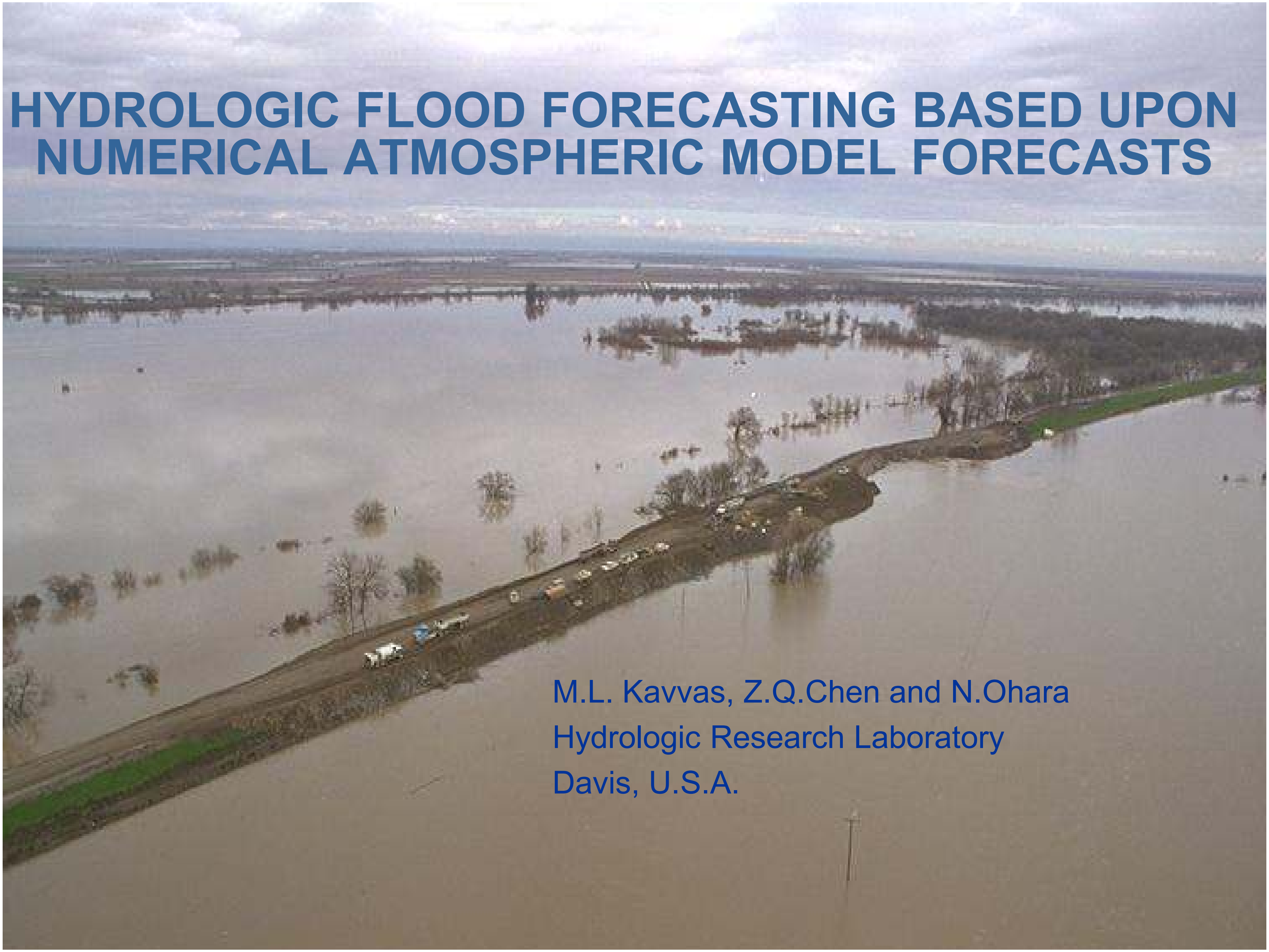
HYDROLOGIC FLOOD FORECASTING BASED UPON NUMERICAL ATMOSPHERIC MODEL FORECASTS



