) \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y (H - z_b) \frac{\partial H}{\partial y}\right) + R = \frac{\Delta S}{\Delta t}$

$H =$ water head ;
$S_y =$ specific yield ;
$R =$ recharge rate ;
$S =$ storage ;
$K_x, K_y =$ conductivity ;



Numerical scheme

Explicit time-stepping cell-centered finite volume method.

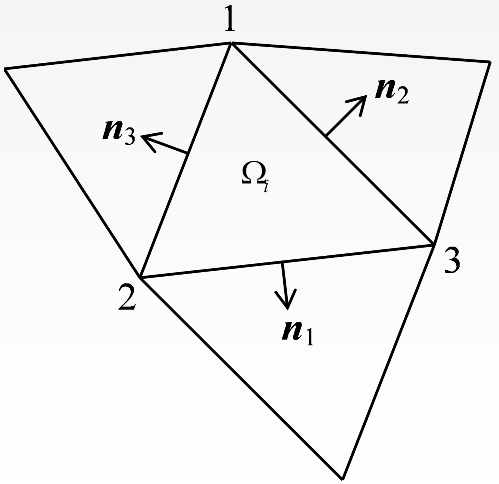
Advantage: Mass conservation; Parallelizable computing;

$$\frac{\partial \mathbf{U}}{\partial t}+\nabla\cdot\mathbf{F}=\mathbf{S}$$

$$\int_{\Omega_i}\frac{\partial \mathbf{U}}{\partial t}\,d\Omega+\int_{\Omega_i}\nabla\cdot\mathbf{F}\,d\Omega=\int_{\Omega_i}\mathbf{S}\,d\Omega$$

$$\int_{\Omega_i}\frac{\partial \mathbf{U}}{\partial t}\,d\Omega+\oint_{\Gamma_i}\tilde{\mathbf{F}}\cdot\mathbf{n}\,d\Gamma=\int_{\Omega_i}\mathbf{S}\,d\Omega$$

$$\frac{\mathbf{U}_i^{n+1}-\mathbf{U}_i^{n}}{\Delta t}+\frac{1}{\Omega_i}\sum_{j=1}^{3}\tilde{\mathbf{F}}_{ij}\cdot\mathbf{n}_{ij}\,\Delta\Gamma_{ij}=\mathbf{S}_i$$

