ICHARM

IFAS SYSTEM INSTRUCTION GUIDEBOOK

[Type the document subtitle]

IFAS1

9/8/2011

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

IFAS OPERATION PROCEDURES

IFAS ANALYSIS METHODS

1.Simulation engine general overview: the Public Works Research Institute Distributed Hydrological Model

1.1 A distributed model

PWRI distributed hydrological model is a runoff analysis model converting rainfall into runoff for a given river basin. It can be classified as both conceptual or parametric and physically-based, fully distributed model.

Conceptual models are based on assumed physically realistic equations combined with semi-empirical ones to relate rainfall and outflows. The relationshipsareparametric and parameters have to be estimated. The parameters can be set according to observed rainfall and discharge data, or estimated from similar rivers.

. Physically-based distributed models treat discharge as a migration phenomenon of rainfall in the river basin and represent the migration process by using infiltration and/or non-equilateral flow equations

Currently, there is no model that can represent the migration process by physical functions perfectly. Generally, physically-based distributed models need a huge amount of information on soil, geology, and river shape for modeling; consequently, the time for calculation becomes too long. However, conceptual models use equations governing “natural laws” in order to estimate outflow that comes from the river basin. This greatly shortens the calculation time and is considered as the appropriate model for flood forecasting.

1.2 Feature of the PWRI Distributed Model

So far, three versions of the PWRI Distributed Hydrological Model (ver.1 to ver.3) have been developed with specifications as follow:

- Ver1: configured as three tanks or more connected vertically (Table1, Figure 1)
- Ver2: configured as two tanks connected vertically (shortening the calculation time for flood outflow) (Figure 1)
- Ver3: considering evaporation and transpiration for low outflow calculation

IFAS ver 1.3βuses PWRI Distributed Hydrological Model (ver.2 and modified ver.1) as the runoff simulation engine with the features shown below:

① The outflow from each mesh is calculated by non-linear relationships based on the tank model philosophy. The non-linear relationshipsare not a complete Black Box or system in which only inputs and outputs are viewed but are also based on Manning and hyperbolic approximations.

② PWRI Distributed Hydrological Model has been using a two-layer non-linear tank configuration in order toshorten the calculation time.

③ In general, flows simulated from tank function model for small and medium floods are poorly fitted.

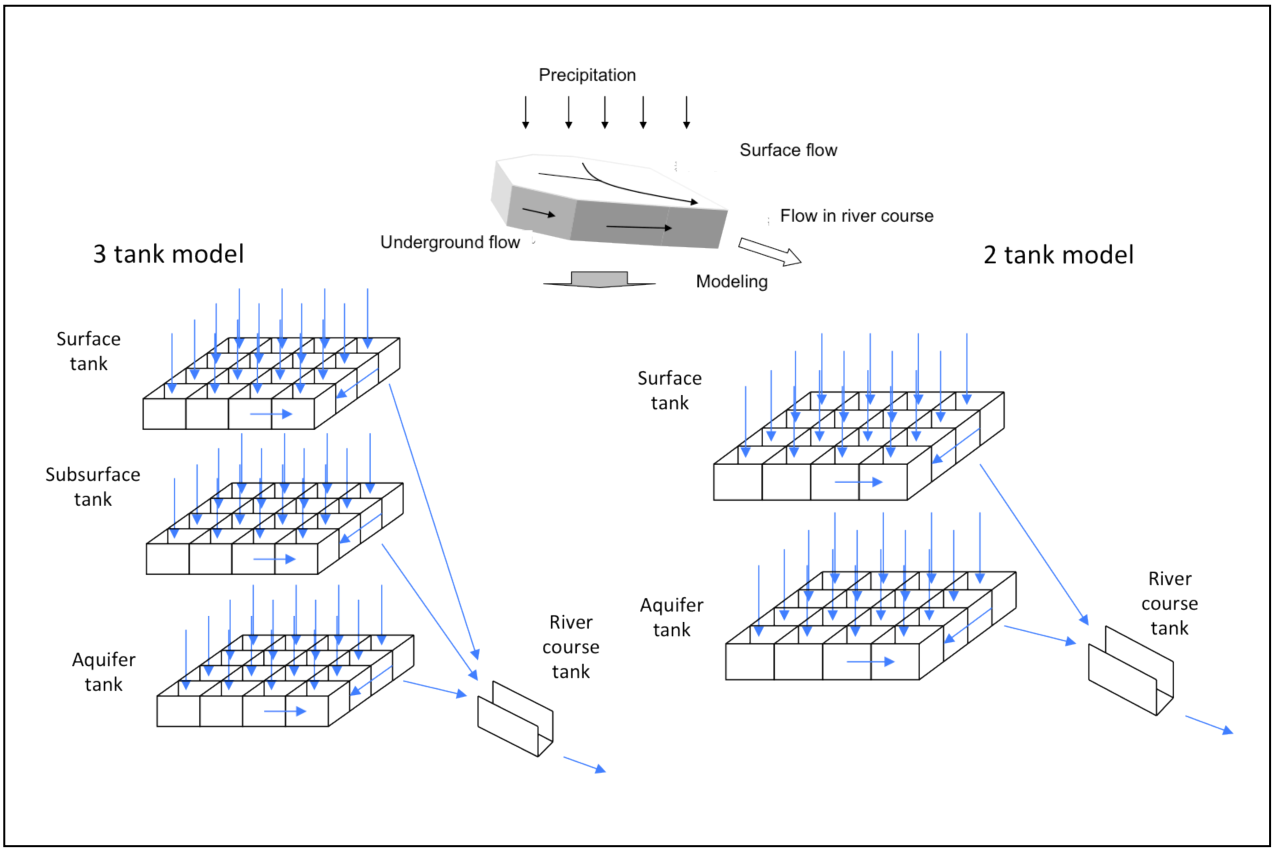
④ For numerical calculation, PWRI DHM does not use the convergence calculation to solve the differential equation. It uses approximation functions to solve the time integral equation. For this reason, the system can conduct numerical calculations smoothly and for real-time operation.

⑤ To calculate discharge in the river course tank, PWRI DHM uses Kinematic Wave Model.

The ver.1 of PWRI Distributed Hydrological Model is configured as a 3 layer tanks or more connected vertically and following the concept described here (Table 1) :

Table 1 Model configuration

Model	Function
Surface tank model	Infiltration to unsaturated layer, surface runoff, surface storage, evapotranspiration, rapid unsaturated subsurface flow
Subsurface tank model (for the 3 tank model)	Infiltration to aquifer, subsurface runoff, subsurface storage, slow unsaturated subsurface flow
Aquifer tank model	Outflow from aquifer, aquifer loss
River tank model	River course discharge



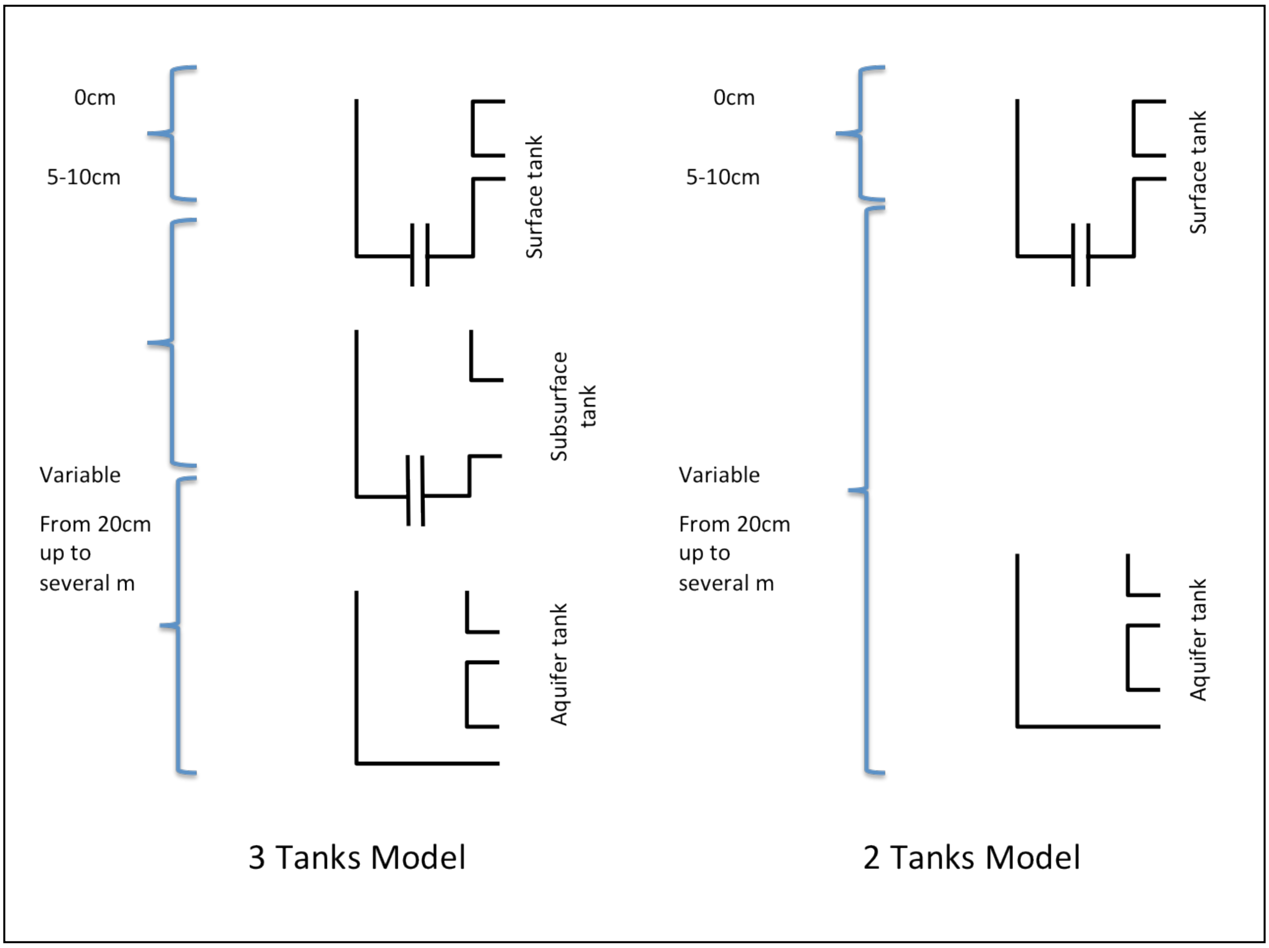


Figure 1 Schematic representation of the model (indicative soil profile depth for Japanese soil)

