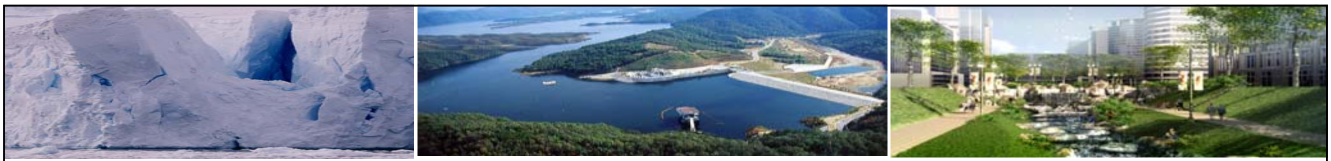


Program of the AWCI training course for the Climate Change Assessment and Adaptation Study

2. Hydrologic Modeling

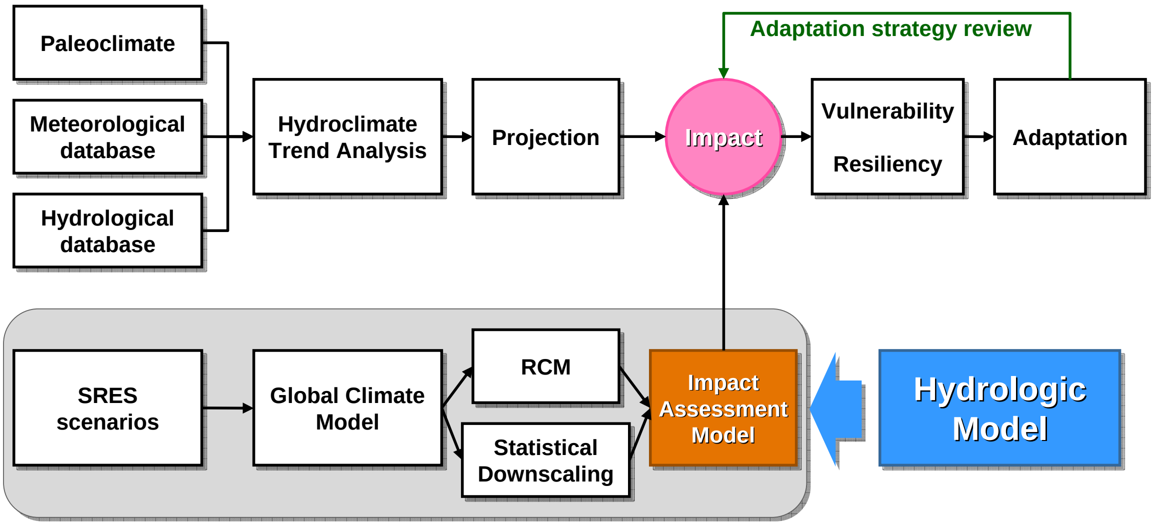
2011.03.12

Deg-Hyo Bae(dhbae@sejong.ac.kr)

Department of Civil & Environmental Engineering, Sejong University, Seoul, Korea

Backgrounds

☐ **General process for climate change study**



Paleoclimate

Meteorological database

Hydrological database

Hydroclimate Trend Analysis

Projection

Impact

Vulnerability

Resiliency

Adaptation

Adaptation strategy review

SRES scenarios

Global Climate Model

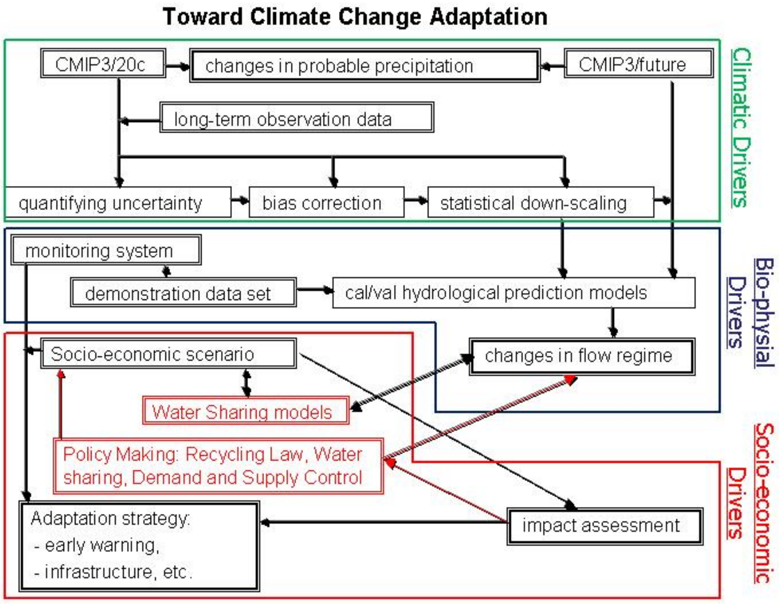
RCM

Statistical Downscaling

Impact Assessment Model

Hydrologic Model

Climate change studies on AWCI framework



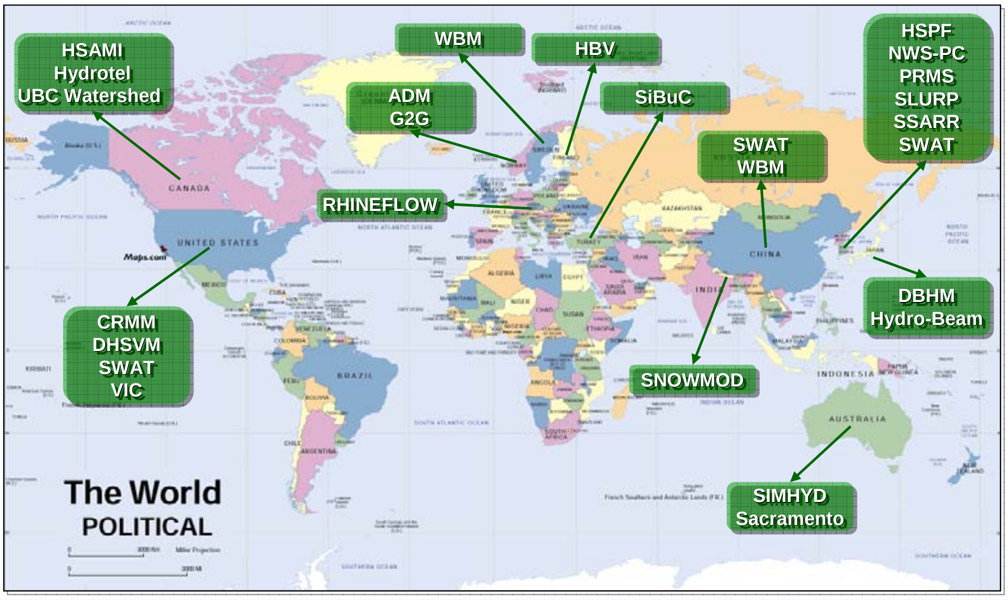
Flowchart of an implementation plan toward assessing impacts of climate change and preparing adaptation strategy – resulting version from breakout group discussions.

Adopted from T. Koike 2010

Review of Hydrologic Model

What kinds of hydrologic models used for CC study

- **Keyword : climate change / water resources, water supply, hydrology**
- **Total number of paper : 56** **(Journal of Hydrology, Water Resources Management, Climatic Change etc.)**



Characteristics of the selected hydrological models

Model	Agency	Model type	Evapotranspiration	Runoff
DBHM	University of Tokyo	Distributed	Penman-Monteith	Surface Groundwater
Hydro-BEAM	University of Kyoto	Distributed	Thornthwaite	Surface Subsurface Groundwater
PRMS	USGS (US)	Semi-dis.	Hamon Jensen-Haise	Surface Subsurface Groundwater
SIMHYD	University of Melbourne	Lumped	Input data	Surface Subsurface Groundwater
SLURP	Hydrologic-Solutions (UK)	Semi-dis.	Penman Monteith Spittlehous-Black Granger	Surface Subsurface Groundwater
SURR	Sejong University (South Korea)			
SWAT	USDA (US)	Semi-dis.	Penman-Monteith Priestley-Taylor Hargreaves	Surface Subsurface Groundwater
VIC	University of Washington	Distributed	Penman-Monteith	Surface Baseflow