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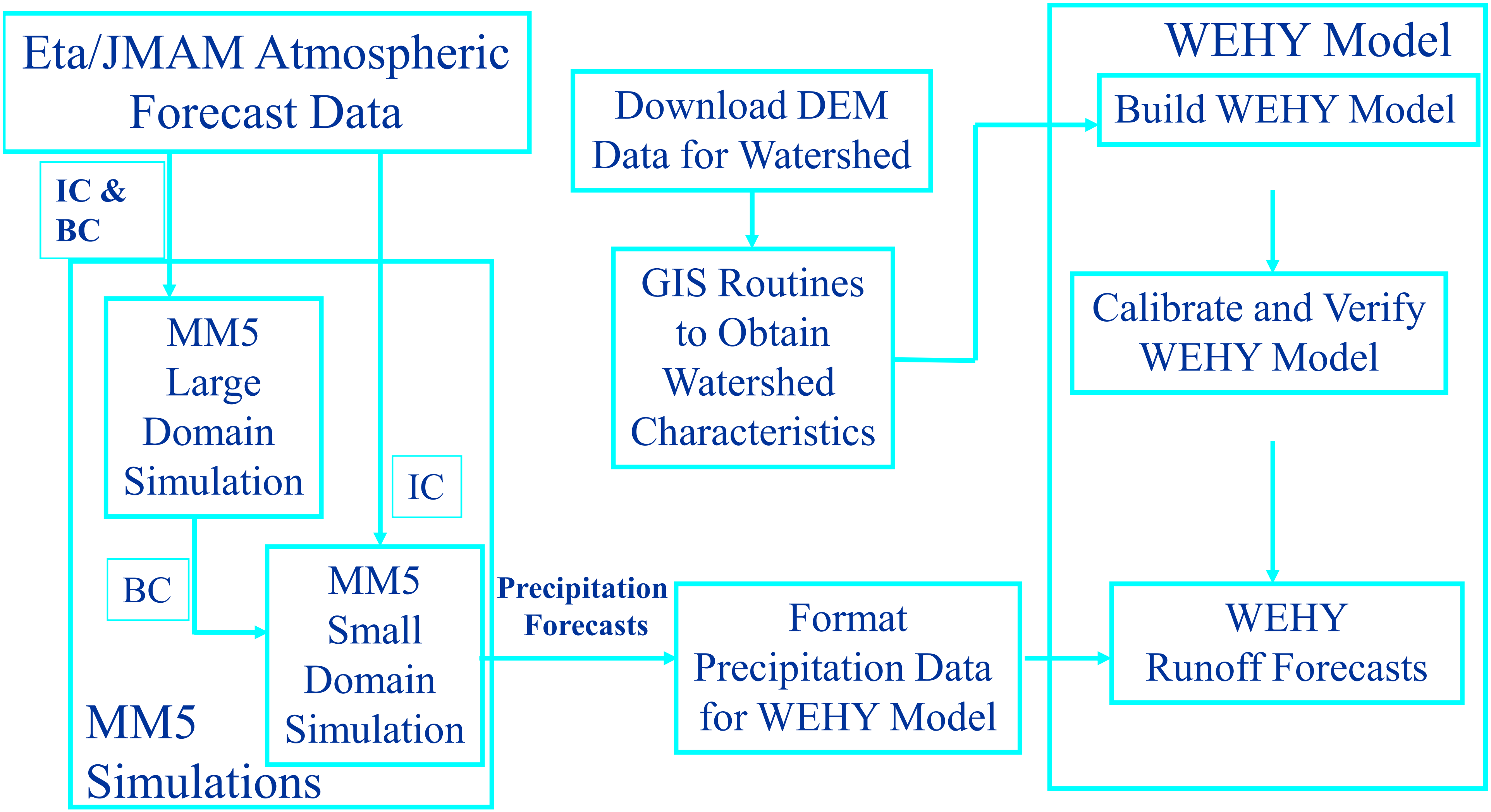
Hydrologic Research Laboratory
Davis, U.S.A.