The lateral connections between mesh depends on the cell type of this mesh. There was an attempt in this model to illustrate how rivers are formed and develop in a catchment. Different cell type categories are then used to represent the different river development stages. Indeed, according to the position of a cell in the catchment, i.e. upstream or downstream in the catchment, it will be classified into one of the four cell type categories, according to the number of cells it has upstream.

The cell type category defines the number of tanks at the vertical of each mesh and their inter-connections (Table 2, Figure 2).

Table 2 Cell type and tank organization set accordingly.

Cell type	Number of tanks (2tanks model)	Number of tanks (3tanks model)	Tanks
0	2	3	Surface tank, (subsurface tank), aquifer tank
1	3	4	Surface tank, (subsurface tank), aquifer tank and river tank type 1 not receiving flow from the aquifer tank. River discharge is calculated according to Manning's law for this cell type.
2	3	4	Surface tank, (subsurface tank), aquifer tank and river tank type 2 receiving flow from the aquifer tank. River discharge is calculated according to Manning's law for this cell type.
3	3	4	Surface tank, (subsurface tank), aquifer tank and river tank discharge calculated according to the kinematic wave method.

Figure 2 illustrates then how the different cells are connected both vertically and horizontally according to DHM engine:

- Type 0 cells correspond to the most upstream cells where there is no river yet. Rainfall water infiltrates and participates to aquifer discharge after considering evapotranspiration.
- Type 1 cells correspond to the cells more downstream where a river formed. The water table is too low to contribute to river discharge but the river contributes to aquifer recharge.
- Type 2 cells correspond to cells even more downstream. Aquifer starts to participate to river base flow. Surface flow, subsurface saturated and unsaturated flows keep on contributing to river discharge.
- Type 3 cells correspond to the cells in which there is the river channel.

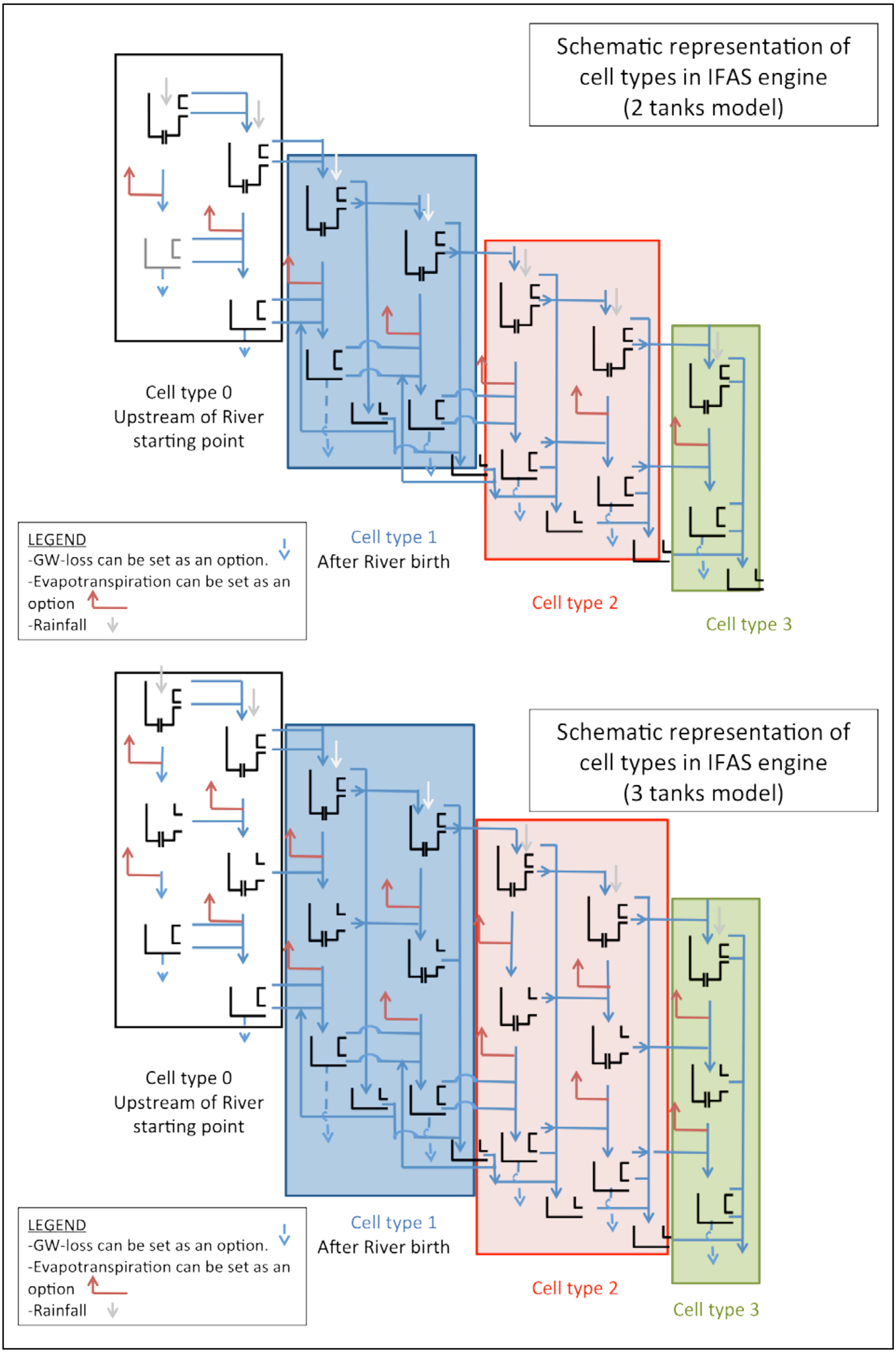


Figure 2 Schematic representation cell lateral and horizontal connections. (Further explanations in Table 3)

1.3 Outlines of each model

1.3.1 Surface tank model

The surface tank model is a model used to divide the rainfall to surface, rapid intermediate, and ground infiltration flows. The top right, bottom right and central bottom orifices represent the surface, rapid intermediate and ground infiltration flows, respectively. The surface / saturated excess overland outflow is estimated as a fraction(3/5) of storage capacity based on the Manning's law. The rapid unsaturated subsurfaceflow is also estimated as a fraction of storage capacity. The ground infiltration is estimated as a fraction of storage capacity based on the Darcy Law.

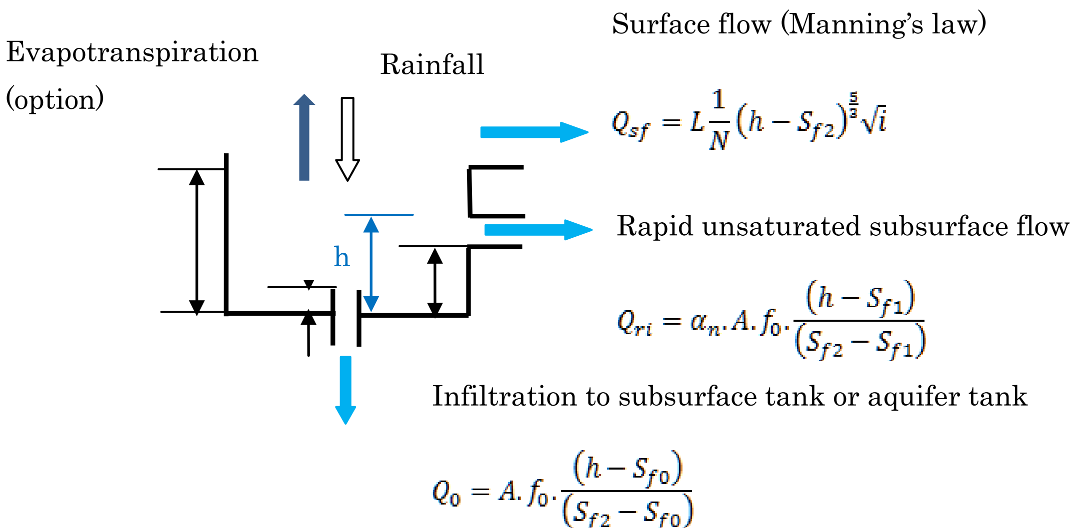


Figure 3 Schematic representation of surface tank

1. If $h<S_{f2}$, then

$$A.\frac{\partial h}{\partial t} = R - E_{ps} - Q_0 - Q_{sf} - Q_{ri} \quad (1)$$

2. f $S_{f1} < h < S_{f2}$, then

$$A.\frac{\partial h}{\partial t} = R - E_{ps} - Q_0 - Q_{ri} \quad (2)$$

3. If $S_{f0} < h < S_{f1}$, then

$$A.\frac{\partial h}{\partial t} = R - \frac{E_{ps}}{S_{f1}}h - Q_0 \quad (3)$$

4. If $h < S_{f0}$, then

$$A.\frac{\partial h}{\partial t} = R - \frac{E_{ps}}{S_{f1}}h \quad (4)$$

With: R: rainfall

E_{ps}: Evapotranspiration

Q_0: infiltration to lower tank (aquifer tank if 2layers model, subsurface tank if 3 layers model)

Q_{sf}: surface flow

Q_{ri}: rapid unsaturated subsurface flow

h: water height for the tank

S_{f2}: height from whichsurface flow occurs

S_{f1}: height from whichrapid unsaturated subsurfaceflow occurs

S_{f0}: height where ground infiltration occurs

$A = L*L$: mesh area with L, mesh length

1.3.2 Subsurface or subsurface tank model

The subsurface tank model makes it possible to simulate low flow conditions as well as long-term periods.