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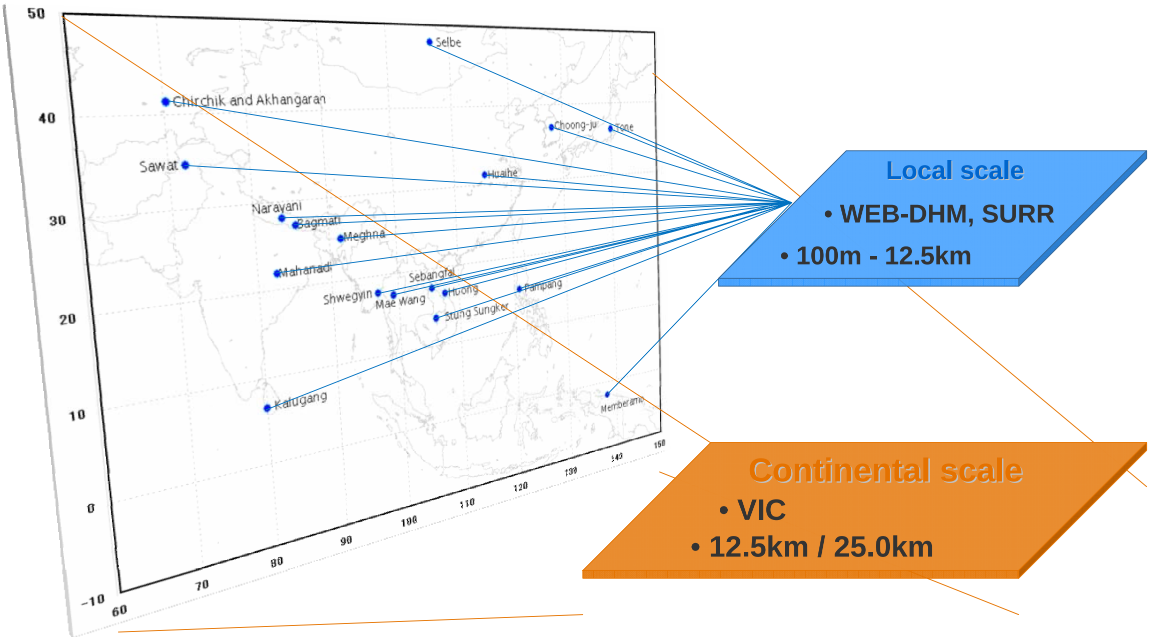
Proposed Hydrologic models for CC Study

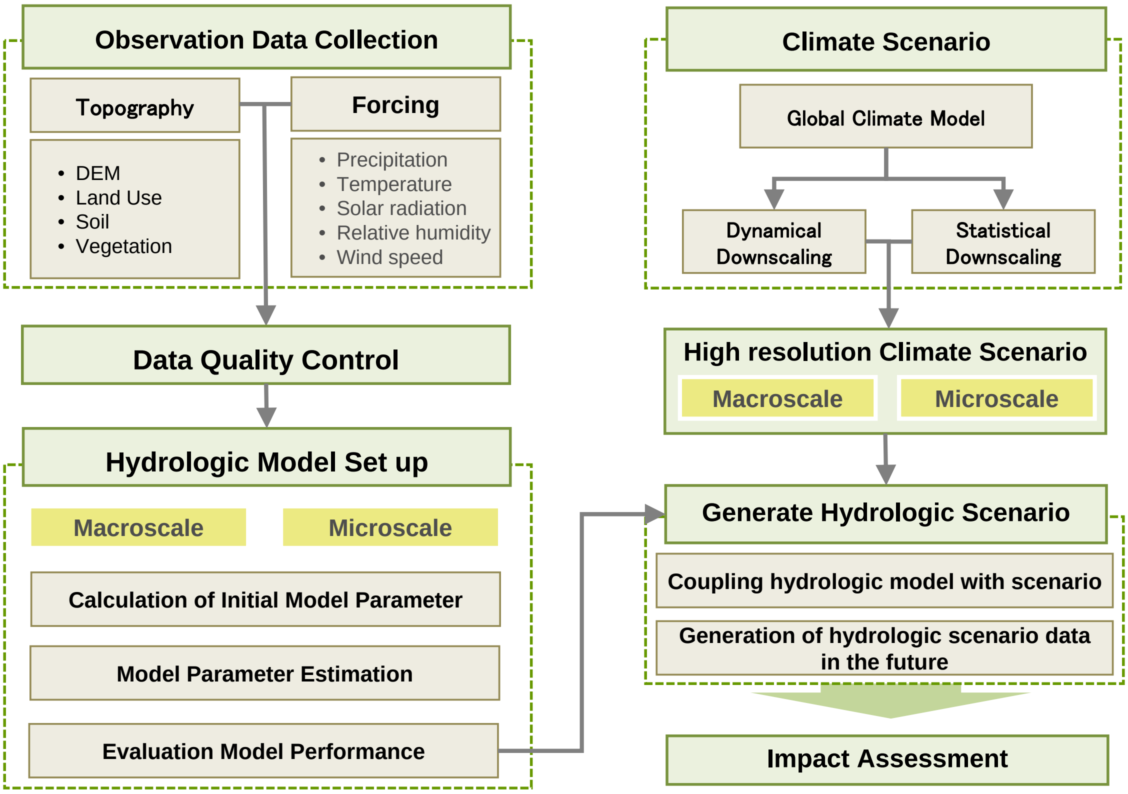
Selection of hydrologic model depends on area scale and model performance – VIC Model, SURR Model



Local scale
- WEB-DHM, SURR
- 100m - 12.5km

Continental scale
- VIC
- 12.5km / 25.0km

Hydrologic Impact Assessment Process



Observation Data Collection

Topography

- DEM
- Land Use
- Soil
- Vegetation

Forcing

- Precipitation
- Temperature
- Solar radiation
- Relative humidity
- Wind speed

Data Quality Control

Hydrologic Model Set up

Macroscale | Microscale

Calculation of Initial Model Parameter

Model Parameter Estimation

Evaluation Model Performance

Climate Scenario

Global Climate Model

Dynamical Downscaling

Statistical Downscaling

High resolution Climate Scenario

Macroscale | Microscale

Generate Hydrologic Scenario

Coupling hydrologic model with scenario

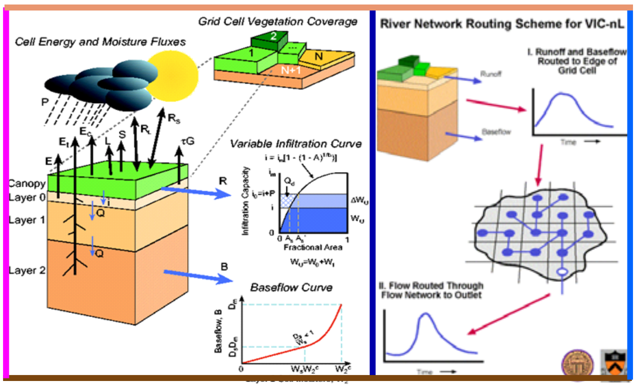
Generation of hydrologic scenario data in the future

Impact Assessment

Hydrologic Model Theory – Macroscale

☐ Global Hydrologic Model

- The VIC(Variable Infiltration Capacity) model is soil vegetation atmospheric transfer scheme that considers both energy and water balances
- A grid-based macro-scale model that is usually implemented at various spatial scales from 1/8 °to 2°
- Widely used for analyzing the variations of water resources due to climate change



Parameter	Input Data
Basin	DEM
Forcing	Precipitation Maximum Temperature Minimum Temperature Wind Speed
Soil	Soil Properties
Vegetation	Landuse

☐ Theoretical Overview

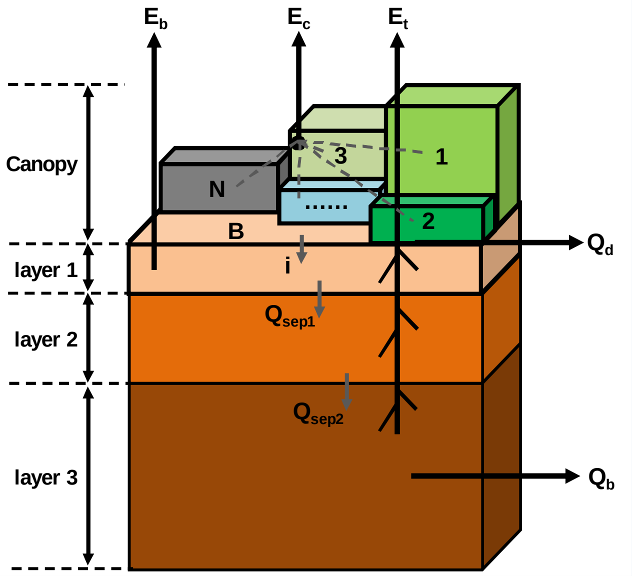
The VIC-3L is a macroscale surface hydrologic model that represents evapotranspiration, runoff, baseflow, and soil moisture storage for large basins.

Important components of the model include:

- **•Infiltration : Variable infiltration capacity (VIC) representation at the surface**
- **• Three soil moisture layers (3L)**
- **•N canopy types plus bare soil represented for each grid cell**
- **•Full water balance includes**
  - **-Evaporation from canopy and Top thin layer**
    - **-Transpiration from Vegetation in 3L**
    - **-Direct Runoff is calculated for top thin and upper layer**
    - **-Baseflow, or horizontal transport from bottom layer**
  - **-Vertical moisture transport only, in upper two layers either through evapotranspiration, or drainag**

VIC Model

Schematic of the Water Balance



➢ Water balance

$$\frac{\partial S}{\partial t} = P - E - R$$

dS/dt is the change of water storage
P is the precipitation
E is the evapotranspiration
R is the runoff

➢ Evapotranspiration(E)

The VIC model considers three types of evaporation :

- The potential evaportranspiration is calculated from the Penman-monteith equation
- Evaporation from the canopy layer(E_c, mm) of each vegetation tile
- Transpiration(E_t, mm) from each of the vegetation tiles
- Evaporation from the bare soil(E_b, mm)

$$E = \sum_{n=1}^{N} C_n \cdot (E_{c,n} + E_{t,n}) + C_{N+1} \cdot E_b$$

Where : C_n is the vegetation fractional coverage for the nth vegetation tile, C_N+1 is the bare soil fraction , and $\sum_{n=1}^{N+1} C_n = 1$