Proposed Methodology

- Obtain coarse time-space resolution atmospheric forecasts from a regional/continental scale atmospheric model (eg.Eta or JMAM) 48 hours in advance;
- Downscale the coarse time-space resolution precipitation forecasts of the regional/continental scale atmospheric model (eg. NCEP or JMAM) to fine time (hourly) and space (~2km) resolution over the watershed of interest by means of MM5 model, 48 hours in advance of the runoff event;
- Utilize the fine time-space resolution precipitation forecasts of MM5 as input to Watershed Environmental Hydrology (WEHY) Model in order to produce 48-hours-ahead runoff forecasts.

Forecasting Procedure



Eta/JMAM Atmospheric Forecast Data

IC & BC

MM5 Large Domain Simulation

IC

BC

MM5 Small Domain Simulation

MM5 Simulations

Precipitation Forecasts

Download DEM Data for Watershed

GIS Routines to Obtain Watershed Characteristics

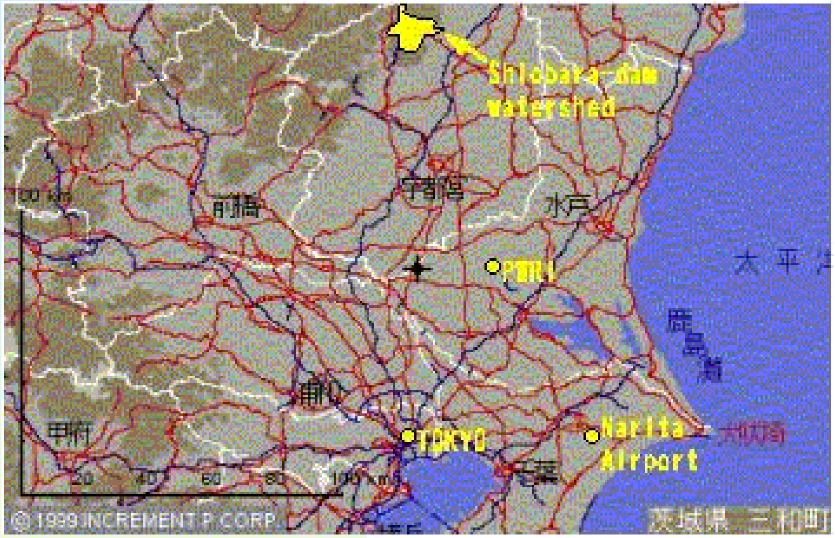
Format Precipitation Data for WEHY Model