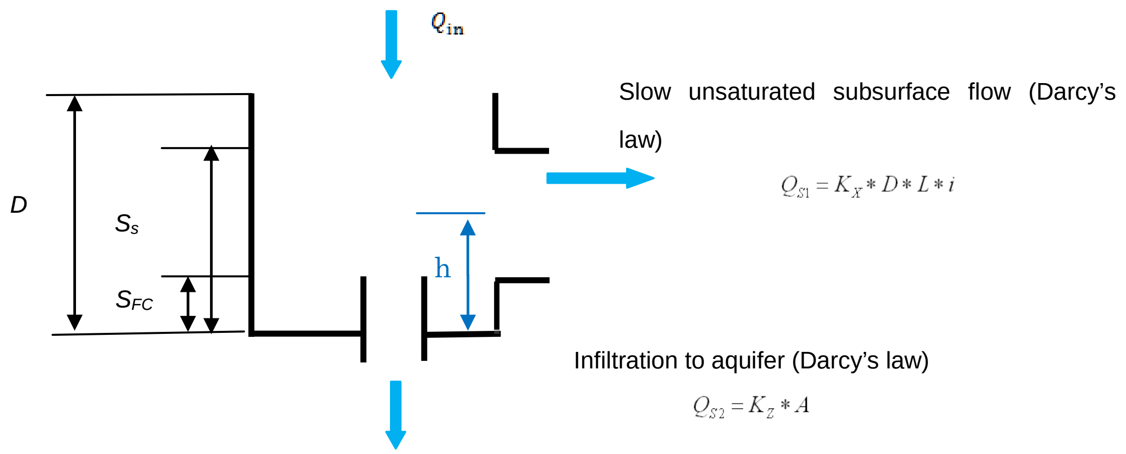


Figure 4 Schematic representation of subsurface tank

1. If $h \geq S_S$, then the subsequent flow is considered coming out from the surface tank as rapid unsaturated subsurface flow.
2. If $S_S > h \geq S_{FC}$, then

$$A.\theta_S \frac{\partial h}{\partial t} = Q_{in} - E_{ps} - Q_{s1} - Q_{s2} \quad (5)$$

3. If $h < S_{FC}$, then, there is no slow unsaturated flow nor infiltration to aquifer

$$A.\theta_S \frac{\partial h}{\partial t} = Q_{in} - \frac{E_{ps}}{S_{FC}}.h \quad (6)$$

With:

E_{ps}: Evapotranspiration

Q_{in}: flow entering the subsurface tank (according to cell type refer to Table 3)

Q_{S1}: slow unsaturated subsurface lateral flow

Q_{S2}: slow unsaturated subsurfacevertical flow

D: maximumwater height for subsurface tank *h*: water height for this tank

i: slope with the adjacent cell

S_S: height when $\theta=\theta_S$, soil moisture is equal to soil moisture at saturation and $\theta_S=S_S/D$

S_{FC}: height when $\theta=\theta_{FC}$, soil moisture is equal to soil moistureat wilting point and $\theta_{FC}=S_{FC}/D$

θ: soil moisture content (=h/D)

b: constant depending on soil total porosity and ranging from 0-100

A: mesh area.

K_X: horizontal hydraulic conductivity at θ

K_Z: vertical hydraulic conductivity at θ

$K_x$and $K_z$are calculated following Hillel model (Hillel, 1983) to relate hydraulic conductivity at a given volumetric soil moisture and this volumetric soil moisture content:

$$K = a * \exp(b * \theta) \quad \text{.....(7)}$$

K_x and K_z are calculated so that when $h=D^*\,\theta_{S,}$, $K=Ks$ and when $h=D^*\,\theta_{FC}$, $K=0$.

Thus, withK_{SX}, the horizontalhydraulic conductivity at θ_S

$$K_X = K_{SX}.\frac{\exp(b.\theta)-\exp(b.\theta_{FC})}{\exp(b.\theta_S)-\exp(b.\theta_{FC})} \quad \text{.....(8)}$$

and with K_{SZ}, the horizontalhydraulic conductivity at θ_S

$$K_Z = K_{SZ}.\frac{\exp(b.\theta)-\exp(b.\theta_{FC})}{\exp(b.\theta_S)-\exp(b.\theta_{FC})} \quad \text{.....(9)}$$

1.3.3 Aquifer tank model

The configuration of aquifer model is shown as figure below. The top right and bottom right orifices represent the unconfined and confined aquiferoutflows, respectively. Outflow of ground water is considered as a fraction of confined aquifer to *h*, and of unconfined aquifer to h^2. These relationships were determined experimentally.

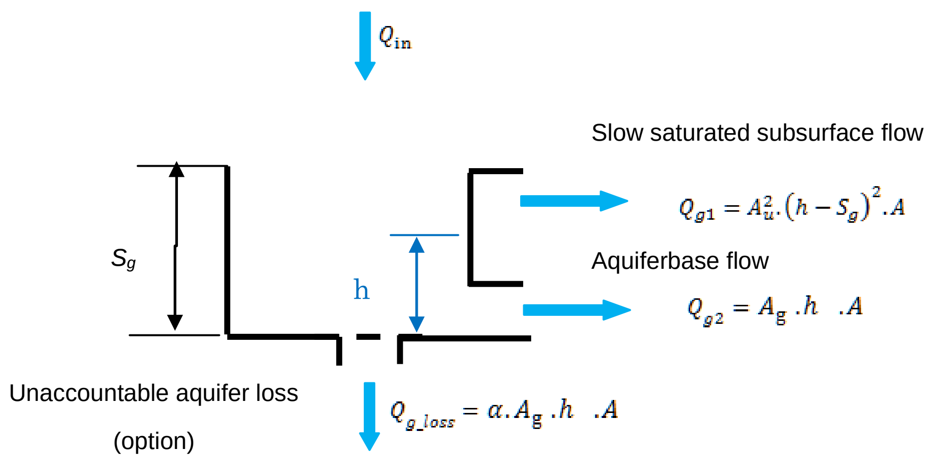


Figure 5 Schematic representation of aquifer tank

1. If $h>S_g$, then

$$A.\frac{\partial h}{\partial t}=Q_{in}-Q_{g1}-Q_{g2}-Q_{g\_loss} \quad (10)$$

2. If $h<S_g$, then

$$A.\frac{\partial h}{\partial t}=Q_{in}-Q_{g2}-Q_{g\_loss} \quad (11)$$

With,

Q_{in}: inflow to the aquifer tank (Table 3 for details)

h: water height of model

Q_{g1}:slow saturated subsurface flow

S_g:height from whichslow saturated subsurface flow

Q_{g2}:base flow

Q_{g_loss}:unaccountable aquifer loss

The outflows of unconfined and confined aquifer are as follows

$$Q_{g1}=A_u^2(h-S_g)^2A \quad (12)$$

$$Q_{g2}=A_g hA \quad (13)$$

With A_u and $A_g$being the coefficients used tocalculate slow saturated subsurface flow and base flow. If the option “unaccountable aquifer loss” is selected, then

$$Q_{g\_loss}=\alpha_{g\_loss}Q_{g2} \quad (14)$$

1.3.4 River coursetank model

For river discharge calculation, the equations used differ according to the cell type.

A. River discharge calculation for cell type 1 and 2.

Outflow from the river course tank is based on Manning equation for cell type 1 and 2.

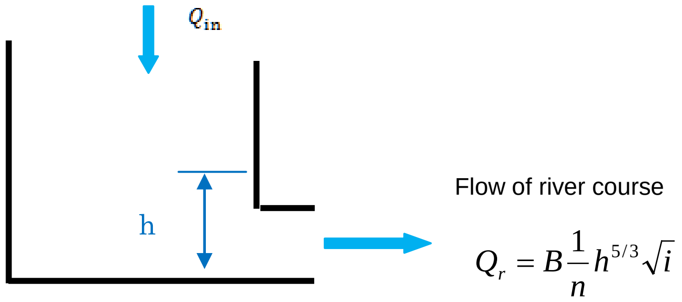


Figure 6 Schematic representation of river tank

$$LB\frac{\partial h}{\partial t} = Q_{in}\text{-}Q_r \quad (15)$$

With,

Q_{in}: flow entering the river course tank (Table 3 for details)

Q_r: outflow fromriver course

L: length of river course

B: breadth of river course

The river course breadth is calculated according to the Resume Law:

$$B = cA^s \quad (16)$$

With c and s are constants (generally s<1).