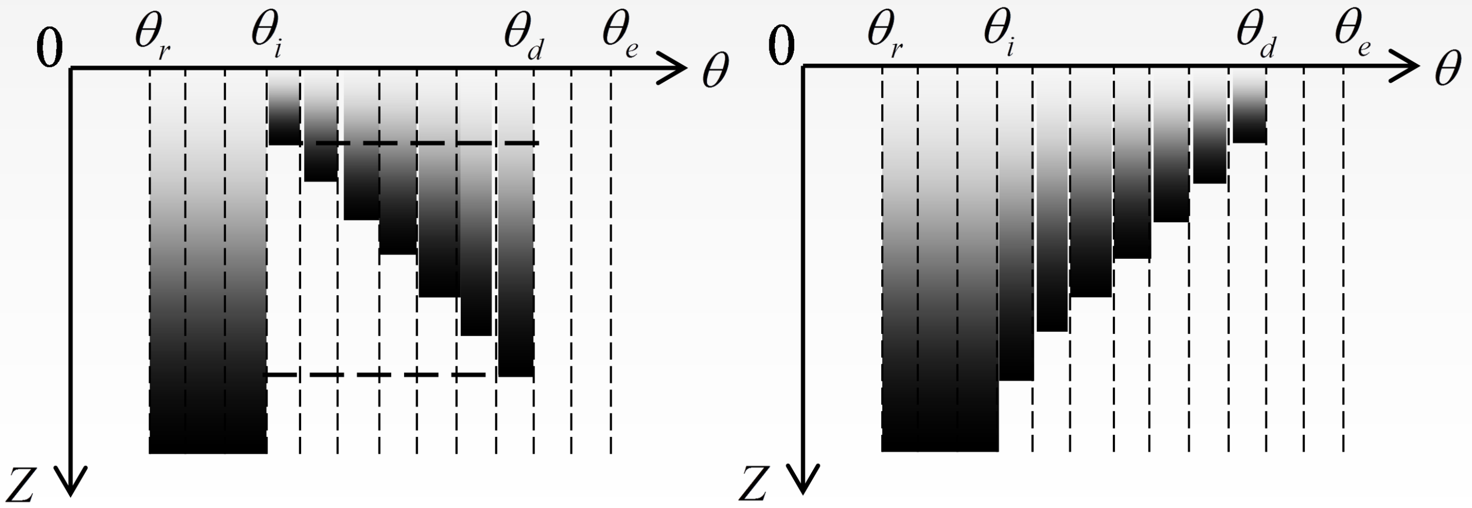


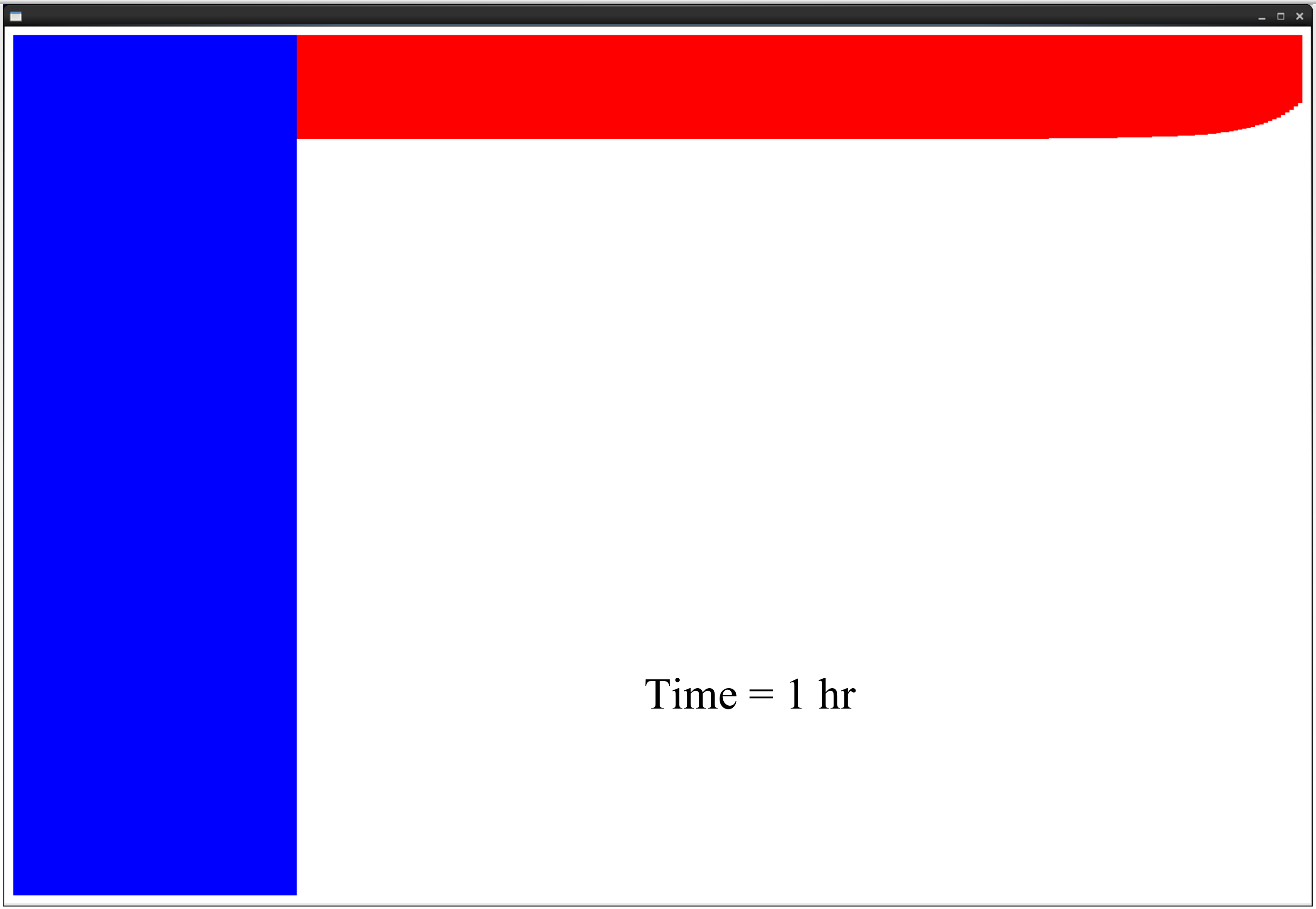
Improvement of T-O infiltration model

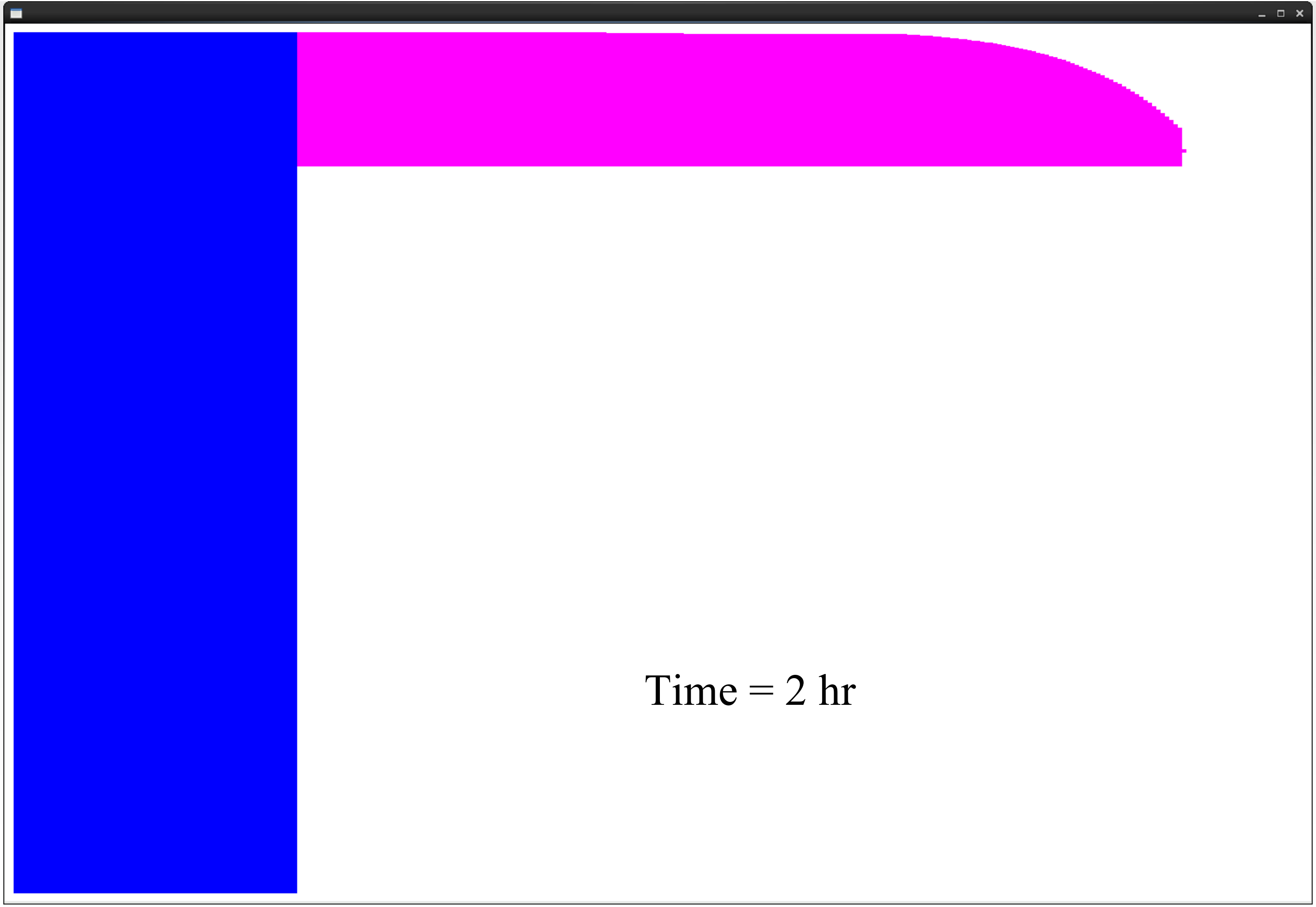
Introduce slugs;