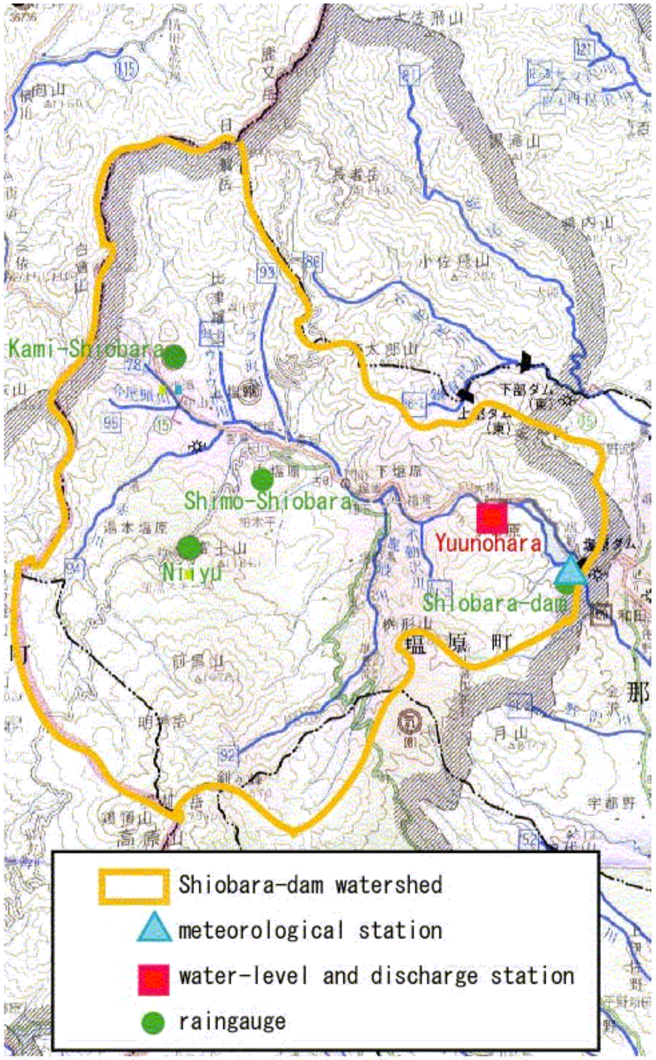
WEHY Model

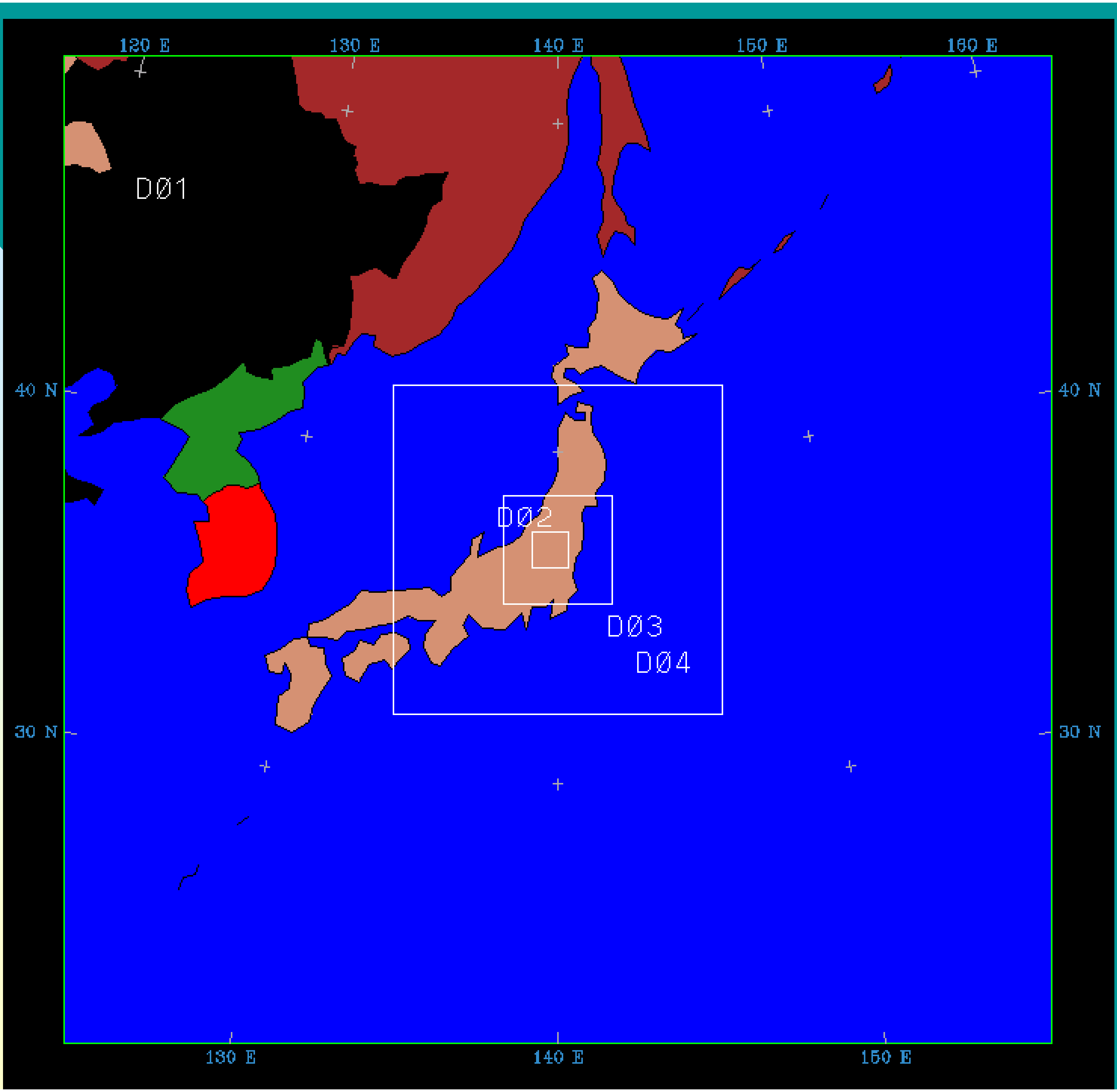
Build WEHY Model

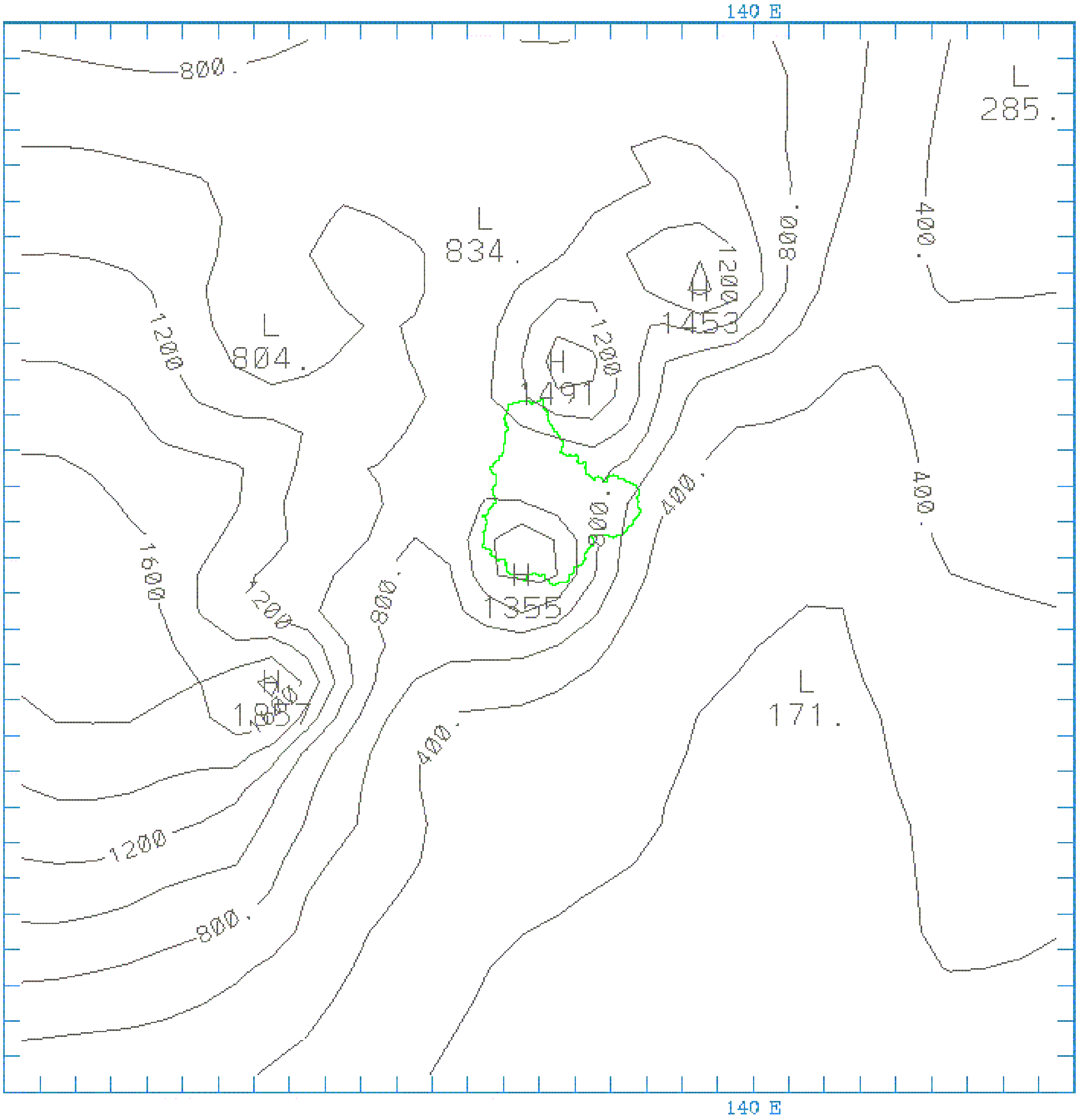
Calibrate and Verify WEHY Model

WEHY Runoff Forecasts


Shiobara-dam watershed
宇都宮
前橋
水戸
PWRI
太平洋
鹿島灘
浦和
甲府
TOKYO
Narita Airport
千葉
犬吠埼
100 km
20
40
60
80
100 km
© 1999 INCREMENT P CORP.
茨城県 三和町


Kami-Shiobara
Shimo-Shiobara
Niiyu
Yuunohara
Shiobara-dam
塩原町
Shiobara-dam watershed
meteorological station
water-level and discharge station
raingauge


120 E
130 E
140 E
150 E
160 E
D01
40 N
40 N
D02
D03
D04
30 N
30 N
130 E
140 E
150 E


140 E
L
285.
800.
400.
L
834.
L
804.
1200
H
1491
H
1453
1200
800.
400.
H
1355
1600
1200
800.
H
1857
800
400.
1200
800.
L
171.
140 E

Atmospheric Forecasts by JMAM