Because the model is considering runoff, the influence on the river course outflow is omitted.

B. *River discharge calculation for cell type 3*

For river course tank in cell type 3, the river routing method is the kinematic wave method using the difference method:

$\frac{\partial Q}{\partial t} + C\frac{\partial Q}{\partial x} = 0$ and $C = \frac{dQ}{dA}$ with C: the kinematic wave celerity.

Continuity equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad \textbf{(17)}$$

i Differential equation solved is presented here:

$$\frac{1}{2\Delta t}\left(Q_i^{n+1} + Q_{i+1}^{n+1} - Q_i^n - Q_{i+1}^n\right) + \frac{C}{2\Delta x}\left(Q_{i+1}^n + Q_{i+1}^{n+1} - Q_i^n - Q_i^{n+1}\right) = 0 \quad \textbf{(18)}$$

with, *i*being the spatial incrementation and*n*being the time incrementation.

$$Q_{i+1}^{n+1} = \frac{\left(\frac{1}{2\Delta t} + \frac{C}{2\Delta x}\right)Q_i^n + \left(\frac{1}{2\Delta t} - \frac{C}{2\Delta x}\right)Q_{i+1}^n + \left(-\frac{1}{2\Delta t} + \frac{C}{2\Delta x}\right)Q_i^{n+1}}{\frac{1}{2\Delta t} + \frac{C}{2\Delta x}} \quad \textbf{(19)}$$

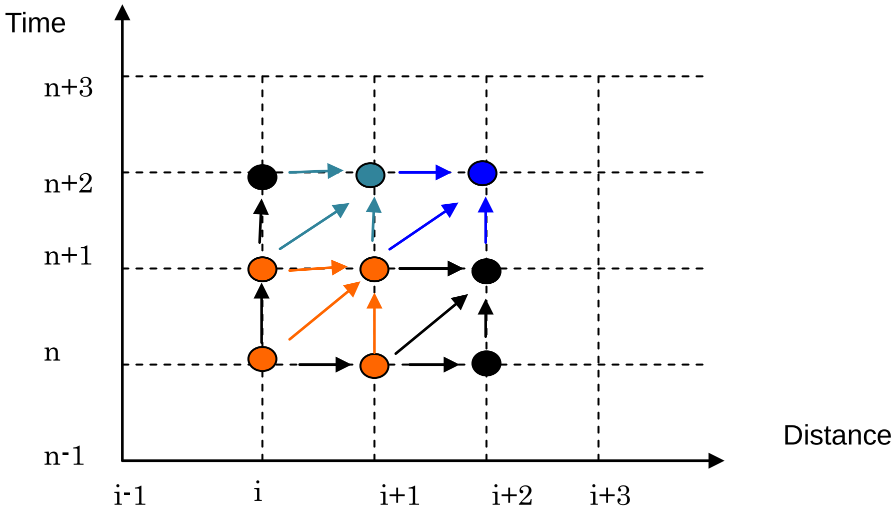


Figure 7 Image of Kinematic Wave difference method

This model conducts calculation by treating *Δx* as the mesh length and by shortening the *Δt.*

ii Calculation method for C, the kinematic wave celerity

In addition, river course with compound sections also can be calculated within this model. Furthermore, the model assumes that the flow rate of flood channel is 0 m^3/hour or day, and calculates the discharge of low flow channel section only. Because the section area contains also the flood channel, a storage effect considering the flood channel has been included in the model. Finally, the storage effect of flood channel (considered as flood area) around the river can be optionally selected.

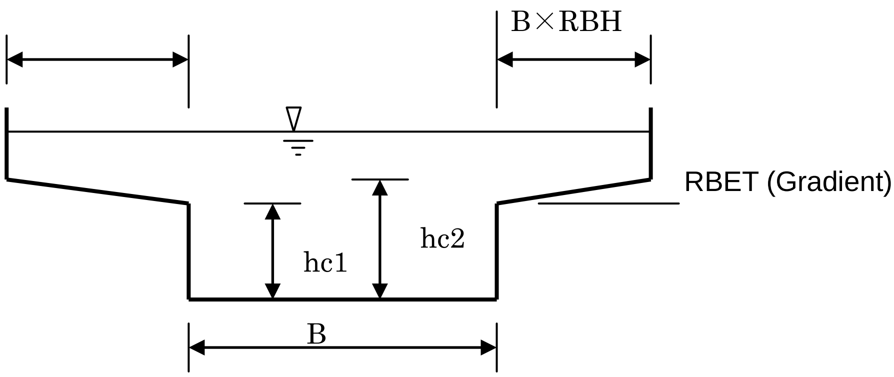


Figure 8 Schematic representation of river course with multiple cross-sections.

Both Resume law and Manning's law are used to calculate C.

Manning equation:

$$Q = \frac{1}{n} Bh^{5/3} I^{1/2} \quad \text{......} \quad (\mathbf{20})$$

Where *Q* is the flow;

A is the area of the cross-section and *A=Bh, h* is water depth

I is gradient of riverbed;

n is coefficient of roughness;

x is the spatial variablein the flow direction;

t is the time variable.

- *B* is set as:

$B = RBW \cdot A^{RBS}$ with*B* is river breadth (m); *A* is area of river basin (km^2); *RBW* and *RBS* are constants.

- *hc1* is set as:

$hc1 = RHW \cdot A^{RHS}$ with*B* is river breadth (m); *A* is area of river basin (km^2); *RHW* and *RHS* are constants.

- *hc2* is set as:

$$hc2 = RHW \cdot A^{RHS} + B \cdot RBH \cdot RBET$$

- Because the wave speed when *h≦hc1* is $A = Bh$, then

$$C_0 = \frac{\frac{dQ}{dh}}{\frac{dA}{dh}} = \frac{\frac{5}{3}\frac{1}{n} Bh^{2/3} i^{1/2}}{B} = \frac{5}{3}\frac{1}{n} h^{2/3} i^{1/2} = \frac{5}{3} Q^{2/5} n^{-3/5} I^{3/10} B^{-2/5} \quad \text{......} \quad (21)$$

- Wave speed, when *hc1≤h<hc2*

Because $A = Bh + RBET \cdot (h - h_{c1})^2$, then

$$C = \frac{\frac{dQ}{dh}}{\frac{dA}{dh}} = \frac{\frac{5}{3}\frac{1}{n} Bh^{2/3} i^{1/2}}{B + 2(h - h_{c1}) / RBET} = \frac{B}{B + 2\left(\left(\frac{Qn}{BI^{1/2}}\right)^{3/5} - h_{c1}\right) / RBET} C_0 \quad \text{......} \quad (22)$$

- Wave speed, when *hc2≤h*

Because $A = Bh + RBET \cdot (h_{c2} - h_{c1})^2 + 2B \cdot RBET(h - h_{c2})$, then

$$C = \frac{\frac{dQ}{dh}}{\frac{dA}{dh}} = \frac{\frac{5}{3}\frac{1}{n} Bh^{2/3} i^{1/2}}{B + 2B \cdot RBH} = \frac{1}{1 + 2RBH} C_0 \quad \text{......} \quad (23)$$

Table 3 Flows in and out of a cell according to its cell type.

Cell type	Tank	Possible flow in	Possible flow out
0	Surface tank	• Rainfall • Surface flow from upstream cell • Rapid unsaturated subsurface flow from upstream cell	• Evapotranspiration • Surface flow • Rapid unsaturated subsurface flow • Infiltration to subsurface tank
	Subsurface tank	• Infiltration flow from surface tank • Slow unsaturated subsurface flow from upstream cell	• Evapotranspiration • Slow unsaturated subsurface flow • Infiltration to aquifer tank
	Aquifer tank	• Infiltration flow from subsurface tank • Slow saturated subsurface flow from upstream cell • Base flow from upstream cell	• Slow saturated subsurface flow • Base flow • Unaccountable groundwater loss
1	Surface tank	• Rainfall • Surface flow from upstream cell • Rapid unsaturated subsurface flow from upstream cell	• Evapotranspiration • Surface flow • Rapid unsaturated subsurface flow • Infiltration to subsurface tank
	Subsurface tank	• Infiltration flow from surface tank • Slow unsaturated subsurface flow from upstream cell	• Evapotranspiration • Slow unsaturated subsurface flow • Infiltration to aquifer tank
	Aquifer tank	• Infiltration flow from subsurface tank • Slow saturated subsurface flow from upstream cell • Base flow from upstream cell	• Slow saturated subsurface flow • Base flow • Unaccountable groundwater loss
	River tank (river discharge calculation according to Manning's law)	• Rainfall • Surface flow from upstream cell • Rapid unsaturated subsurface flow from upstream cell	• Evapotranspiration • Surface flow • Rapid unsaturated subsurface flow • Infiltration to subsurface tank