Canopy Evaporation

$$E_c = \left(\frac{W_i}{W_{i\max}}\right)^{2/3} \cdot E_p \frac{r_w}{r_w + r_o}$$

W_{im} is maximum amount of water the canopy can intercept(mm), which is 0.2(LAI)
W_i is canopy intercepted water(mm)
E_p is Potential evapotranspiration(mm)
r_o is architectureal resistance
r_w is arerodynamic resistance

Vegetation Transpiration

- **The vegetation transpiration from a certain vegetation tile is the contribution from all three soil layers, weighted by the fractions of roots in each layer**

$$E_c = \left(\frac{W_i}{W_{i\max}}\right)^{2/3} \cdot E_p \frac{r_w}{r_w + r_o + r_c}$$

W_i is canopy intercepted water(mm)
r_o is architectureal resistance
r_w is arerodynamic resistance

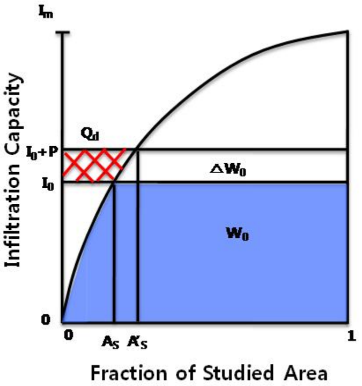
Bare soil evaporation

$$E_c = E_p \left[\int_0^{A_s} dA + \int_{A_s}^{1} \frac{i_0}{i_m (1 - 1 - A)^{1/b_i})} dA \right]$$

A_s is saturated soil area
A is the fraction of area for which the infiltration
i_0 is the infiltration capacity

Infiltration and Surface Runoff

- **The VIC model uses the variable infiltration curve to account for the spatial heterogeneity of runoff generation**



- Maximum Infiltration capacity(mm)

$$I_m = (1 + b_i) \cdot W^{\max}$$

- Infiltration capacity(mm)

$$I = I_m [1 - (1 - A)^{1/b_i}]$$

A is the fraction of area for which the infiltration
b_i is the infiltration shape parameter
$W^{\max}$ is soil porosity

- **Surface runoff from the upper two soil layers is generated by those areas for which precipitation, when added to soil moisture storage at the end of the previous time step, exceeds the storage capacity of the soil**

$$Q_d = P + W_0 - W^{\max} \qquad I + P \geq I_m$$

$$Q_d = P + W_0 - W^{\max}\left[1 - \left(1 - \frac{I + P}{I_m}\right)^{1+b_i}\right] \qquad I + P \leq I_m$$

P is the precipitation
$W^{\max}$ is the soil prorocisy
W_0 is the current soil moisture

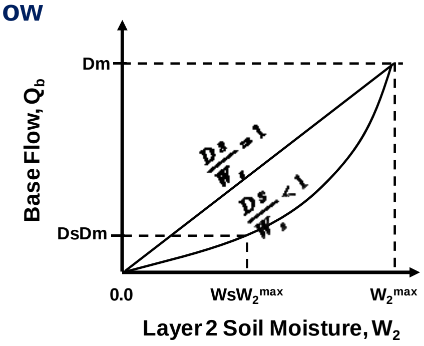
Subsurfase flow(Q_b)

- **d1 : Storage Constant in the linear storage-outflow**

$$d_1 = D_m \cdot \frac{Ds}{W_s}$$

- **d2 : Coefficient for the nonlinear part**

$$d_2 = \frac{W_3 - W_s}{1 - W_s}$$



- **Compute Baseflow**

- $W_3 < W_s \cdot W_3max$

$$Q_b = d_1 \cdot W_3$$

- $W_2 > W_s \cdot W_3max$

$$Q_b = d_1 \cdot W_3 + d_2 (W_3 - W_s W^{max})^c$$

D_m is the maximum subsurface flow(mm/d)

D_s is a fraction of D_m**,** **W_{max}** is maximum soil moisture content of layer, **W_s** is a fraction of W_{max}

W_3 is current soil moisture contents

d_1 is Storage Constant in the linear storage-outflow

d_2 is Coefficient for the nonlinear part

Model Input & Output

Input data

Soil

Numb	Variable Name	Description	Units
1	**b_infilt**	Infiltration shape parameter	-
2	**Ds**	Fraction of Dsmax where nonlinear baseflow begins	-
3	**Dsmax**	Maximum velocity of subsurface runoff	mm/day
4	**Ws**	Fraction of maximum soil moisture where nonlinear subsurface runoff occurs	mm
5	**C**	Exponent used in subsurface curve, normally set to 2	-
6	**Wmax**	Maximum soil moisture contents	mm
7	**expt**	Parameter describing the variation of Ksat with soil moisture	-
8	**Ksat**	Saturated Hydrologic Conductivity	mm/day
9	**phi_s**	Soil moisture diffusion parameter	mm/mm
10	**init_moist**	Initial layer moisture content	mm
11	**elev**	Average elevation of grid cell	m
12	**depth**	Thickness of each soil moisture layer	m
13	**avg_T**	Average soil temperature, used as the bottom boundary for soil heat flux solution	℃
14	**dp**	Soil thermal damping depth	m
13	**Bubble**	Bubbling pressure of soil	c m
14	**Bulk density**	bulk density of soil layer	kg/m^3
15	**Soil density**	soil particle density, normally 2685kg/m^3	kg/m^3
16	**off_gmt**	Time zone offset from GMT	hour
17	**Wcr_Fract**	Fractional soil moisture content at the critical point	%
18	**Wpwp_Fract**	Fractional soil moisture contents at the wilting point	%
19	**rough**	Surface roughness of baresoil	m
20	**snow_rough**	Surface roughness of snowpack	m
21	**Annual prec**	Average annual precipitation	mm
22	**resid_moist**	Soil moistrure layer residual moisture	%

- **Vegetation**

Numb	Name	Description	Units
	veg_class	Vegetation class identification number	-
1	**Cv**	Fraction of grid cell covered by vegetation class	%
2	**rarc**	Architectual Resistance	s/m
3	**r_s**	Minimum Stomatal Resistance	s/m
4	**root depth**	Root zone thickness	%
5	**root_fract**	Fraction of root in the current root zone	%
6	**LAI**	Monthly Leaf Area Index (by Ground Area)	m^2 / m^2
7	**rough**	roughness of vegetation	-
8	**displacement**	displacement	m

- **Forcing**

Numb	Variable Name	Units
1	**Precipitation**	mm/d
2	**Max Temperature**	℃
3	**Min Temperature**	℃
4	**Mean Windspeed**	mm/d

Output data

Numb	Variable Name	Description	Units
1	**PRCP**	Precipitation for current record	mm/d
2	**evap**	Evaporation for current record	mm/d
3	**runoff**	surface Runoff for current record	mm/d
4	**baseflow**	subsurface runoff for current record	mm/d
5	**Wdew**	Canopy interception of liquid water	mm/d
5	**moist**	Moisture content of each soil layer	mm/d
6	**rad_temp**	Radiative temperature of the surface	K
7	**net_short**	Net shortwave radiation at the surface	W/m^2
8	**r_net**	Net radiation at the surface, includes long and shortwave radiation	W/m^2
9	**latent**	Latent heat from the surface	W/m^2
10	**evap_canp**	Evaporation from canopy storage	mm/d
11	**evap_veg**	Transpiration from the vegetation	mm/d
12	**evap_bare**	Evaporation from bare soil	mm/d
13	**sub_canop**	Sublimation from canopy interception	mm/d
14	**sub_snow**	Sublimation from ground snow pack	mm/d
15	**sensible**	Sensible heat flux from the surface	W/m^2
16	**grnd_flux**	Ground heat flux plus heat storage in the top soil layer	W/m^2
17	**aero_resist**	Rate of change in heat storage	s/m
18	**surf_temp**	Surface temperature	℃
19	**albedo**	Albedco of surface cover	-

Model Application on South Korea domain with local data

Meteorological data

- **Data information**

- Max & Min Temperature, Mean windspeed
- Precipitation

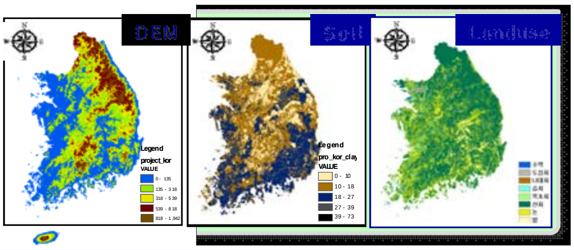
- **Data source :**

- Weather : KMA(Korea Meteorological Administration)
- Precipitation : KMA, MItm(Ministry of Land, Transport and Maritime Affairs)

- **Data period : 30year(1971~2009yr)**

- Weather : 79
- Precipitation : 596

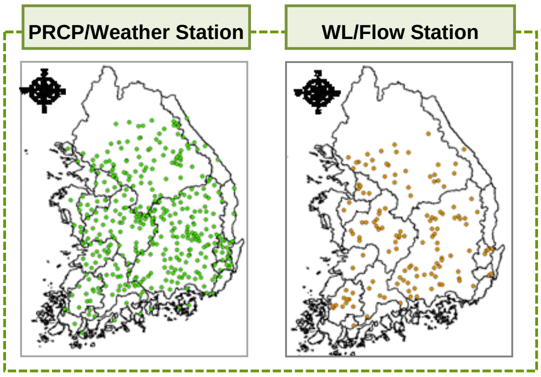
Topography data



WL / Flow data

- **Data Source : MItm(Ministry of Land, Transport and Maritime Affairs)**
- **Time interval : Daily**
- **Data Period : 20year(1984~2004yr)**