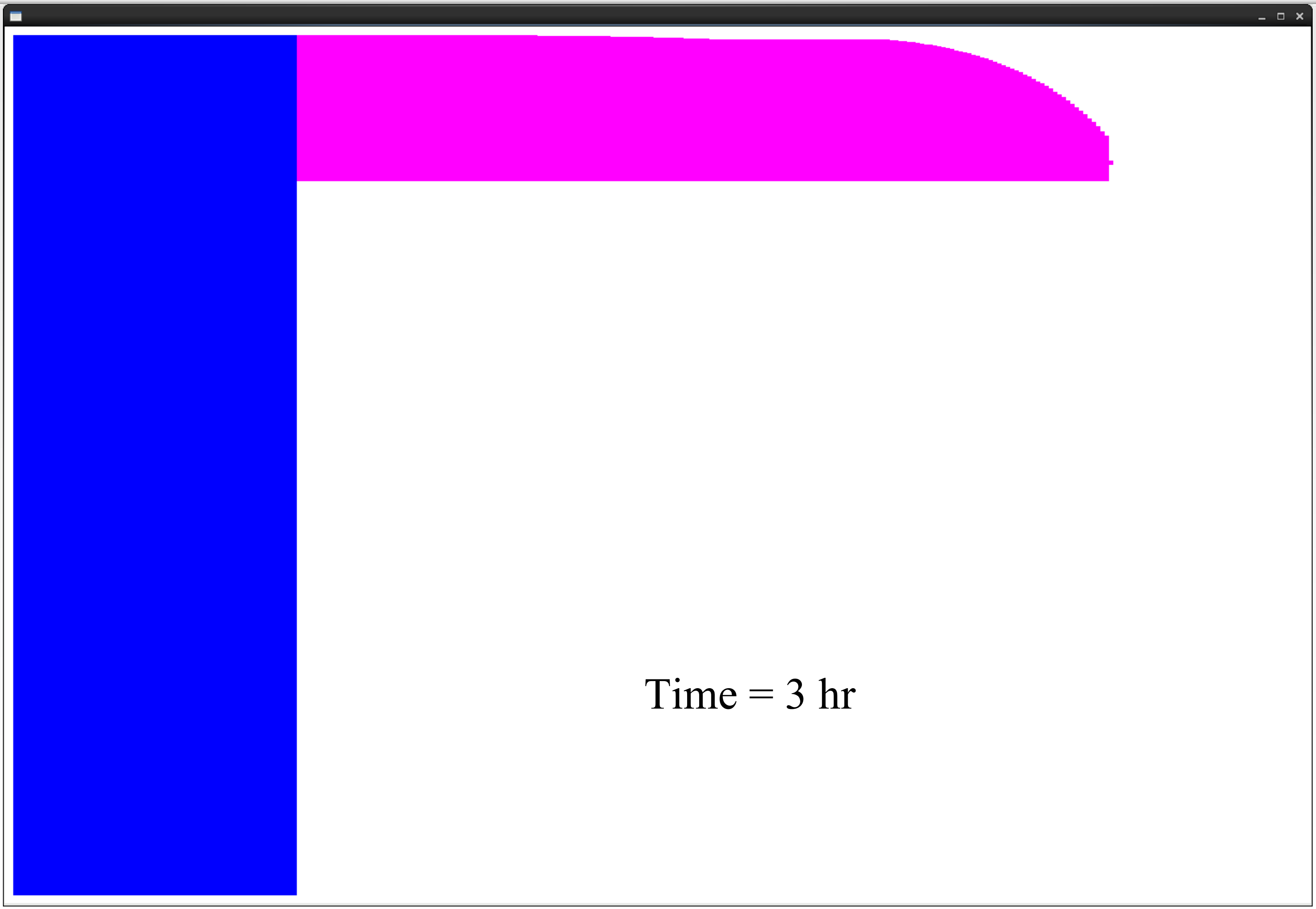
$$\frac{dZ_k}{dt} = \frac{K(\theta_d) - K(\theta_i)}{(\theta_d - \theta_i)}\left(\frac{|\Psi(\theta_d)|}{Z_k} + 1\right)$$