2	Surface tank	• Rainfall • Surface flow from upstream cell • Rapid unsaturated subsurface flow from upstream cell	• Evapotranspiration • Surface flow • Rapid unsaturated subsurface flow • Infiltration to subsurface tank
	Subsurface tank	• Infiltration flow from surface tank • Slow unsaturated subsurface flow from upstream cell	• Evapotranspiration • Slow unsaturated subsurface flow • Infiltration to aquifer tank
	Aquifer tank	• Infiltration flow from subsurface tank • Slow saturated subsurface flow from upstream cell • Base flow from upstream cell	• Slow saturated subsurface flow • Base flow • Unaccountable groundwater loss
	River tank (river discharge calculation according to Manning's law)	• Rainfall • Surface flow from upstream cell • Rapid unsaturated subsurface flow from upstream cell • Slow saturated subsurface flow from aquifer tank • Base flow from aquifer tank	• Evapotranspiration • Surface flow • Rapid unsaturated subsurface flow • Infiltration to subsurface tank
3	Surface tank	• Rainfall • Surface flow from upstream cell • Rapid unsaturated subsurface flow from upstream cell	• Evapotranspiration • Surface flow • Rapid unsaturated subsurface flow • Infiltration to subsurface tank
	Subsurface tank	• Infiltration flow from surface tank • Slow unsaturated subsurface flow from upstream cell	• Evapotranspiration • Slow unsaturated subsurface flow • Infiltration to aquifer tank
	Aquifer tank	• Infiltration flow from subsurface tank • Slow saturated subsurface flow from upstream cell • Base flow from upstream cell	• Slow saturated subsurface flow • Base flow • Unaccountable groundwater loss
	River tank (river discharge	• Rainfall • Surface flow from upstream	• Evapotranspiration • Surface flow

	calculation according to Kinematic wave method)	cell • Rapid unsaturated subsurface flow from upstream cell • Slow saturated subsurface flow from aquifer tank • Base flow from aquifer tank	• Rapid unsaturated subsurface flow • Infiltration to subsurface tank

2 Setting parameters: calibration process

2.1 Calibration definition

Models are simplified representations of reality. Therefore, it is necessary to adjust the model to reality. To do so, model parameters adjustment is necessary. It is advised to conduct calibration within recommended ranges, with the aim to optimize the agreement between measured data and model simulation results. (Tolson et al, 2007)

2.2 Description of parameters

The PWRI model (ver.1, 3 layers and ver.2, 2 layers) is the runoff simulation engine in IFAS. The PWRI model consists in a three or four tanks model, which are surface, unsaturated if 3 layers, aquifer and river course tanks. The figures below show the outlines and parameters of each tank.

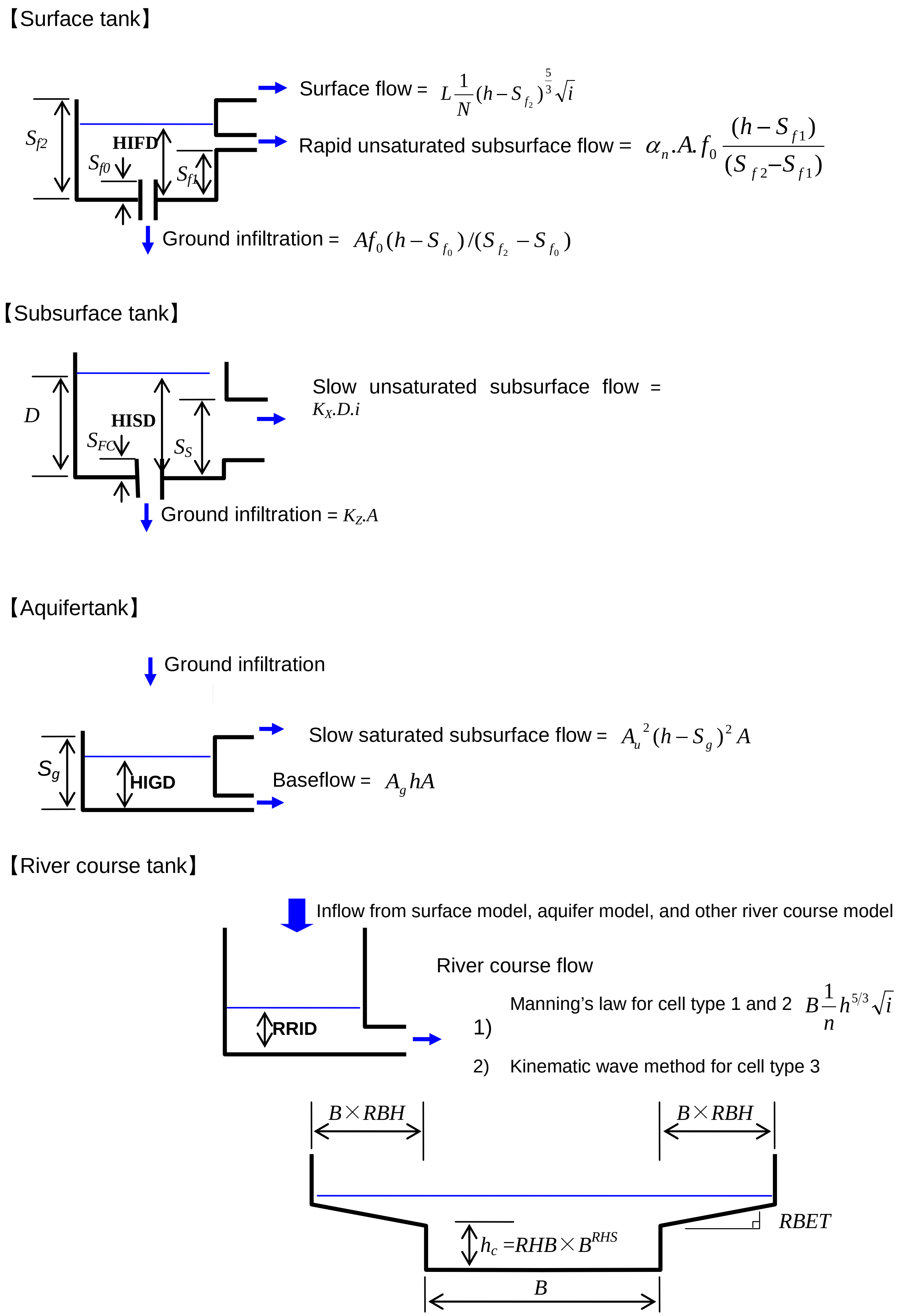


Figure 9 Model schematic representation and its parameters (PWRI DHM ver.1 and 2)

The tables below present the definition and explanation for each parameter.

Table 4Surface tank parameters list

Parameter	Symbol	Notation	Unit	Explanation
Vertical hydraulic conductivity	f_0	SKF	cm/s	This coefficient regulates the flow of water infiltrating from surface to underground. The higher the coefficient is, the lower the surface outflow will be. Values approximated from reference for different land use are listed below: ・for paddy field and urban land: 10^{-4}～10^{-5} ・for mountain and natural forest: 10^{-3} ・for active fault: 10^{-2}
Maximum water height	S_{f2}	HFMXD	m	Water height from which surface runoff occurs.
Height where rapid unsaturated subsurface flow occurs	S_{f1}	HFMND	m	The height from which rapid intermediate flow occurs
Minimum height for infiltration to start	S_{f0}	HFOD	m	The minimum height from which ground infiltration occurs The storage water doesn't flow if its height is less than S_{f0}
Surface roughness coefficient	N	SNF	$m^{-1/3}/s$	The roughness coefficient of ground surface.
Mesh length	L	—	m	Unit mesh/grid length of the model. To be set by the user.
Rapid unsaturated subsurface flow regulation coefficient	α_n	FALFX	Non-dimensional	Regulation factor that determines the rate of rapid intermediate flow. Set as a value of primary outflow rate. The standard value for rivers in Japan is 0.5 (calculated using the storage function method). For volcanic basin from the fourth epoch of the geological time, this value is 0.65.. This value changes with the soil saturation's state.
Initial water height	—	HIFD	m	Initial height of water in the surface tank. It is assumed that soil surface is dry before the flood event and set to the value 0.

Table 5Subsurface tank parameters list

Parameter	Symbol	Notation	Unit	Explanation
Tank height	D	HMXSD	m	Maximum water height in the subsurface tank.
Horizontal saturated hydraulic conductivity	K_{sx}	SKX	cm/s	It is estimated as 10^2-10^4 times bigger than the actual roughness coefficient because the flow is attributed to pipe flow, therefore very fast.
Vertical saturated hydraulic conductivity	K_{sz}	SKD	cm/s	Should estimate the actual infiltration rate.
Saturated moisture content	θ_S	STS	-	Saturated soil moisture content measured at pF0.6.
Moisture content at field capacity	θ_{FC}	STW	-	Soil moisture content measured at pF2.7 (highest pF that can be measured by a suction device) when water movement by capillarity becomes minimum. It is the drainage upper limit.
	b	SBD	-	Constant linking Φ (total porosity) and θ (moisture content) with a value between 1 and 100. When the value of b decreases, the value of hydraulic conductivity increases.
Vertical hydraulic conductivity at field capacity (θ_{FC})	K_{FC_z}	SK0D	cm/s	Hydraulic conductivity when $\theta = \theta_W$

Initial water height	—	HISD	m	Initial value for subsurface tank.