- 20km resolution JMAM forecasts are obtained from the internet;
- JMAM provides atmospheric forecasts at 12-hour intervals for 48 hours ahead;
- The 3D forecasts of precipitation, relative humidity, wind and atmospheric pressure by JMAM provide the boundary conditions for MM5 atmospheric model forecasts.

MM5 Atmospheric Model

- Fifth generation regional atmospheric model of NCAR (National Center for Atmospheric Research) and Penn State University;
- Nonhydrostatic dynamic simulation of atmospheric processes (JMAM is hydrostatic);
- Downscaling and upscaling capabilities;
- Many modeling options for various atmospheric processes (eg. at least 5 options for convective modeling of precipitation).

WEHY (Watershed Environmental Hydrology) Model

WEHY Model is a physically-based, spatially-distributed
watershed hydrology model
that is based upon
conservation equations that were **upscaled** from
standard point-scale hydrologic conservation equations.

Therefore, the **emerging parameters** in the WEHY model are
areal averages and areal variance/covariances of the
original point-scale parameter values
(eg. grid areal average hydraulic conductivity,
grid areal variance of the hydraulic conductivity).

It is possible to implement and use

WEHY model

at any ungauged or sparsely-gauged watershed in the world

since

its parameters are estimated directly from

the land features of the watershed,

and not from fitting to historical rainfall-runoff data.

Furthermore,

WEHY parameters are scalable

with the scale of the modeling grid area sizes,

incorporating subgrid area heterogeneity.