Better capturing ponding time;

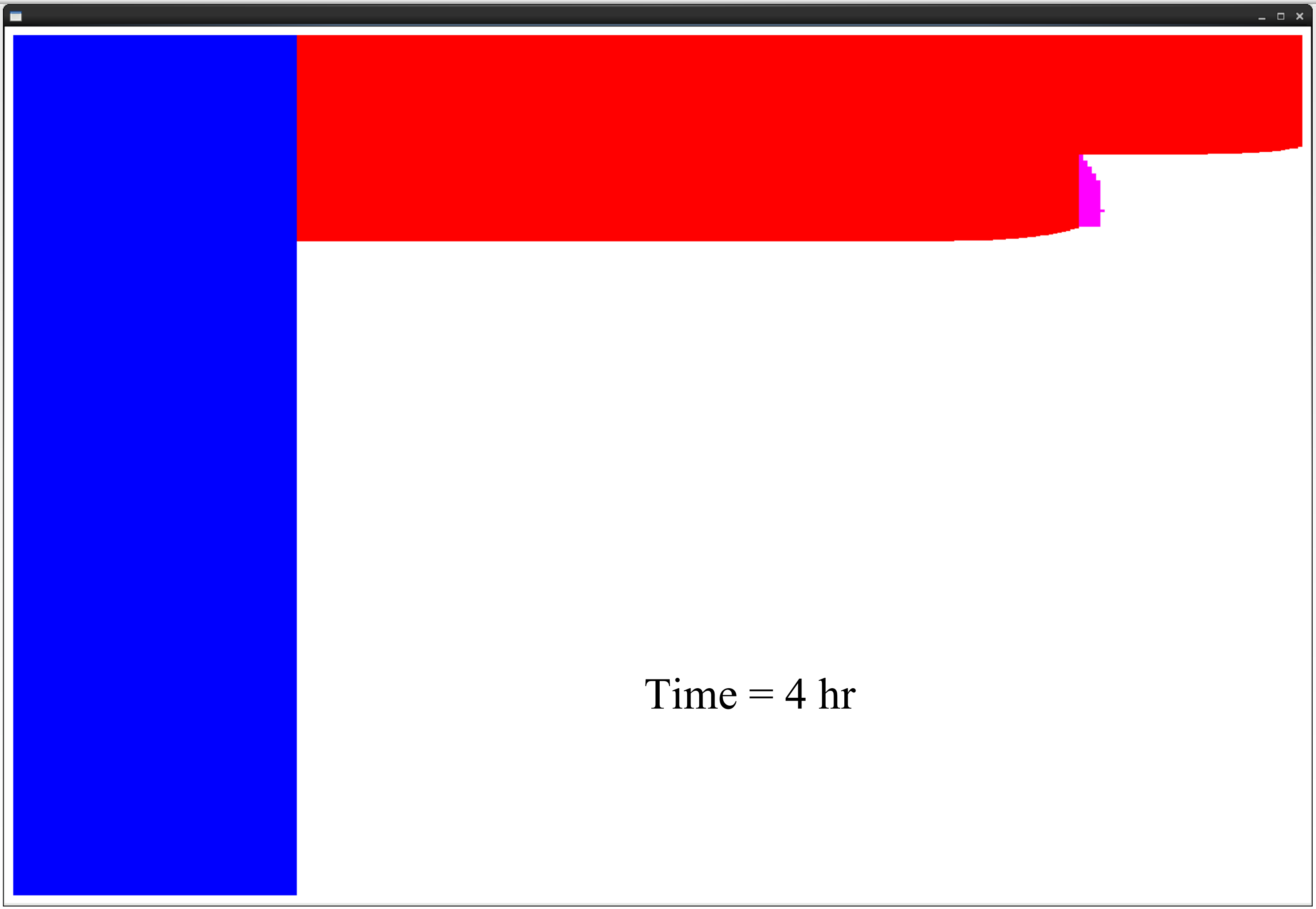



Time = 1 hr

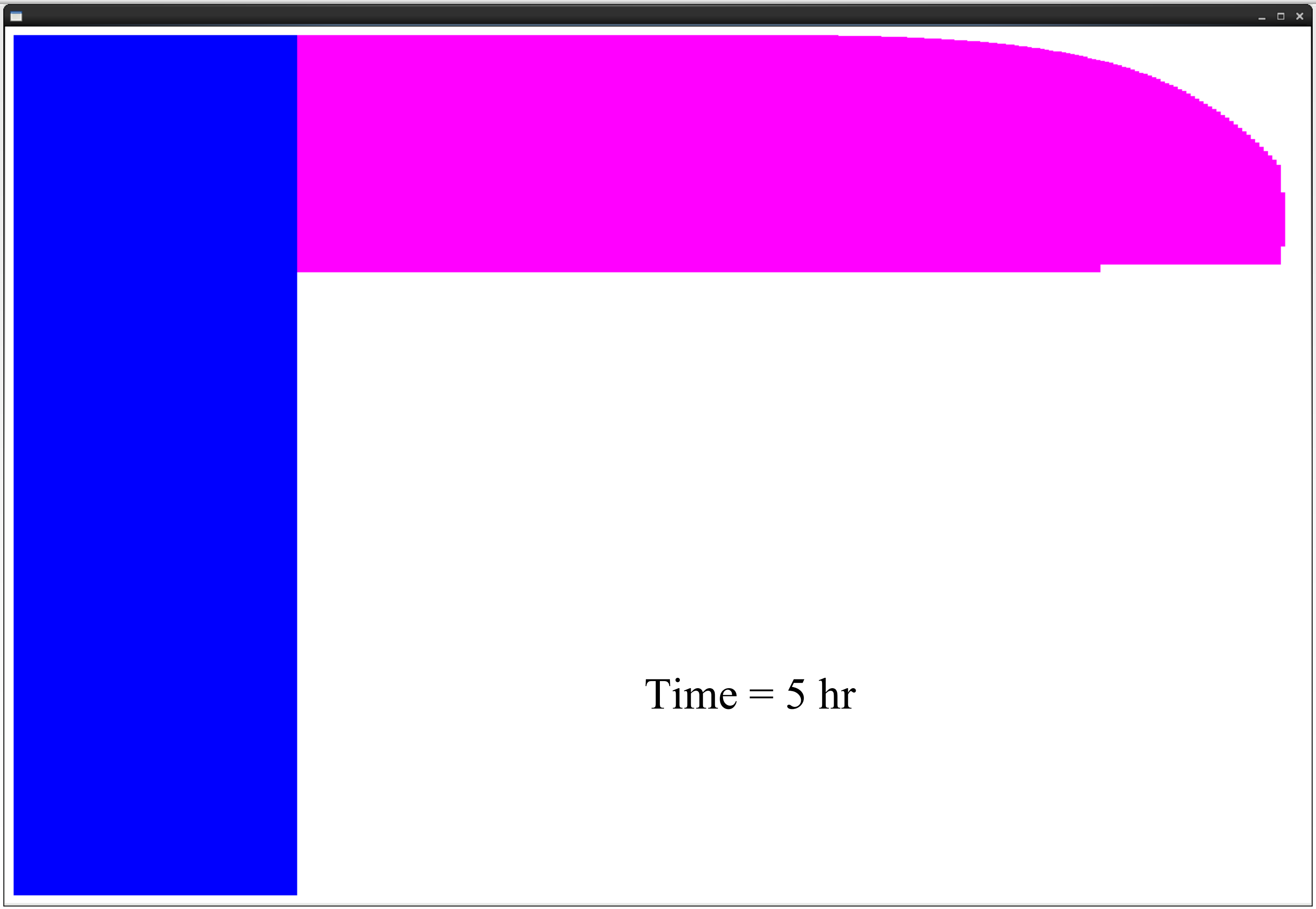

Time = 2 hr

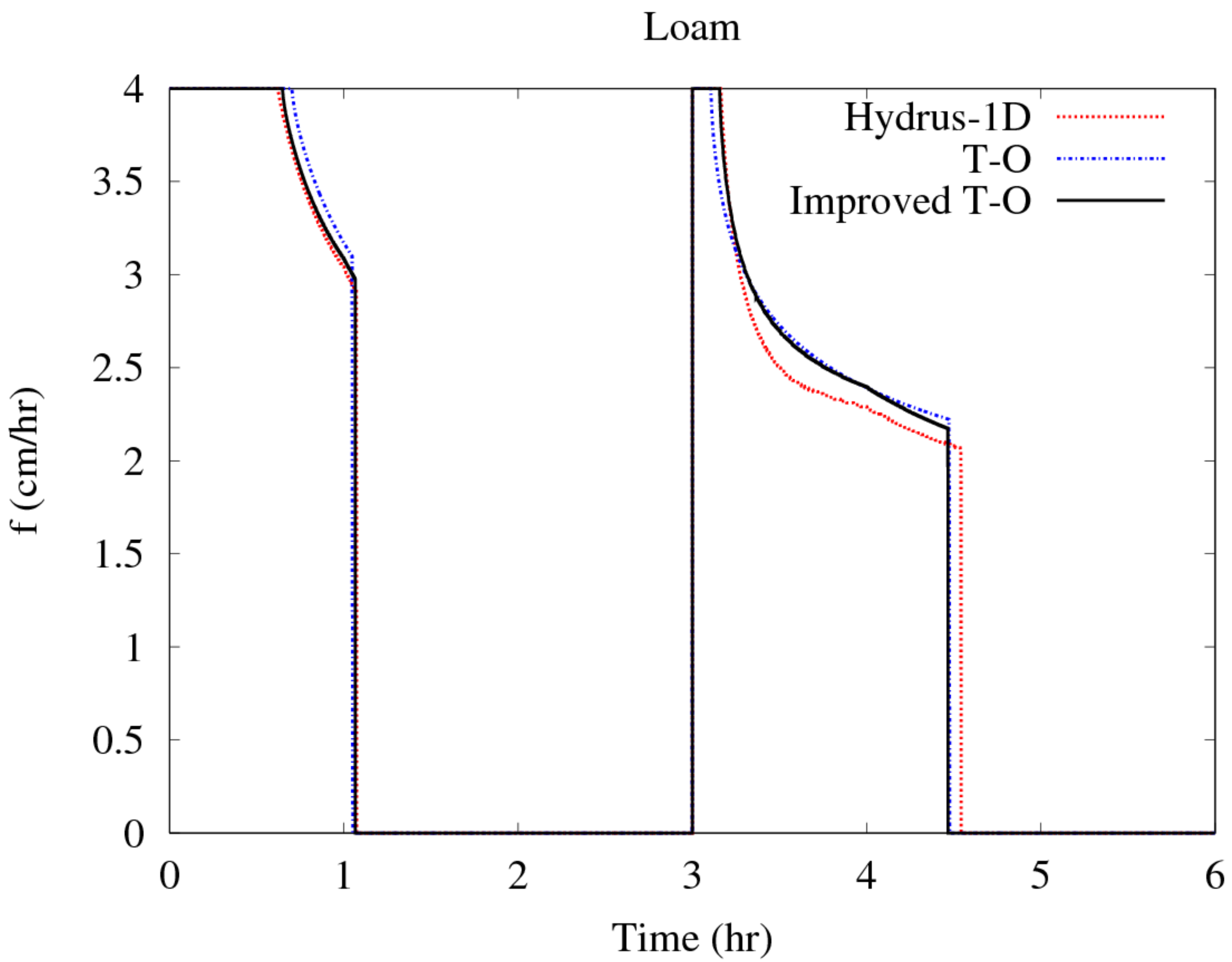


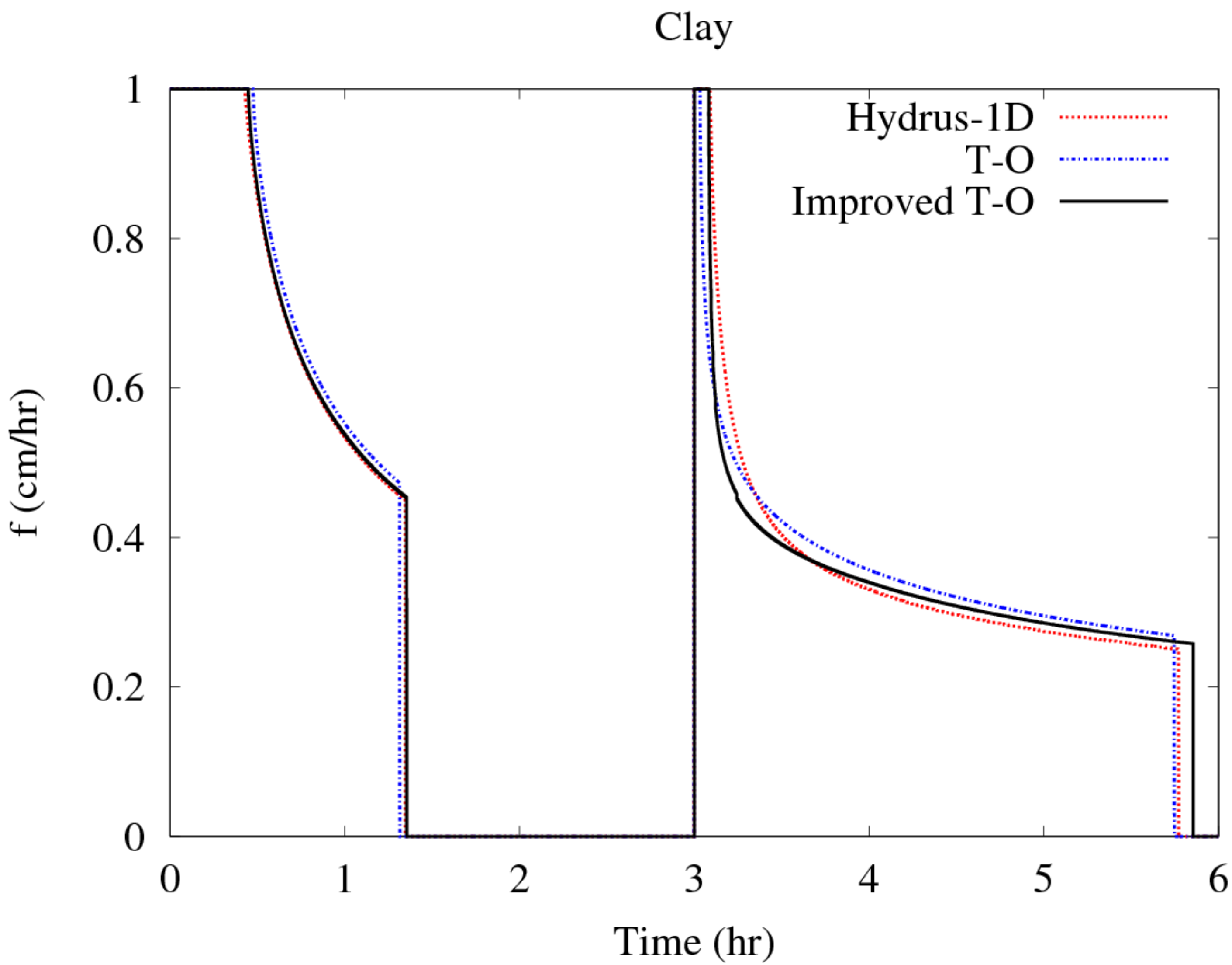
Time = 3 hr



Time = 4 hr


Time = 5 hr


Loam
Hydrus-1D
T-O
Improved T-O
f (cm/hr)
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (hr)
0
1
2
3
4
5
6


Clay
Hydrus-1D
T-O
Improved T-O
f (cm/hr)
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
Time (hr)

Ponding time error

	First pulse (hr)			Second pulse (hr)		