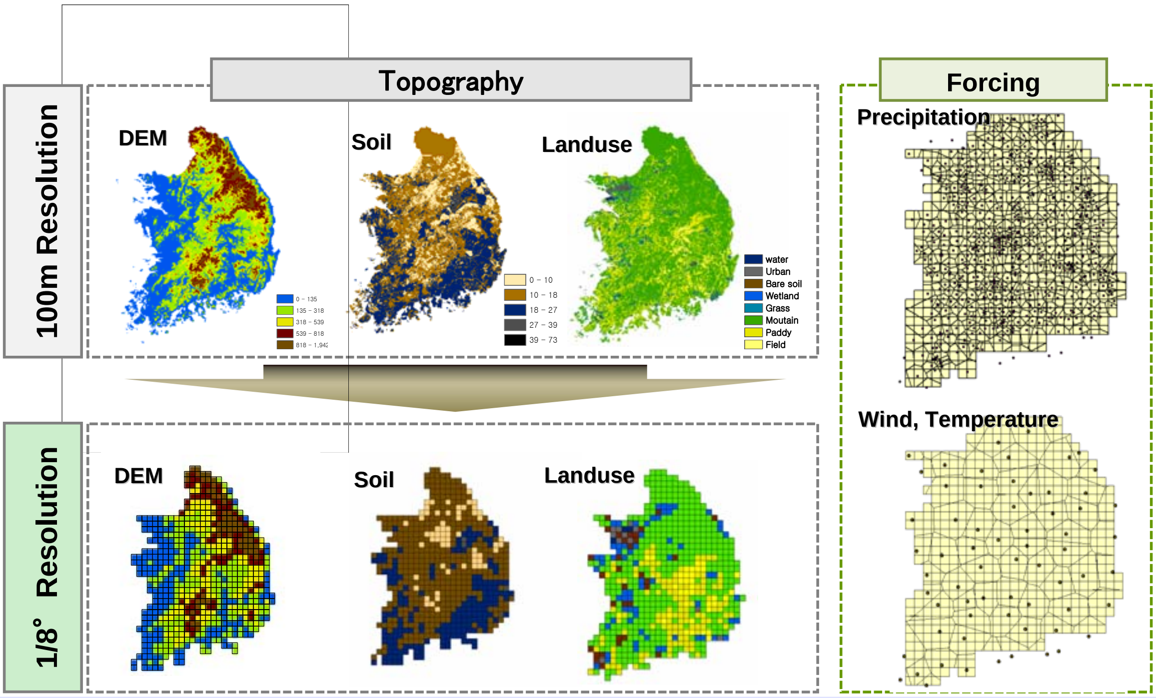
- Dam site: 21
- Water level station : 135


PRCP/Weather Station

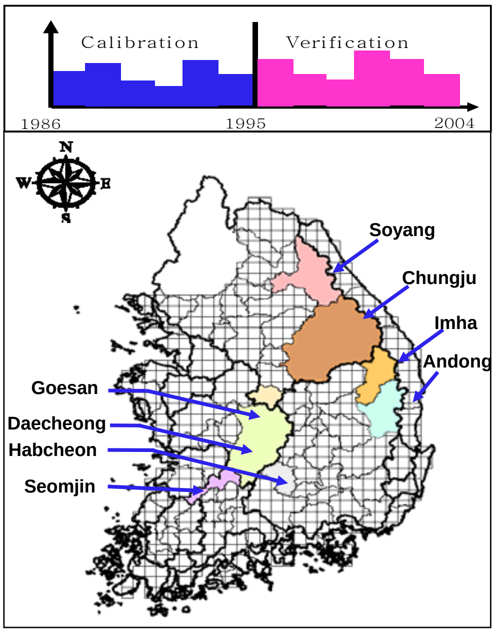
WL/Flow Station

➢ Input data construction with local data

- Conversion of 100m resolution into 1/8° (12.5km) resolution to make model input data



➢ Selection of the study area and period for parameter estimation



Site		Basin Name	Area (km^2)	Data Period	Annual Mean Precipitation (mm)
Calibration Site	1	Andong	1590.7	1986~2004	1081.4
	2	Goesan	676.7	1986~2004	1156.2
	3	Habcheon	928.9	1989~2004	1250.0
	4	Imha	1367.7	1993~2004	923.4
	5	Seomjin	763.5	1986~2004	1315.9
Verification Site	6	Chungju	2703.0	1986~2004	1266.3
	7	Daecheong	4190.5	1986~2000	1177.5
	8	Soyang	6661.0	1986~2004	1155.7

Application analysis

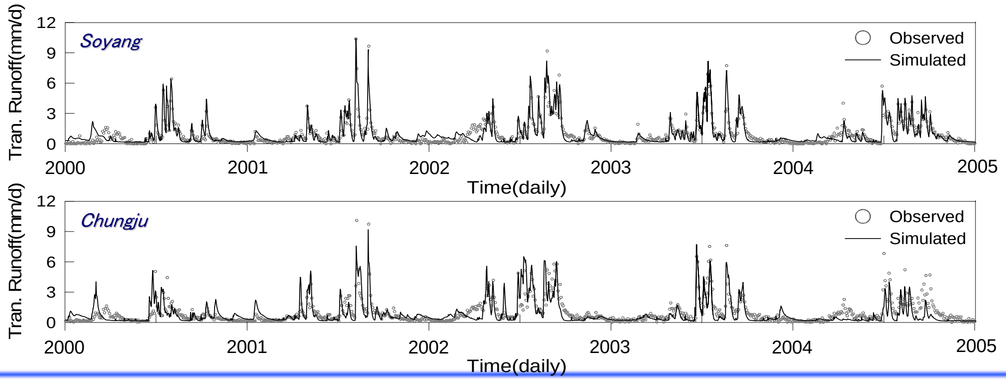
Calibration and Verification of model parameter for 8 dam site based on local topography and forcing data

Statistical results

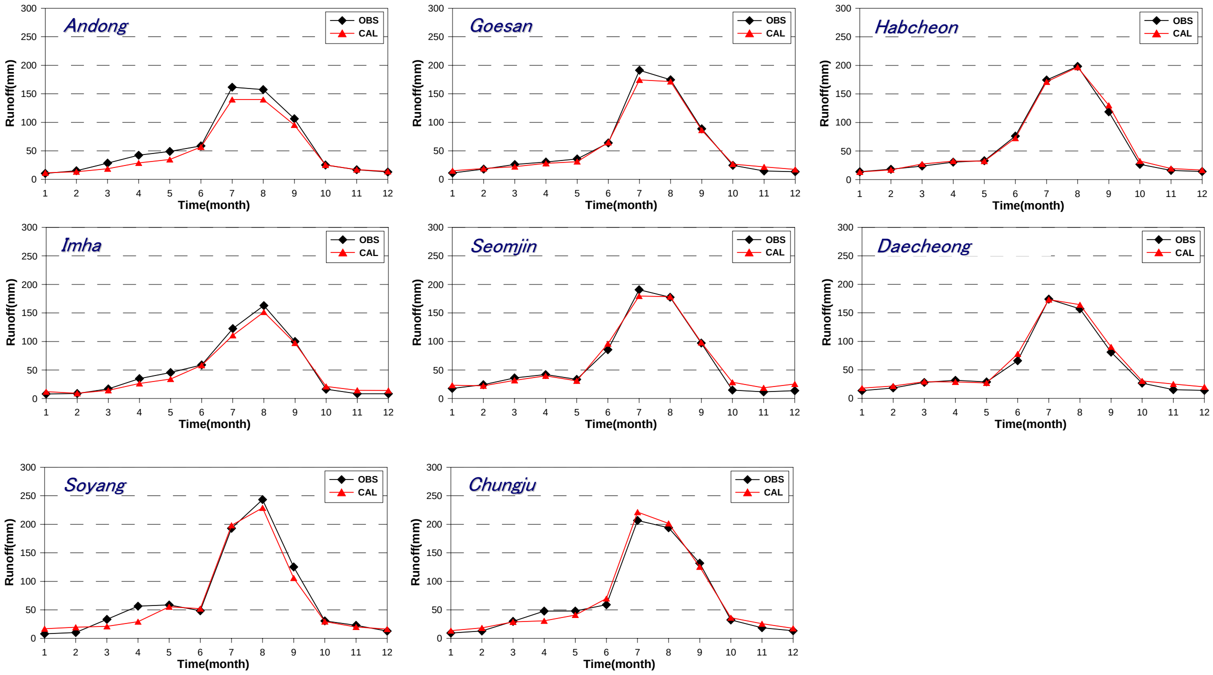
- CORR : 0.83 ~ 0.87
- RMSE : 2.28 ~ 3.90(mm/d)
- ME : 0.68 ~ 0.79
- VE : -8.78 ~ 7.96(%)

Name	CORR	RMSE (mm/day)	ME	VE (%)
Andong	0.84	2.47	0.71	-7.90
Goesan	0.87	3.22	0.74	-8.78
Habcheon	0.85	2.28	0.70	3.85
Imha	0.86	2.59	0.73	4.95
Seomjin	0.86	3.33	0.74	3.05
Daecheong	0.83	3.10	0.68	7.96
Soyang	0.89	3.36	0.79	-6.65
Chungju	0.83	3.90	0.68	3.31