WEHY model

has

areally-averaged, upscaled conservation equations

for

interception;

snow accumulation/snowmelt,

evapotranspiration,

infiltration, unsaturated flow, subsurface stormflow,

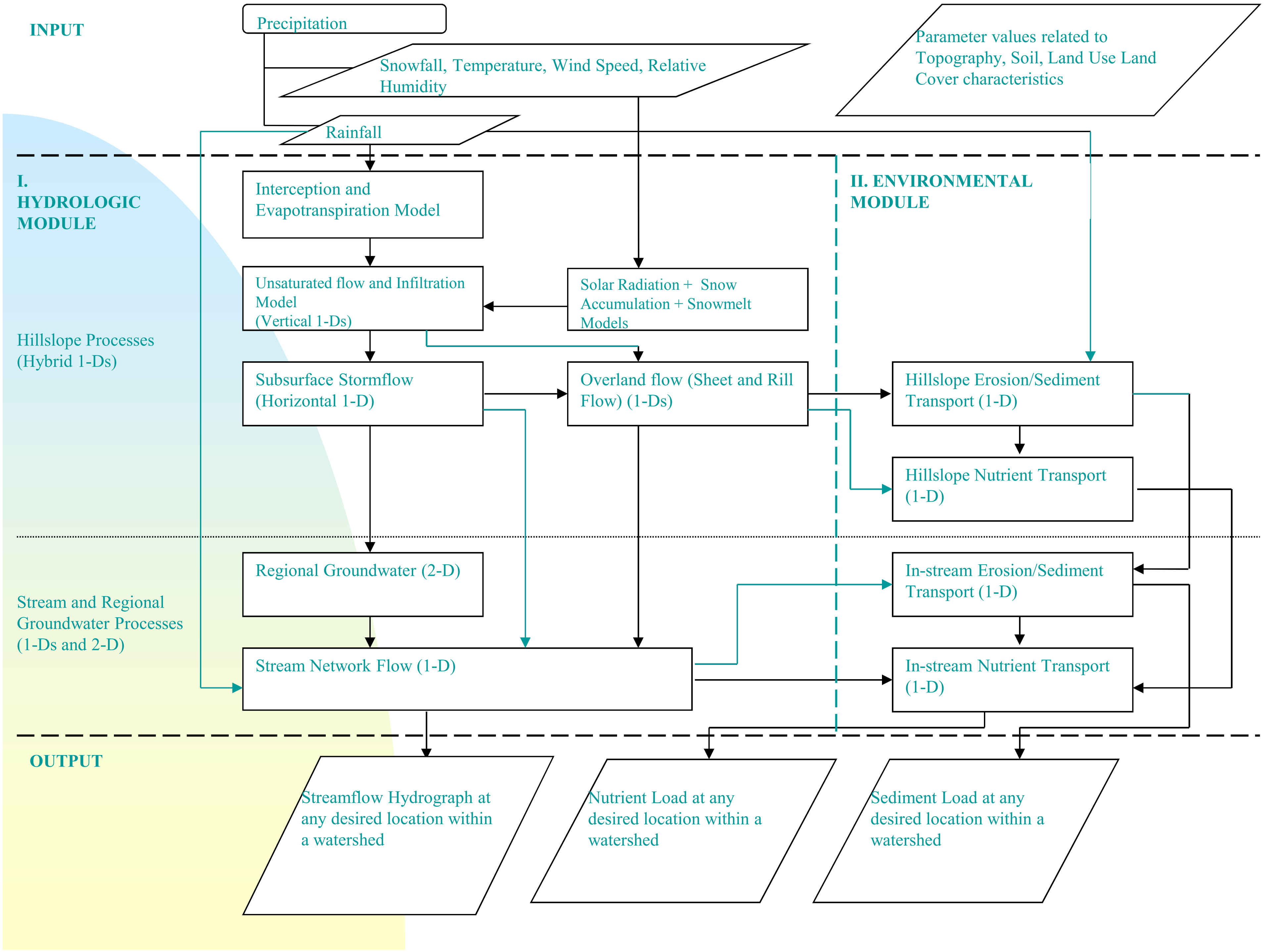
overland flow (with interacting rill/gully flow and sheet flow),