	t_{p_RE}	$t_{p\_\mathrm{TO}}-t_{p\_\mathrm{RE}}$	$t_{p\_\mathrm{TO2}}-t_{p\_\mathrm{RE}}$	t_{p_RE}	$t_{p\_\mathrm{TO}}-t_{p\_\mathrm{RE}}$	$t_{p\_\mathrm{TO2}}-t_{p\_\mathrm{RE}}$
Sand	0.0620	0.0296	0.0018	3.0352	0.0204	0.0003
Loamy sand	0.1762	0.0161	0.0007	3.0806	-0.0257	-0.0081
Sandy loam	0.4092	0.0505	0.0071	3.1125	-0.0431	-0.0036
Loam	0.6229	0.0791	0.0251	3.1625	-0.0562	-0.0052
Silt loam	0.5604	0.0541	0.0048	3.1292	-0.0625	-0.0314
Sandy clay loam	0.6395	0.0750	0.0215	3.1688	-0.0584	-0.0310
Clay loam	0.4166	0.0416	0.0119	3.0833	-0.0375	-0.0169
Silty clay loam	0.6375	0.0513	0.0227	3.1625	-0.0736	-0.0540
Sandy clay	0.4861	0.0694	0.0425	3.1278	-0.0639	-0.0147
Silty clay	0.2569	0.0138	0.0030	3.0264	-0.0195	0.0041
Clay	0.4277	0.0458	0.0202	3.0903	-0.0584	-0.0072

Error analysis

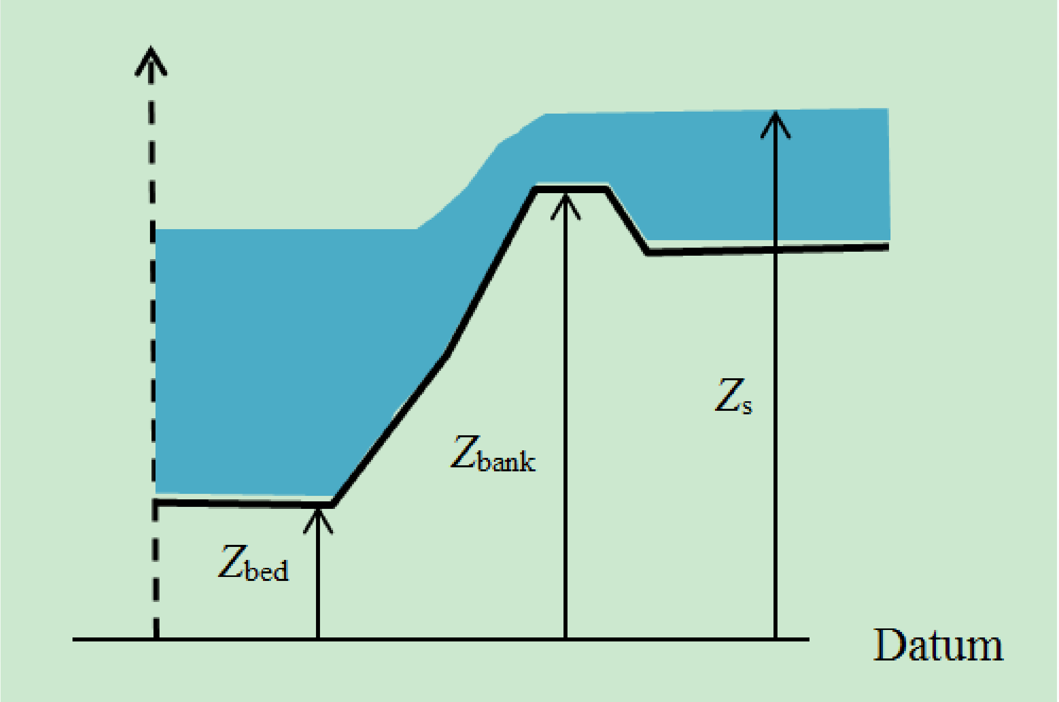
	Original T-O method			Improved T-O method		
	NSE	PBIAS (%)	RMSE (cm)	NSE	PBIAS (%)	RMSE (cm)
Sand	0.98439	-0.88117	1.76080	0.99123	0.28432	1.3326
Loamy sand	0.97731	-0.13587	0.70480	0.98990	0.00380	0.47025
Sandy loam	0.96744	-0.12265	0.44903	0.97270	-0.02703	0.41120
Loam	0.96470	-0.15186	0.30142	0.97091	-0.10980	0.27360
Silt loam	0.96806	-0.20591	0.26058	0.98785	-0.18041	0.16092
Sandy clay loam	0.96958	-0.48253	0.13350	0.99184	-0.46368	0.06915
Clay loam	0.95822	-0.43289	0.12544	0.99029	-0.39823	0.06047
Silty clay loam	0.98100	-0.47849	0.10352	0.98760	-0.38760	0.08362
Sandy clay	0.96881	-0.97932	0.06049	0.99172	-0.88693	0.03115
Silty clay	0.95426	-0.39015	0.09972	0.99429	-0.25234	0.03522
Clay	0.96815	-0.98815	0.05446	0.97945	-0.90124	0.04373