Observed and simulated runoff at Soyang & Chungju dam site



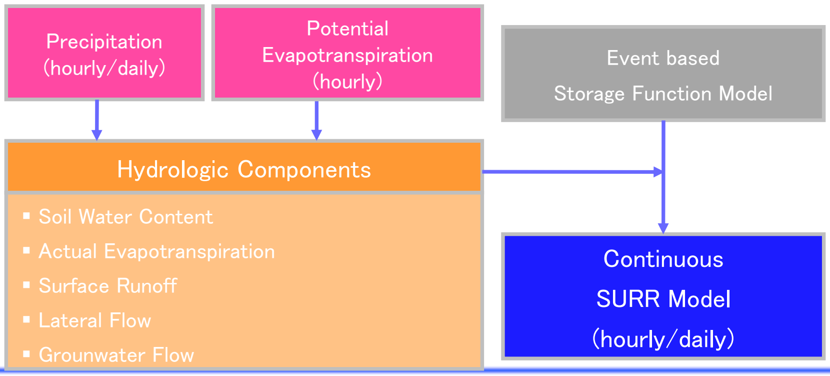
Monthly Mean Runoff Analysis



Hydrologic Model Theory – Microscale

SURR(SEJONG University Rainfall-Runoff) Model

- Storage Function Model based Continuous Rainfall-Runoff Model
- Connection of basin and channel storage function model with Physical - based hydrology Component calculation technique(Lee et al. 2010)
- Properties : Lumpt model based on basin
- Water balance & Channel routing
- Simulation time interval : hourly, daily
- Available and useful both monitoring the flood & drought



Precipitation (hourly/daily)

Potential Evapotranspiration (hourly)

Event based Storage Function Model

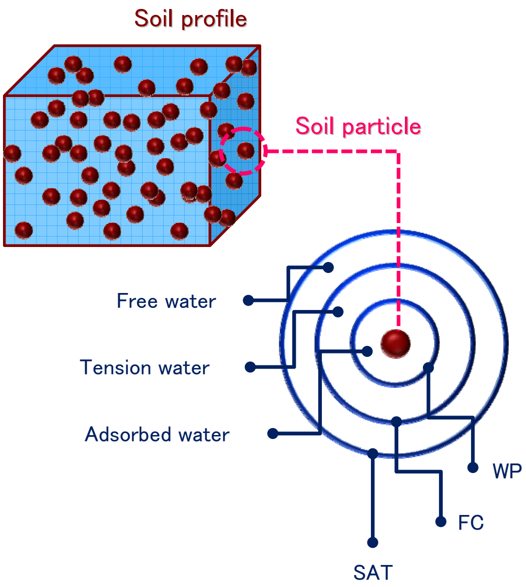
Hydrologic Components

- Soil Water Content
- Actual Evapotranspiration
- Surface Runoff
- Lateral Flow
- Grounwater Flow

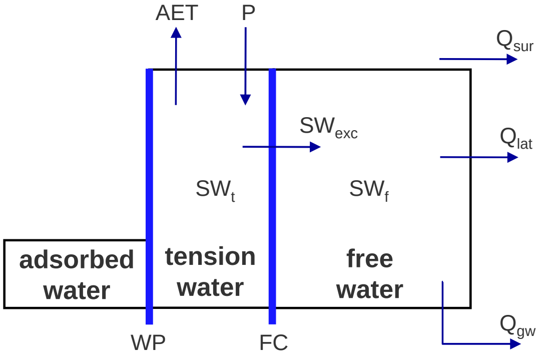
Continuous SURR Model (hourly/daily)

Model Theory

- **Soil Water Content**
  - Definition of two-storage in soil profile



- **Hydrologic Components Variation**
  - Construction of one soil layer by considering the characteristics of Lumped model



SW_{exc} : drainable soil water (mm)

→ $SW_{exc} = SW - FC$

SW_t : SW in the tension water (mm)

SW_f : SW in the free water (mm)

➢ Calculation Soil Water based on the water balance

$$\frac{dSW(t)}{dt} = P(t) - AET(t) - Q_{sur}(t) - Q_{lat}(t) - Q_{gw}(t)$$

SW(t) : soil water content (mm)
P(t) : mean areal precipitation (mm)
AET(t) : actual evapotranspiration (mm)
Q_{sur}(t): surface flow (mm)
Q_{lat}(t): lateral flow (mm)
Q_{gw}(t): groundwater flow (mm)

➢ Evapotranspiration

Potential evapotranspiration : FAO Penman-Monteith Method for time step hourly

$$AET = \frac{0.408\Delta(R_n - G) + \gamma \frac{37}{T_{hr} + 279} u_2 (e^0(T_{hr}) - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

R_n : net radiation at the grass surface
(MJ/(m^2hour))
G : soil heat flux density (MJ/(m^2 hour))
T_{hr} : mean hourly air temperature (° C)
Δ : saturation slope vapour pressure curve
at T_{hr} (kPa /° C)
γ : psychrometric constant (kPa /° C)
e° (T_{hr}) : saturation vapour pressure at air
temperature T_{hr} (kPa)
e_a : average hourly actual vapour pressure (kPa)
u2 : average hourly wind speed (m/s)

Actual evapotranspiration

$$AET(t) = PET(t)\left(\frac{SW_t(t)}{SW_t^0}\right) \;, \quad SW_t^0 = (FC - WP)Z$$

➢ Daily Surface Runoff

SCS runoff curve number(USDA-SCS,1972)

- Estimating the amounts of runoff under varying land use and soil types.
- Runoff will only occur when total precipitation(P) greater than initial abstractions(0.2S).
- Fixing CN, S in Rainfall event, Varying CN under Antecedent Moisture Conditions(AMC)

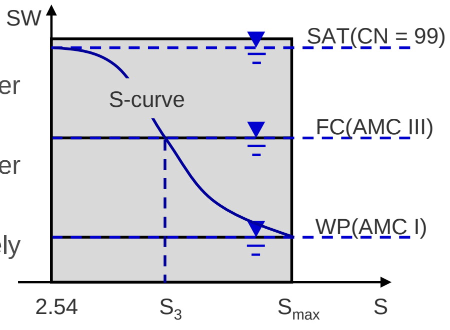
$$Q_{dir} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$S = \frac{25400}{CN} - 254$$

P : total precipitation (mm)
S : maximum potential retention (mm)
Q_{dir} : direct runoff (mm)
CN : runoff curve number

Assumptions

- S for AMCI curve number corresponds to WP soil profile water content (Smax).
- S for AMCIII curve number corresponds to FC soil profile water content (S3).
- The soil has a curve number of 99 (S=2.54) when completely saturated.



Daily Surface Runoff Formulation

- Model Parameter CN2(AMCII) :
  Basin specific Characteristics with varying land cover, soil properties

$$Q_{sur}(t) = \frac{(P_{day}(t) - 0.2S(t))^2}{(P_{day}(t) + 0.8S(t))}$$

$$S(t) = S_{\max} \cdot \left(1 - \frac{SW(t)}{\left[SW(t) + \exp(w_1 - w_2 \cdot SW(t))\right]}\right)$$

$$w_1 = \ln\left[\frac{FC}{1 - S_3 \cdot S_{\max}^{-1}} - FC\right] + w_2 \cdot FC$$

$$w_2 = \frac{\ln\left[\frac{FC}{1 - S_3 \cdot S_{\max}^{-1}} - FC\right] - \ln\left[\frac{SAT}{1 - 2.54 S_{\max}^{-1}} - SAT\right]}{(SAT - FC)}$$

$$CN_1 = CN_2 - \frac{20(100 - CN_2)}{(100 - CN_2 + \exp\left[2.533 - 0.0636(100 - CN_2)\right]}$$

$$CN_3 = CN_2 \cdot \exp\left[0.00673(100 - CN_2)\right]$$

$P_{day}(t)$: daily precipitation for a given day (mm)

$Q_{sur}(t)$: daily surface flow for a given day (mm)

S(t) : retention parameter for a given SW (mm)

S_{max} : maximum retention parameter (mm)

S_3 : retention parameter for AMC III (mm)

CN : runoff curve number

SW(t) : current soil water content for a given day (mm)

w_1 & w_2 : first and second shape coefficient

FC : SW at field capacity (mm)

SAT : SW at completely saturated soil (mm)

2.54 : retention parameter for a CN of 99

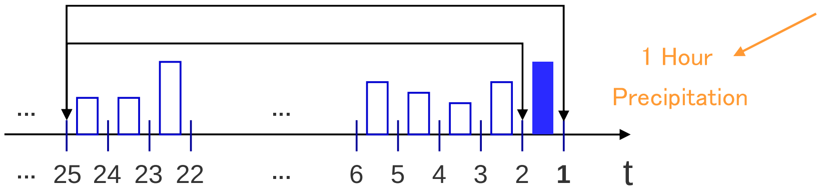
➢ Hourly Surface Runoff

SCS-CN values calculated Background:
Using less than a daily rainfall data occurred a large flood

$$Q_{sur}(t) = \frac{(P_{day}(t) - 0.2S(t))^2}{(P_{day}(t) + 0.8S(t))}$$

only apply when $P_{day} > 0.2S$

Hourly Surface Runoff Calculation by applying the concept of cumulative rainfall



$$Q_{sur}(t) = \frac{\left(\sum_{t=1}^{24} P(t) - 0.2S\right)^2}{\sum_{t=1}^{24} P(t) + 0.8S} - \frac{\left(\sum_{t=1}^{23} P(t) - 0.2S\right)^2}{\sum_{t=1}^{23} P(t) + 0.8S}$$