Table 6 Aquifer tank parameters list

Parameter	Symbol	Notation	Unit	Explanation
Slow unsaturated subsurface flow regulation coefficient	A_u	AUD	$(1/\text{mm}/\text{day})^{1/2}$	Regulation factor that determines the rate of slow intermediate flow.
Base flow coefficient	A_g	AGD	1/day	Regulation factor that determines the rate of base flow.
Water height where the slow unsaturated subsurface flow occurs	S_g	HCGD	m	Water height from which the slow intermediate flow occurs.
Initial water height	—	HIGD	m	The value of Initial storage in the aquifer tank This value and A_g determine the outflow before the flood event. Set HIGD≦HCGD
Coefficient for unaccountable aquifer loss	α_{GW}	α	Non-dimensional	This is set as an option in IFAS. A coefficient to report aquifer loss, which is not accountable.

Table 7 River course tank parameters list

Parameter	Symbol	Notation	Unit	Explanation
Breadth of river course	B	-	m	The width B of the river course is calculated according to the Resume Law ($B = c \times Q^s$; where Q is the outflow).
Coefficientof the Resume Law: c	c	RBW	Non-dimensional	Coefficient of the Resume Law Generally c＝3.5～7
Coefficient of the Resume Law: *s*	*s*	RBS	Non-dimensional	Constant of the Resume Law Generally s = 0.5
Manning's roughness coefficient	*n*	RNS	$m^{-1/3}/s$	Manning's roughness coefficient n=1/M
Initial water level in the river course	—	RRID	m	Initial value for calculation
Infiltration from river tank to the aquifer tank	—	RGWD	1/day	Coefficient of infiltration from the river course to the aquifer tank .
Coefficient for cross section shape	—	RHW	Non-dimensional	Coefficient to calculate the height of water (h_c)from low flow to bankfull condition h_c = RHW×A^{RHS}, A being the area of the basin.
Coefficient for cross section shape	—	RHS	Non-dimensional	Coefficient to calculate the height of water (h_c)from low flow to bankfull condition h_c = RHW×A^{RHS}, A being the area of the basin.
Coefficient for cross section shape	—	RBH	Non-dimensional	Channel width under flood condition is calculated based on B and is equal to B+2*B×RBH
Coefficient for cross section shape	—	RBET	Non-dimensional	Vertical gradient of the additional width in floodplain estimation
Meander coefficient	—	RLCOF	Non-dimensional	The length of the river is calculated according to the number of mesh it goes through but on a rectilinear way. As rivers are not rectilinear even within a mesh, correction is necessary and is operated with this coefficient.

2.3 How to set parameters for calibration

This section explains how to set parameters.

Default or un-tunedvalues are set as initial values for each parameter.All parameters have to be calibrated using observed and/or hydrological reference data.

2.3.1 .Un-tuned parameters

The un-tuned parameters are used as the initial values of parameter verification and for calculation when there is no observed flood data. Even though IFAS can calculate runoff by using the un-tuned parameters when the historical hydrology data are not available, we recommend the user to check the flood marks data and/or flow ratio data (outflow/basin area) around the target calculation area, confirming the validity of results, and calibrating the parameters with site measurements.

2.3.2 How to set the parameters for surface, unsaturated and aquifer tanks

This section explains how to set the parameters for the surface, unsaturated and aquifertanks. The parameters are set by trial and error, by comparing simulated and measured flood outflow values. The tablebelow shows the principles for setting parameters.

Table 8 Surface tank model

<table>
<tr><th>Parameter</th><th>Symbol</th><th>Notation</th><th>Unit</th><th>How to set</th></tr>
<tr><td>Vertical hydraulic conductivity</td><td>f_0</td><td>SKF</td><td>cm/s</td><td>Set by trial and error</td></tr>
<tr><td>Maximum water height</td><td>S_{f2}</td><td>HFMXD</td><td>m</td><td>Set by trial and error</td></tr>
<tr><td>Height where rapid unsaturated subsurface flowoccurs</td><td>S_{f1}</td><td>HFMND</td><td>m</td><td>Set by trial and error</td></tr>
<tr><td>Height where ground infiltration occurs</td><td>S_{f0}</td><td>HFOD</td><td>m</td><td>Set by trial and error</td></tr>
<tr><td>Surface roughness coefficient</td><td>N</td><td>SNF</td><td>$m^{-1/3}/s$</td><td>This value refers to equivalent roughness coefficient
Reference equivalent roughness coefficient (N)
<table>
<tr><th colspan="3">Land use</th><th>Std. value</th></tr>
<tr><td colspan="3">Water surface</td><td>0.0</td></tr>
<tr><td colspan="3">Paddy filed</td><td>2.0</td></tr>
<tr><td colspan="3">Mountain forest</td><td>0.7</td></tr>
<tr><td colspan="3">Hills, pastures, parks, golf ground, cropland</td><td>0.3</td></tr>
<tr><td colspan="3">Urban land</td><td>0.03</td></tr>
<tr><td rowspan="4">Urbanization level</td><td>1°</td><td>Road and street are partly paved, lots of bare ground are left. Drainage network is completed</td><td>0.1</td></tr>
<tr><td>2°</td><td>Road and street pavement is in progress Sewage nets is not completed</td><td>0.05</td></tr>
<tr><td>3°</td><td>50% road and street are paved Sewage network is almost completed</td><td>0.01</td></tr>
<tr><td>4°</td><td>Road and street are completely p□ve□. Sewage network is completed</td><td>0.005</td></tr>
</table>
Source）Hashimoto et., al., 1977. Runoff model and civil technological material for evaluating land use. In Japanese. We added water surface as a new item</td></tr>
<tr><td>Mesh length</td><td>L</td><td>—</td><td>m</td><td>Mesh length of the simulation model</td></tr>
<tr><td>Rapid unsaturated subsurface flow regulation coefficient</td><td>α_n</td><td>FALFX</td><td>Non-dimensional</td><td>Set by trial and error</td></tr>
<tr><td>Initial water height</td><td>—</td><td>HIFD</td><td>m</td><td>Basically, as 0 m</td></tr>
</table>

Subsurface tank parameters are a description of catchment soil hydraulic properties. These properties are related to soil types. Although there are global databases relating soil type (CGWM which can be downloaded in IFAS) and soil texture (Weeb et al, 2000), there are some problems when applying hydraulic properties determined at a different scale (Tartakovsky et al, 2000). Those values from the literature, like Rawls soil water properties estimation (Table 9) should be considered to determine ranges for these values and give an order of magnitude.

Table 9 Soil physical parameters by textural class (rearranged from Rawls et al, 1982, Smedema and Rycroft, 1983))

Texture Class	θ_{sat} (-)	θ_{FC}(-)	θ_{PWP} (-)	K_{sat}(m/day)
Sand	0.437	0.115	0.033	>5
Loamy Sand	0.437	0.168	0.055	1-5
Sandy Loam	0.453	0.245	0.095	1-3
Loam	0.463	0.279	0.117	0.5-2
Silt Loam	0.501	0.324	0.133	
Sandy Clay Loam	0.398	0.241	0.148	0.2-0.5
Clay Loam	0.464	0.321	0.197	
Silty Clay Loam	0.471	0.350	0.208	0.002-0.2
Sandy Clay	0.430	0.311	0.239	
Silty Clay	0.479	0.371	0.250	
Clay*	0.475	0.368	0.272	<0.002

*θ_{sat} volume water fraction at saturation, θ_{FC} volume water fraction at field capacity, θ_{PWP} volume water fraction at permanent wilting point, K_{sat} saturated hydraulic conductivity. *Dense clay with no cracks, no pores. Smedema and Rycrofts warn " soils with identical texture may have quite different Ksat values due to differences in structure, some heavy clay soils have well-developed structures and much higher Ksat values than those indicated in this table."*

Table 10Subsurface tank parameters list

Parameter	Symbol	Notation	Unit	How to set
Tank height	*D*	HMXSD	m	Set by trial and error.
Horizontal saturated hydraulic conductivity	K_{sx}	SKX	cm/s	Estimated first as 10^2-10^4 times bigger than the actual roughness coefficient and than vertical saturated hydraulic conductivity. Then tuned by trial and error around that value.
Vertical saturated hydraulic conductivity	K_{sz}	SKD	cm/s	Set by trial and error in the same order of magnitude of the value in the literature according to soil type.
Saturated moisture content	θ_S	STS	-	Set by trial and error in the same order of magnitude of the value in the literature according to soil type.
Moisture content at field capacity	θ_{FC}	STW	-	Set by trial and error in the same order of magnitude of the value in the literature according to soil type.
	b	SBD	-	Set by trial and error.(value between 1 and 100)
Vertical hydraulic conductivity at permanent wilting point soil moisture (θ_W)	K_{wz}	SK0D	cm/s	Set by trial and error in the same order of magnitude of the value in the literature according to soil type.
Initial water height	—	HISD	m	Set by trial and error.

Table 11 Aquifer tank model

Parameter	Symbol	Notation	Unit	Explanation
Slow saturated subsurface flow runoff coefficient	A_u	AUD	$(1/mm/day)^{1/2}$	Set by trial and error
Base flow runoff coefficient	A_g	AGD	1/day	Set by trial and error
Height where the slow saturated subsurface flow starts	S_g	HCGD	m	Set by trial and error
Initial water height	—	HIGD	m	Set by trial and error

Table 12 Parameters features for surface and aquifer tanks.