Overland and channel flows interaction

Weir type equations:

$$Q = C_d L (Z_s - Z_{bank}) \sqrt{2g(Z_s - Z_{bank})}$$

Q = flow rate ;
L = weir length ;
C_d = discharge coefficient ;
Z_s = surface water elevatoin
Z_{bank} = bank elevation ;

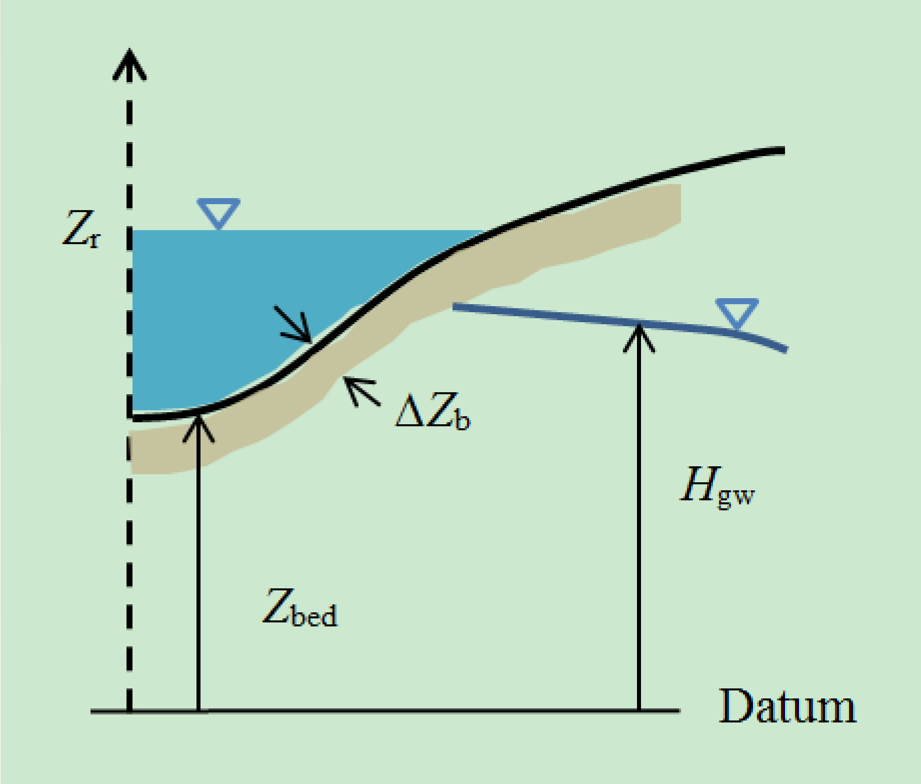


Groundwater and channel flows interaction

Conductance concept type equation:

$$V=\begin{cases} K_r \dfrac{H_{gw}-(Z_{bed}+h)}{\Delta Z_b}, & H_{gw}>Z_{bed}-\Delta Z_b \\ -K_r \dfrac{h+\Delta Z_b}{\Delta Z_b}, & H_{gw}\le Z_{bed}-\Delta Z_b \end{cases}$$

V = flow velocity;
h = channel water depth;
K_r = river bed conductivity;
Z_{bed} = river bed elevation
H_{gw} = groundwater elevation;
Δz_b = river bed thickness;



Future works

Geometry data for channel, lake, reservoir;

Land use / land cover and soil data;

Snowmelt model;

Water management model;