P(t) : daily precipitation for a given hourly time t (mm)

$Q_{sur}(t)$: daily surface flow for a given hourly time t (mm)

S : retention parameter for a given current SW (mm)

Surface Runoff Lag Calculation

- **Surface Runoff storage feature to lag a portion of Surface Runoff release to the sub-basin**
- **Applied of Exponential weighting** function

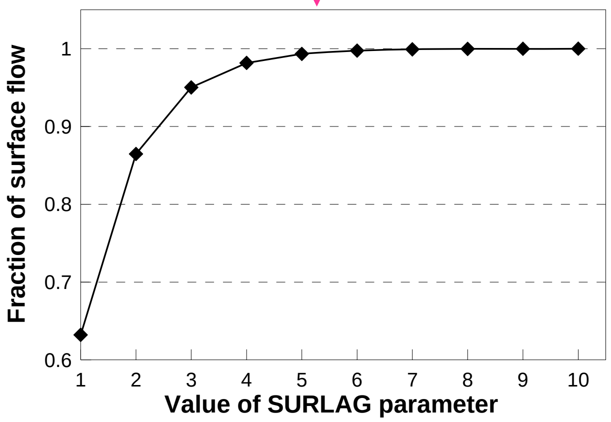
$$Q_{sur}(t)=\left(Q_{sur}'(t)+Q_{surstor}(t-1)\right)\boxed{\left(1-\exp\left[-surlag\right]\right)}$$

$$Q_{surstor}(t-1)=Q_{sur}'(t-1)-Q_{sur}(t-1)$$

$Q_{sur}(t)$: surface flow contributing to the discharge of each subbasin for an hour (mm)

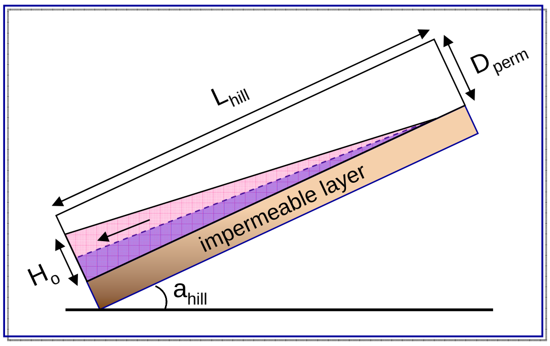
$Q_{sur}'(t)$: surface flow generated from each subbasin for an hour (mm)

$Q_{surstor}(t-1)$: surface flow stored from the previous time (mm)



Lateral Flow

- **Kinematic storage model - Sloan et al.(1998)**
  - Based on the mass continuity equation, or mass water balance, with the entire hillslope segment used as the control volume.
  - The kinematic wave approximation of saturated subsurface or lateral flow assumes that the lines of flow in the saturated zone are parallel to the impermeable boundary and the hydraulic gradient equals the slope of the bed.



$$Q_{lat}=H_0\cdot V_{lat}$$

$$H_0=\frac{2\cdot SW_{exc}}{1000\cdot\psi_d\cdot L_{hill}}$$

$$V_{lat}=K_{sat}\cdot\sin(\alpha_{hill})=K_{sat}\cdot\tan(\alpha_{hill})$$
$$=K_{sat}\cdot slp$$

$$Q_{lat}=0.002\left(\frac{SW_{exc}(t)\cdot K_{sat}\cdot slp}{\psi_d\cdot L_{hill}}\right)$$

H_0 : fraction of the total thickness (mm/mm)
Ψ_d : drainable porocity of the soil (mm/mm)
L_{hill} : hillslope length (m)

K_{sat} : saturated hydraulic conductivity (mm/h)
slp : elevation per unit distance (m/m)

Lateral Flow Lag

- **Lateral Flow storage feature to lag a portion of Surface Runoff release to the sub-basin**
- **Applied of Exponential weighting function**

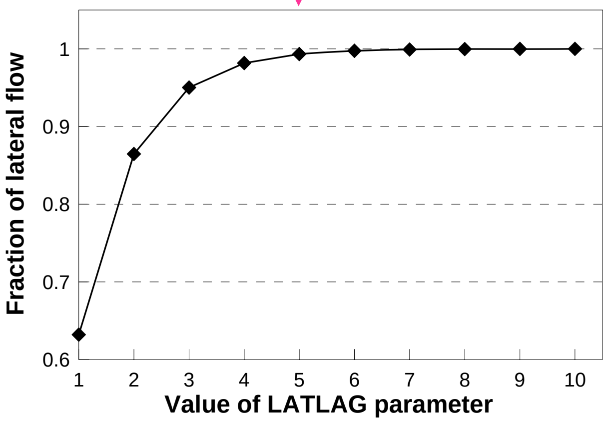
$$Q_{lat}(t) = \left(Q_{lat}'(t) + Q_{latstor}(t-1)\right)\boxed{\left(1-\exp\left[-latlag\right]\right)}$$

$$Q_{latstor}(t-1) = Q_{lat}'(t-1) - Q_{lat}(t-1)$$

$Q_{lat}(t)$: lateral flow contributing to the discharge of each subbasin for an hour (mm)

$Q_{lat}'(t)$: lateral flow generated from each subbasin for an hour (mm)

$Q_{latstor}(t-1)$: lateral flow stored from the previous time (mm)



Groundwater/Base Flow

- **Classified into recharge moving soil zone from the aquifer and groundwater flow in the aquifer**

- **Recharge**
  - An Exponential decay weighting function was applying (Venetis,1969).
  - The delay function accommodates situations where the recharge from the soil zone to the aquifer is not instantaneous.

$$W_{rchrg}(t) = \left(1-\exp\left[-1/\delta_{gw}\right]\right)\cdot W_{perc}(t) + \exp\left[-1/\delta_{gw}\right]\cdot W_{rchrg}(t-1)$$

$$W_{perc}(t) = SW_{exc}(t)\cdot\left(1-\exp\left[\Delta t\cdot latlag\right]\right)$$

$W_{rchrg}(t)$: recharge entering the aquifer for an hour (mm)

$W_{perc}(t)$: percolation of the soil profile for an hour (mm)

δ_{gw} : delay time (day/hrs)

- **Groundwater Flow**
  - Assume that variation in grounwter flow is linearly related to the change.

$$Q_{gw}(t) = Q_{gw}(t-1)\cdot\exp\left[-\alpha_{gw}\cdot\Delta t\right] + W_{rchrg}(t)\cdot\left(1-\exp\left[-\alpha_{gw}\cdot\Delta t\right]\right)$$

$$Q_{gw}(t) = Q_{gw}(t) - GWQMN,\ \ if\, Q_{gw}(t) > GWQMN \qquad Q_{gw}(t) = 0,\ \ if\, Q_{gw}(t) \le GWQMN$$

Q_{gw} : groundwater flow contributing to the discharge from each subbasin (mm)

α_{gw} : baseflow recession constant, GWQMN : threshold water level for base flow (mm)

Basin and Channel Runoff Calculation

Basin

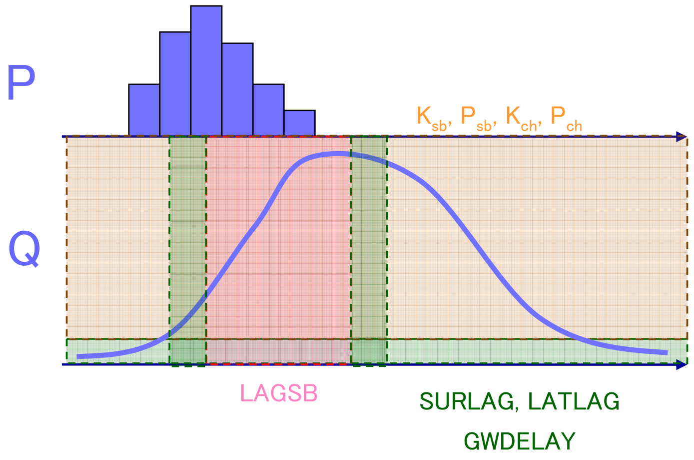
$$\frac{dS(t)}{dt} = \boxed{[Qsur(t-\tau)+Qlat(t-\tau)+Qgw(t-\tau)]} - Q(t)$$

$$Q(t) = \left(\frac{S(t)}{K_{sb}}\right)^{1/P_{sb}}$$

Channel

$$\frac{dS_c(t)}{dt} = \sum\left(\frac{S(t)}{K_{sb}}\right)^{1/P_{sb}} - Q_c(t)$$

$$Q_c(t) = \left(\frac{S_c(t)}{K_{ch}}\right)^{1/P_{ch}}$$



Model Input & Output

Input data

Soil

Numb	Variable Name	Description	Units
1	**AKM**	Subbasin area	km^2
2	**SLP**	Mean slope of the subbasin	m/m
3	**Z**	Depth of soil layer	m
4	**SAT**	Rate of water content at saturation	mm/mm
5	**FC**	Rate of water content at field capacity	mm/mm
6	**WP**	Rate of water content at wilting point	mm/mm
7	**KS**	Saturated hydraulic conductivity	mm/h
8	**CN2**	Runoff curve number under AMC Ⅱ	-
9	**SURLAG**	Surface runoff lag coefficient	-
10	**LHIL**	Mean slope length	m
11	**LATLAG**	Lateral flow lag coefficient	-
12	**GWDELAY**	Delay time for aquifer recharge	h(d)
13	**ALPHA_BF**	Baseflow recession constant	-
14	**AQMIN**	Threshold water level in shallow aquifer for baseflow	mm
15	**KSB**	Storage function constant of the subbasin	h(d)PSB
16	**PSB**	Storage function constant of the subbasin	-
17	**LAGSB**	Lag time of the Subbasin	h(d)
18	**KCH**	Storage function constant of the channel	-
19	**PCH**	Storage function constant of the channel	-