Parameter	Symbol	Notation	Variation in constant	Features
Vertical hydraulic conductivity	f_0	SKF	big	Water height of aquifer tank increases. Because of the increased outflow from aquifer tank, it is effective to enlarge the set part of wave shape and/or delay the peak.
			small	Water height of surface tank increases. Because of the increased outflow from aquifer tank, it is effective to enlarge the rise part of wave shape and/or delay the peak.
Maximum water height	S_{f2}	HFMXD	big	Surface outflow becomes slow. Whether or not the peak flow will become small depends on the flow from tank, landform and land use.
			small	Surface outflow becomes fast. Whether or not the peak flow will become big depends on the flow from tank, landform and land use.
Height where rapid unsaturated subsurface flow occurs	S_{f1}	HFMND	big	Rise part of wave shape becomes small. Peak flow becomes slow.
			small	Rise part of wave shape becomes big. Peak flow becomes fast.
Height where infiltration occurs	S_{f0}	HFOD	big	Whole wave shape becomes small. Water cannot be converted to runoff component increases
			small	Whole wave shape becomes big. When set as 0, water can all be converted to runoff component.
Ground surface roughness coefficient	N	SNF	big	Surface outflow becomes slow. Whether or not the peak flow will become small depends on the flow from tank, landform and land use.
			small	Surface outflow becomes fast. Whether or not the peak flow will become big depends on the flow from tank, landform and land use.
Mesh length	L	—	big	—
			small	—
Rapid unsaturated subsurface flow regulation coefficient	α_n	FALFX	big	Rise part of wave shape becomes big.
			small	Rise part of wave shape becomes small.
Surface tank initial water height	—	HIFD	big	—
			small	—
Slow saturated subsurface flow regulation coefficient	A_u	AUD	big	Set part of wave shape becomes big.
			small	Set part of wave shape becomes small.
Base flow coefficient	A_g	AGD	big	Base flow becomes big.
			small	Base flow becomes small.
Height where slow saturated subsurface flow occurs	S_g	HCGD	big	Set part of wave shape becomes small.
			small	Set part of wave shape becomes big. Peak flow becomes fast.
Aquifer tank initial water height	—	HIGD	big	Base flow becomes big.
			small	Base flow becomes small.

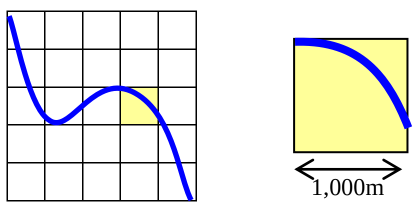
2.3.3 How to set parameters of river course

This section explains how to set the parameters for theriver course. The parameters of river course are set based on the features of river course and without using the adjustment on wave shape of flood. This is for avoiding the complex verifications of parameters by fixing them.

The feature of river course can be determined from local survey, landform map, and air photos.

Table 13 River course tank parameters settings.

<table>
<tr><th>Parameter</th><th>Symbol</th><th>Notation</th><th>Unit</th><th>How to set</th></tr>
<tr><td>Breadth of river course</td><td>B</td><td>-</td><td>m</td><td>Estimated width of river course base on the Resume Law.
$B = c{\times}Q^{s}$; Q is outflow</td></tr>
<tr><td>Constant of the Resume Law: c</td><td>c</td><td>RBW</td><td>m</td><td>Constant of the Resume Law
Generally c＝3.5～7</td></tr>
<tr><td>Constant of the Resume Law: s</td><td>s</td><td>RBS</td><td>Non-dimensional</td><td>Constant of the Resume Law
Generally s = 0.5</td></tr>
<tr><td>Manning’s roughness coefficient</td><td>n
(=1/M)</td><td>RNS</td><td>$m^{-1/3}/s$</td><td>Set from the feature of river course

Reference: Condition of river and waterway and range of roughness coefficient
<table>
<tr><th colspan="2">Condition of river and waterway</th><th>Range of Manning’s n</th></tr>
<tr><td rowspan="8">Artificial waterway and rehabilitated rivers</td><td>Concrete artificial waterway</td><td>0.014～0.020</td></tr>
<tr><td>Half spiral tube waterway</td><td>0.021～0.030</td></tr>
<tr><td>Small waterway with stone-banks (mud bed)</td><td>0.025(Ave.)</td></tr>
<tr><td>Bedrock unregulated</td><td>0.035～0.050</td></tr>
<tr><td>Bedrock regulated</td><td>0.025～0.040</td></tr>
<tr><td>Clay bed, flow rate without scouring</td><td>0.016～0.022</td></tr>
<tr><td>Sandy roam, clay roam</td><td>0.020(Ave.)</td></tr>
<tr><td>Drag line dredge, little grass</td><td>0.025～0.033</td></tr>
<tr><td rowspan="7">Natural rivers</td><td>Plain without small waterway and grass</td><td>0.025～0.033</td></tr>
<tr><td>Plain with small waterway, grass, irrigation</td><td>0.030～0.040</td></tr>
<tr><td>Small waterway, much grass, car polite bed</td><td>0.040～0.055</td></tr>
<tr><td>Mountain channel, gravel, boulder</td><td>0.030～0.050</td></tr>
<tr><td>Mountain channel, gravel, large boulder</td><td>0.040 以上</td></tr>
<tr><td>Big channel, clay, sandy riverbed</td><td>0.018～0.035</td></tr>
<tr><td>Big channel, car polite riverbed</td><td>0.025～0.040</td></tr>
</table>
Source）Supervised by the River Bureau, Ministry of Construction「River Erosion Control Technology Standards (Draft) chapter Survey」</td></tr>
<tr><td>Initial water level</td><td>―</td><td>RRID</td><td>m</td><td>Set from the ordinary water table</td></tr>
<tr><td>Infiltration of aquifer tank</td><td>―</td><td>RGWD</td><td>1/day</td><td>Basically, as 0</td></tr>
<tr><td>Cross-section shape coefficient</td><td>―</td><td>RHW</td><td>Non-dimensional</td><td>Set from the features of river cross-section</td></tr>
<tr><td>Cross-section shape coefficient</td><td>―</td><td>RHS</td><td>Non-dimensional</td><td>Set from the features of river cross-section</td></tr>
<tr><td>Cross-section shape coefficient</td><td>―</td><td>RBH</td><td>Non-dimensional</td><td>Set from the features of river cross-section</td></tr>
<tr><td>Cross-section shape coefficient</td><td>―</td><td>RBET</td><td>Non-dimensional</td><td>Set from the features of river cross-section</td></tr>
<tr><td>Meander coefficient</td><td>―</td><td>RLCOF</td><td>Non-dimensional</td><td>Set from landform and mesh figures.
i.e.）If mesh length is 1,000m, the river length of one mesh will be 1000 m. In field, the river length may be longer than 1000 m, therefore a correction of coefficient is needed.


</td></tr>
</table>

3 Evapotranspiration data calculation

Evapotranspiration calculation is set as an option in both IFAS ver.1.2 and ver.1.3β. If the option is selected, then a module runs attributing an evapotranspiration value derived from NCEP-DOE Reanalysis 2 data.

NCEP-DOE Reanalysis 2

We used the monthly averaged latent heat flux of the NCEP-DOE Reanalysis 2 to estimate evapotranspiration in IFAS.

The URL of websites of the NCEP-DOE Reanalysis 2 is as follows:

http://www.cdc.noaa.gov/data/gridded/data.ncep.reanalysis2.html

The monthly averaged latent heat flux is available for download from the following URL.

ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis2.derived/gaussian_grid/lhtfl.sfc.mon.mean.nc

Spatial coverage of the data is from 88.542 N to 88.542 S and from 0 E to 358.125 E. Spatial resolution is approximately 1.9° degrees in latitude and longitude (Global T62 Gaussian grid 192 x 94). Temporal coverage is from January, 1979 to December, 2008

Calculation of evapotranspiration in the IFAS system

Evapotranspiration used in FAS is estimated from latent heat flux of the NCEP-DOE Reanalysis 2, which is shown as follows.

Latent heat of vaporization at -20°C, 0°C, 20°C is 2.549 x 10^6 J kg^{-1}, 2.5 x 10^6 J kg^{-1}, 2.453 x 10^6 J kg^{-1}, respectively. We used latent heat of vaporization at 20°C in all cases.

Latent heat requited to evaporate 1(mm day^{-1} m^{-2}) of water is calculated in the following equations. As the mass of the water per a unit area is 1 kg m^{-2}, therefore latent heat is calculated in the equation (1)

$$1\ (kg\ m^{-2})\ /\ 86400\ (s) \times 2.5 \times 10^{6}\ (J\ kg^{-1}) = 28.4\ (J\ s^{-1}\ m^{-2}) \qquad (1)$$

As watt (W) is equivalent to joule per a second ($J\ s^{-1}$), therefore 28.4 ($J\ s^{-1}\ m^{-2}$) is equivalent to 28.4 ($W\ m^{-2}$). Evapotranspiration is written as,

$$1\ (mm\ day^{-1}) = 28.4\ (W\ m^{-2}) \qquad (2)$$

We use the equation (2) to calculate evapotranspiration from latent heat flux.

4 Reference

- M.B. Abbott, J.C. Refsgaard, *Distributed hydrological modelling*, 1996, Springer, 321p.

- E. Cauer, W. Mathis, and R. Pauli, "Life and Work of Wilhelm Cauer (1900 – 1945)", *Proceedings of the Fourteenth International Symposium of Mathematical Theory of Networks and Systems (MTNS2000)*, p4, Perpignan, June, 2000.

- Hillel, D., 1983. Advances in Irrigation. Volume 2, Academic Press, New York.

- Rawls, W. J., Brakensiek D. L. and Saxton K. E., 1982. Estimation of soil water properties. Trans. ASAE 25:1316-1320

- Smedema, L.K., and D.W. Rycroft 1983. Land drainage : planning and design of Agricultural DrainageSystems. Batsford, London, 376 p.
- D. M. Tartakovsky, A. Guadagnini and L. Guadagnini, "Effective hydraulic conductivity and transmissivity for heterogeneous aquifers", *Math. Geology*, vol. 32, no. 6, pp. 751-759, 2000

- B.A. Tolson, C.A. Shoemaker, Cannonsville Reservoir Watershed SWAT2000 model development, calibration and validation, Journal of Hydrology, Volume 337, Issues 1-2, 15 April 2007, Pages 68-86.

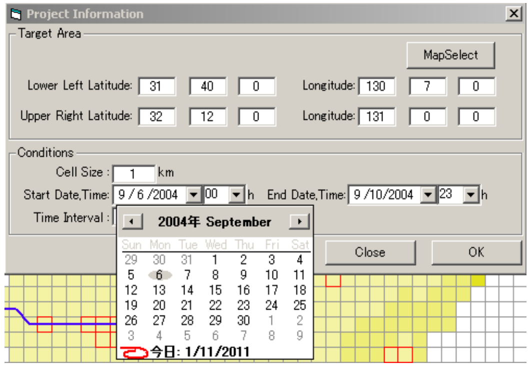
- R.W., Webb, C. E. Rosenzweig, and E. R. Levine. 2000. Global Soil Texture and Derived Water-Holding Capacities (Webb et al.). Data set. Available on-line [http://www.daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.

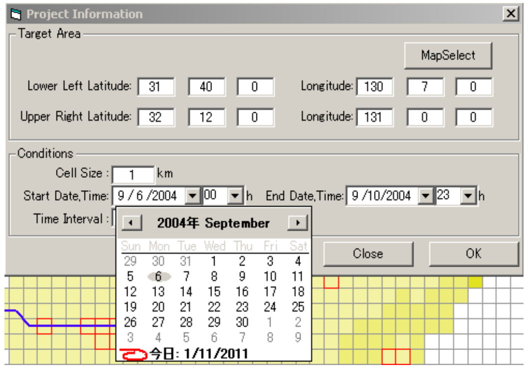
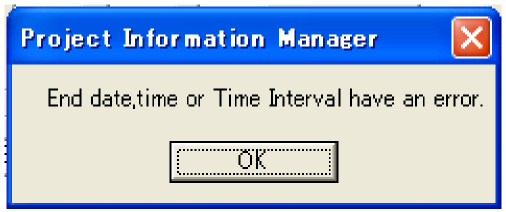
IFAS SYSTEM CONFIGURATION

TROUBLESHOOTING

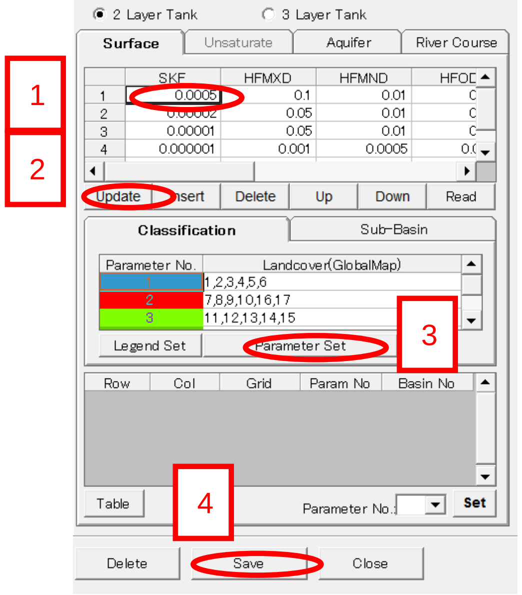
AND

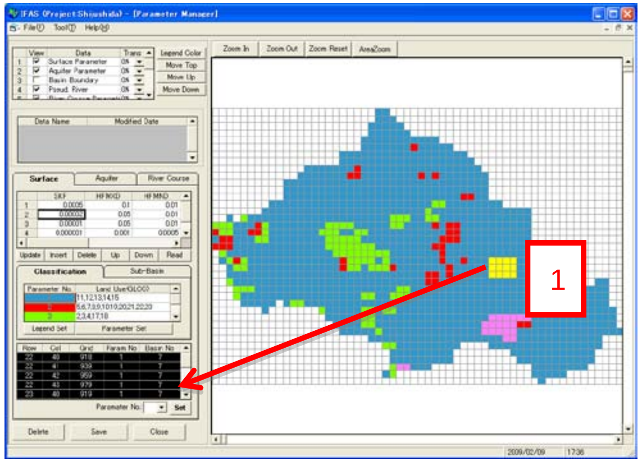
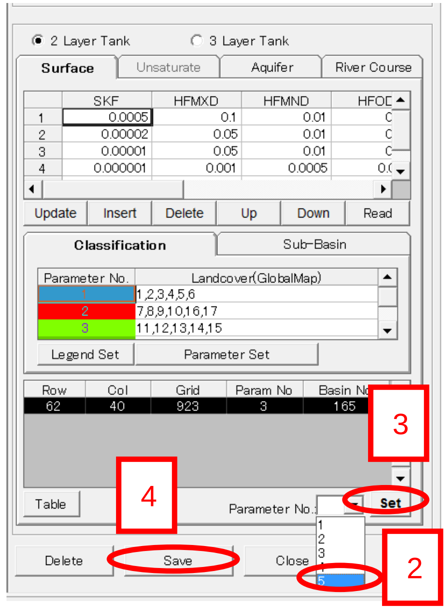
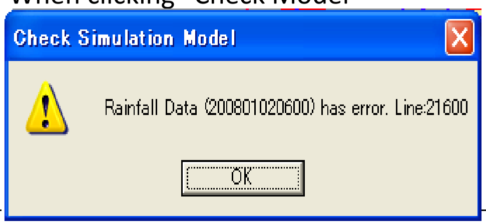
HELPFUL INFORMATION

<table>
<tr><th></th><th>Question</th><th>Answer</th></tr>
<tr><td rowspan="2">Project information manager</td><td>IFAS cannot set the target basin correctly.</td><td>Check setting in "Region and Language" in Windows. IFAS can only run under Windows OS set in English (U.S) or Japanese. In "Region and Language", set "English (U.S)" in the "Format" tab.</td></tr>
<tr><td>Calculation period is not correct.</td><td>Check setting in "Region and Language" in Windows. IFAS can only run under Windows OS set in English (U.S) or Japanese. In "Region and Language", set "English (U.S)" in the "Format" tab. Under Thai settings, the Buddhist calendar is set by default, and IFAS cannot then recognize the correct period. Check also the date format. It shall be Month/Day/Year (MM/DD/YYYY)
Date should be selected through the calendar

</td></tr>
</table>

	End date of the calculation cannot be changed.	When user wants to change calculation period, user has to change start date before changing the end date. 
	When time step is set as 10 minutes, IFAS can't run.	The minimum time step is 60minutes.
	Minimum size cell	100m
		The number of input data must be a multiple of time step.

Basin Data manager	River channel network is not correct.	Check the outlet point. If user doesn't select the lowest point of the river on the basin boundary, IFAS cannot calculate the river channel network correctly.
	IFAS shuts down if cell type number is deleted.	It must be overwritten.
	No progress after indicating the outlet location.	Make sure to select an outlet cell inside the basin.
Rainfall data manager	Ground based rainfall data cannot be imported in IFAS	Check your dialog box in the rainfall data manager. User should input full path to CSV file name.
	Rainfall cannot be imported	Check if there is rainfall data in the folder: C:¥IFAS¥IMPORT_DATA
		Rainfall data period is different from import period
	When user changes the path to the folder where the rainfall data are stored, IFAS cannot import them.	To import GSMaP data, check the path under "GSMaP”: ¥...¥GSMaP_NRT¥hourly
		While importing 3B42RT data, check the path under "3B42RT": ¥...¥3B42RT(V6)
	Time lag between ground based rainfall data and satellite based rainfall data	When user deal with Ground based rainfall data and satellite based rainfall data in the same model, user should input the time difference between ground based rainfall time and UTC in the dialog box in the Rainfall data manager.
	IFAS shuts down after importing rainfall data.	After clicking "close" button, IFAS starts writing in the data base. So user should wait until IFAS finishes writing.

	Change the time series interval of CSV file.	Make sure to have the same time step for simulation and the rainfall data.
Parameter Manager	IFAS does not take in account parameter value changes.	When user wants to change the value of a parameter, user should take the following steps. For each tank, input values to be changed, click "update", and then click "parameter set", "OK" in the dialog box. Once all values to be changed are changed, click "Save" and input the name of this parameter set. 

	IFAS cannot set changes in parameter class.	When user wants to change the parameter class for some cells, user should 1) select the cells on the map, selected cells turned yellow, 2) select another class of parameter (from 1 to 5), 3) click “Set”, 4) click “Save”.  
Simulation Manager	Although parameters were changed, simulation results do not change.	Make sure the parameter changes were taken in account in the Parameter Manager
	When clicking “Check Model”  	Replace the missing data and abnormal data in rainfall data using the “edit” function in the Rainfall Data Manager

Result Viewer	Hydrograph and Time Series Table do not become active.	Make sure to select at least one cell.
General	"Save" and "Close" functions are hidden.	Change the display preferences/resolution in Windows