Soil

Numb	Variable Name	Description	Units
1	PRCP	Precipitation	mm
2	T_MAX	Max temperature	℃
3	T_MIN	Minimum temperaure	℃
4	WNSP	Mean wind speed	mm
5	RLTH	Relative humidity	%
6	SOLR	Solar radiation	hour

Output data

Numb	Variable Name	Description	Units
1	S	Variable storage parameter	mm
2	C N	Curve Number	-
3	TWMX	Max soil moisture	mm
4	FWMX	Max soil moisture in tension water area	mm
5	AET	Actual evapotranspiration	mm/hr(day)
6	STF	Soil moisture over field capacity	mm
7	SM	Soil moisture	mm
8	SEP	Percolation water	mm
9	RCHRG	Aquifer recharge	mm
10	SUR_BS	Surface runoff lag	mm/hr(day)
11	LAT_BS	lateral runoff lag	mm/hr(day)
12	AQU_BS	Groundwater lag	mm/hr(day)
13	QSUB	Surface runoff	mm/hr(day)
14	QLAT	Lateral runoff	mm/hr(day)
15	QGW	Subsurface runoff	mm/hr(day)
16	QTOT	Total runoff in basin	mm/hr(day)
17	ST	Storage water	m^3/s
18	DC	Discharge in channel	m^3/s

Application Analysis on Han River Basin

Weather / Precipitation

Data source

- MItm(Minisrty of Land, Transport and Maritime Affairs)

- KMA(Korea Meteorological Administration)

Data period : 8year(2002~2009yr)

- Weather station: 25

- Precipitation station : 121

WL / Flow data

Time interval : Hourly/Daily

Data period : 8year(2002~2009yr)

- Dam site: 10

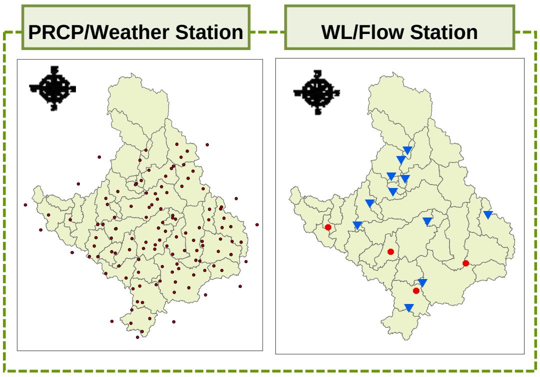
- Water level station : 4

Topography data

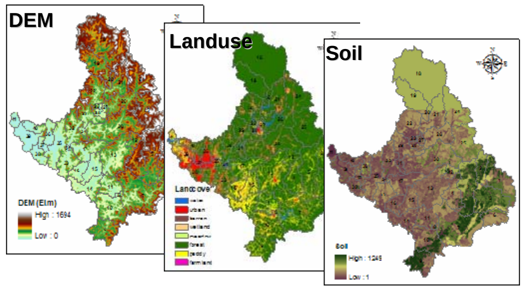
DEM, Landuse, Soil

Resolution : 30m

PRCP/Weather Station **WL/Flow Station**



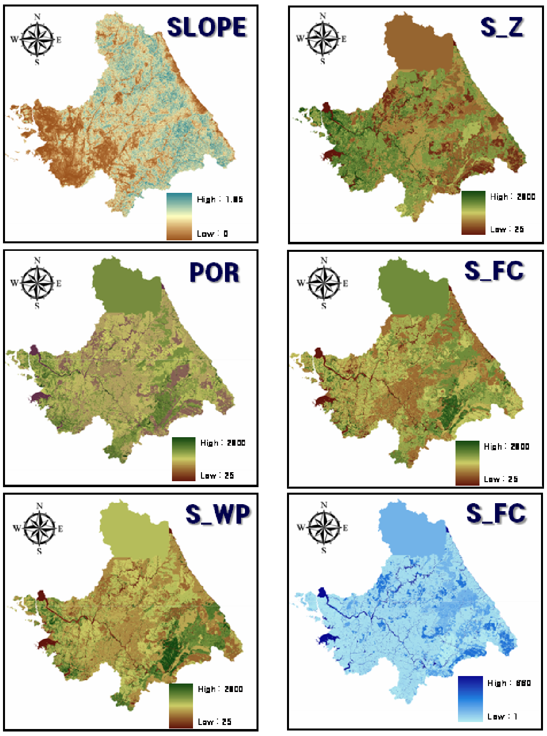
Topography Data



Selection of the study area and period for parameter estimation

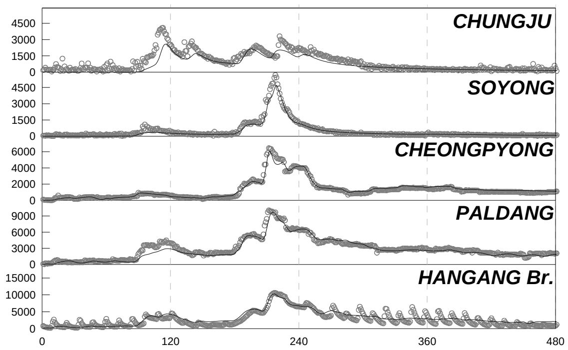
Dam Site	Area(km^2)	Annual Mean Precipitation (mm)
Chungju	6661.58	1,226
Goesan	676.73	1,235
Hoengsung	207.88	1,320
Hwacheon	816.28	1,224
Chuncheon	770.08	1,294
Soyang	2691.52	1,156
Uiam	282.83	1,268
Cheongpyeong	2267.97	1,316
Paldang	6097.49	1,347

Setting Input Data

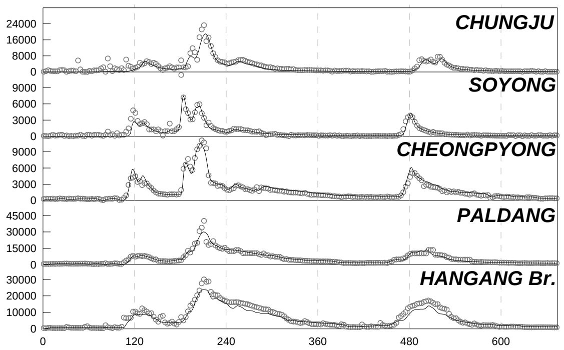


Subbasin No.	AREA	SLP	Z	POR	FC	WP	KS	CN2
1	973.4	0.3123	795	0.3764	0.2343	0.0838	65.8	61.2
2	451.7	0.3343	912	0.3804	0.2358	0.0741	66.2	52.8
3	1022.8	0.3635	807	0.4016	0.2689	0.1114	56.4	68.7
4	607.4	0.2673	822	0.3820	0.2411	0.0794	75.2	57.7
5	1166.0	0.2865	777	0.4424	0.2808	0.1176	63.9	62.9
6	495.3	0.3706	445	0.3465	0.2474	0.0740	114.3	65.8
7	1945.1	0.2953	741	0.3860	0.2562	0.1027	68.7	64.4
8	43.5	0.1835	972	0.3656	0.2200	0.0784	102.3	67.4
9	676.7	0.2497	935	0.4509	0.2383	0.0906	35.4	71.0
10	937.6	0.2183	1043	0.4092	0.2376	0.0844	40.9	65.5
11	524.4	0.1929	902	0.3674	0.1900	0.0647	53.0	55.9
12	207.9	0.2623	786	0.4000	0.2364	0.0733	61.1	50.9
13	1283.1	0.2212	809	0.3678	0.1876	0.0632	51.3	54.7
14	596.6	0.1173	1073	0.3870	0.2003	0.0706	45.1	62.0
15	494.4	0.0923	1042	0.3816	0.1750	0.0622	55.1	62.1
16	309.5	0.0900	1129	0.3941	0.1937	0.0693	42.6	63.5
17	672.3	0.2109	836	0.3481	0.2109	0.0640	79.5	59.3
18	2384.7	0.2702	450	0.4689	0.3000	0.0889	82.0	47.0
19	836.5	0.3121	477	0.4608	0.2941	0.0872	80.2	47.4
20	104.0	0.3860	719	0.3934	0.2646	0.0756	84.5	51.3
21	759.7	0.2848	752	0.3885	0.2394	0.0732	77.5	52.8
22	774.9	0.2984	863	0.3567	0.2121	0.0667	54.3	52.9
23	52.8	0.2243	786	0.3673	0.2322	0.0755	69.3	58.8
24	931.2	0.3177	658	0.4308	0.2694	0.0819	68.6	49.8
25	1084.4	0.3309	684	0.3907	0.2448	0.0729	69.1	50.2
26	678.8	0.3186	936	0.3390	0.2150	0.0664	88.1	53.9
27	88.9	0.2182	1002	0.3619	0.2056	0.0697	52.5	58.8
28	139.1	0.1647	931	0.3475	0.1865	0.0625	94.8	65.5
29	582.6	0.2991	658	0.3403	0.2318	0.0622	105.2	60.3
30	1566.1	0.2607	742	0.3606	0.2317	0.0689	71.1	54.7
31	119.7	0.2596	688	0.3439	0.2322	0.0716	81.3	58.8
32	640.9	0.2626	663	0.3414	0.2234	0.0656	76.0	57.7
33	561.1	0.1867	1114	0.3756	0.2276	0.0732	50.6	57.3
34	43.9	0.1975	975	0.3070	0.1898	0.0612	155.8	62.9
35	815.6	0.1478	1130	0.3848	0.2148	0.0746	67.2	65.3
36	298.7	0.1210	1006	0.3559	0.1866	0.0638	58.4	65.9
37	141.8	0.0956	1193	0.3977	0.1881	0.0671	117.2	77.7
38	281.2	0.1177	1200	0.4200	0.2307	0.0846	40.1	71.9
39	564.9	0.0536	1261	0.4135	0.2317	0.0925	86.6	79.1
40	261.4	0.1157	1176	0.4096	0.2286	0.0844	47.8	67.7
41	146.4	0.0670	387	0.1372	0.0582	0.0227	509.7	85.4

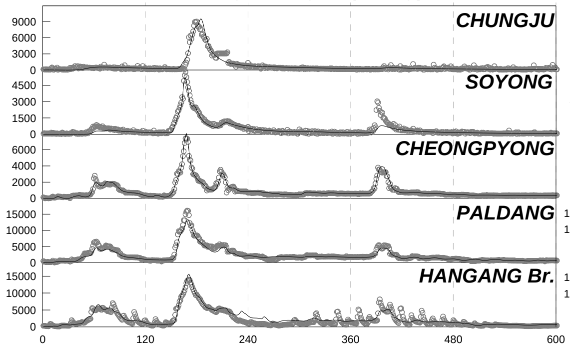
➢ Calibration Period(Time interval : hourly)



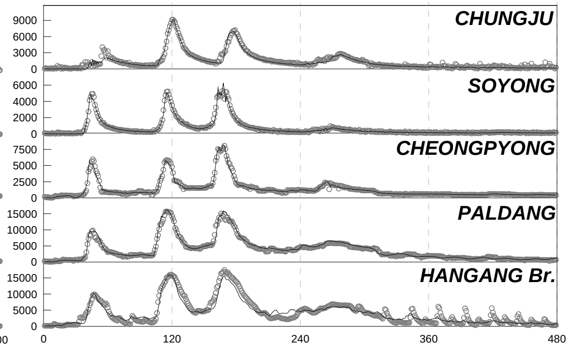
2007 Aug 1 - Aug 20 (hourly)



2006 Jul 8 - Aug 4 (hourly)

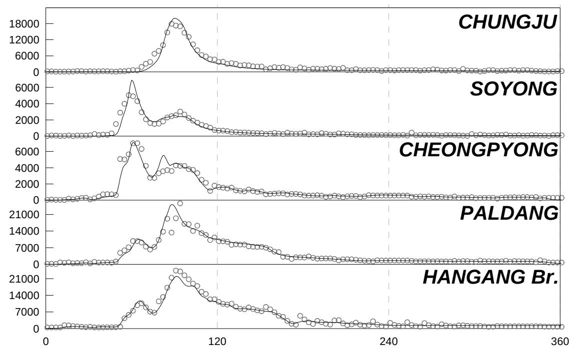


2008 Jul 18 - Aug 11 (hourly)

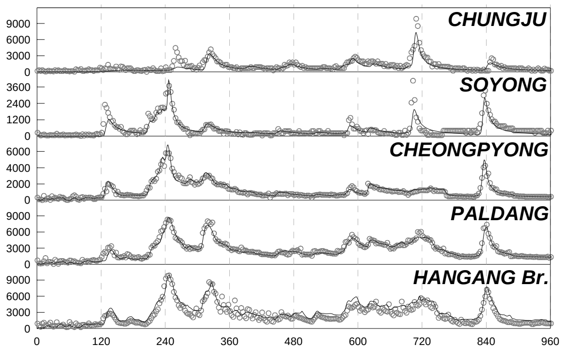


2009 Jul 8 - Jul 27 (hourly)

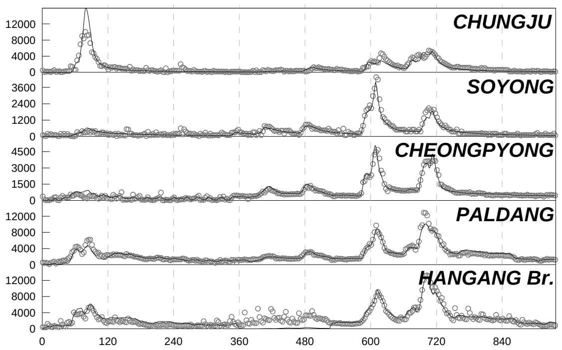
➢ Verification Period(Time interval : hourly)



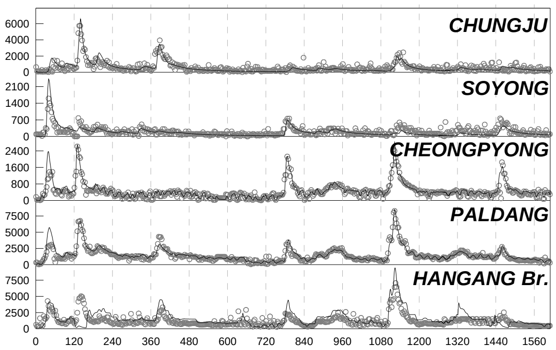
2002 Aug 4 - Aug 18 (hourly)



2003 Aug 15 - Sep 23 (hourly)

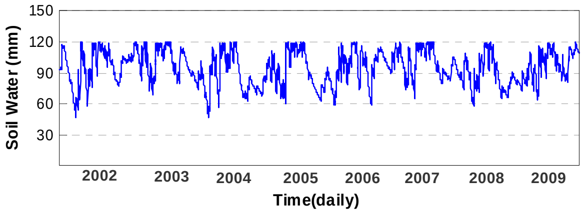


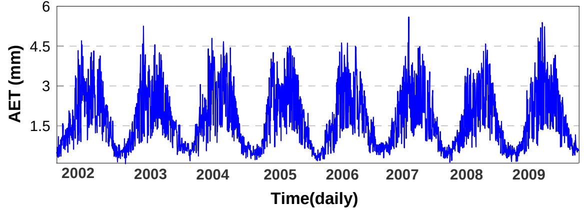
2004 Jul 7 - Jul 26 (hourly)

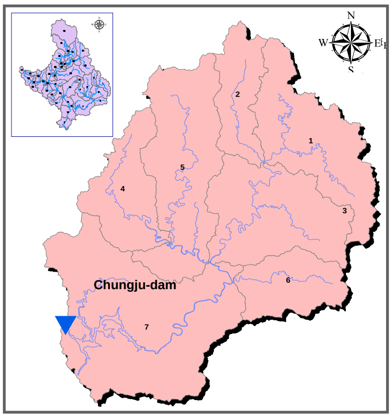


2005 Jun 26 - Aug 31 (hourly)

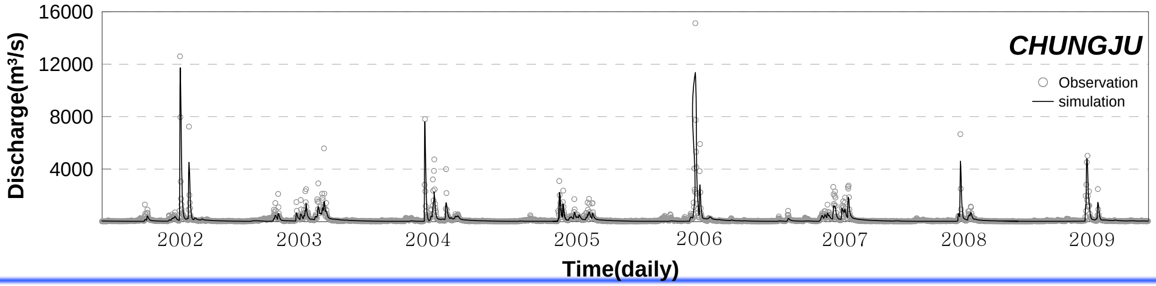
Application assessment of daily simulation







- Comparison observed and simulated discharge at Chungju Dam site



Concluding Remarks

We issued how to apply hydrologic models for climate change study

- Propose and review the theory VIC model based on macroscale and SURR model based on microscale
- Results of model application assessment on South Korea
  - VIC model results by using local data are within the acceptable range reflecting the local complex meteorological and topographical characteristics
  - In terms of statistical and graphical analysis, Both hourly and daily estimations of SURR show good performance

As a results, VIC and SURR model are applicable for climate change assessment using hydrologic analysis

Thank you