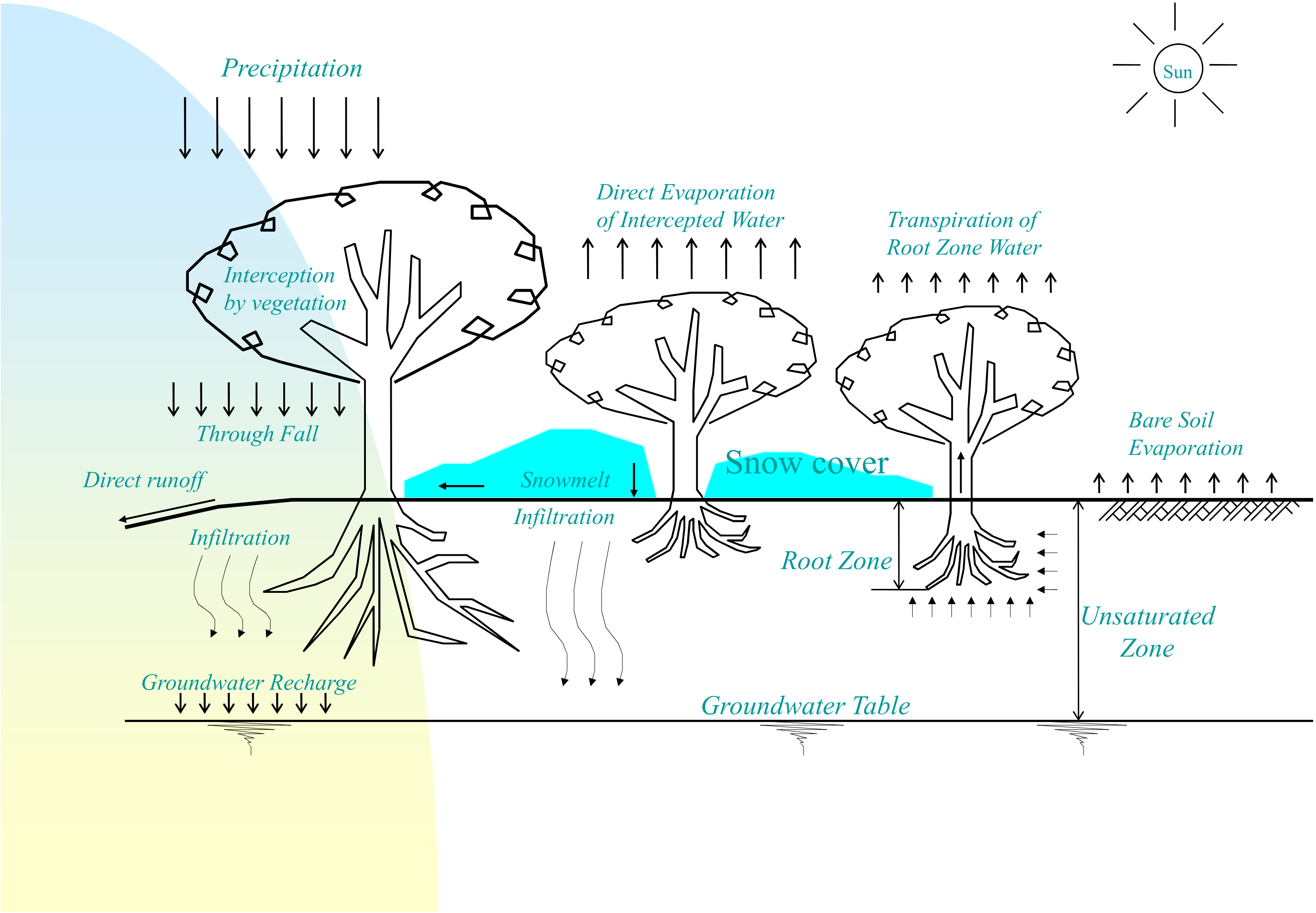
and for

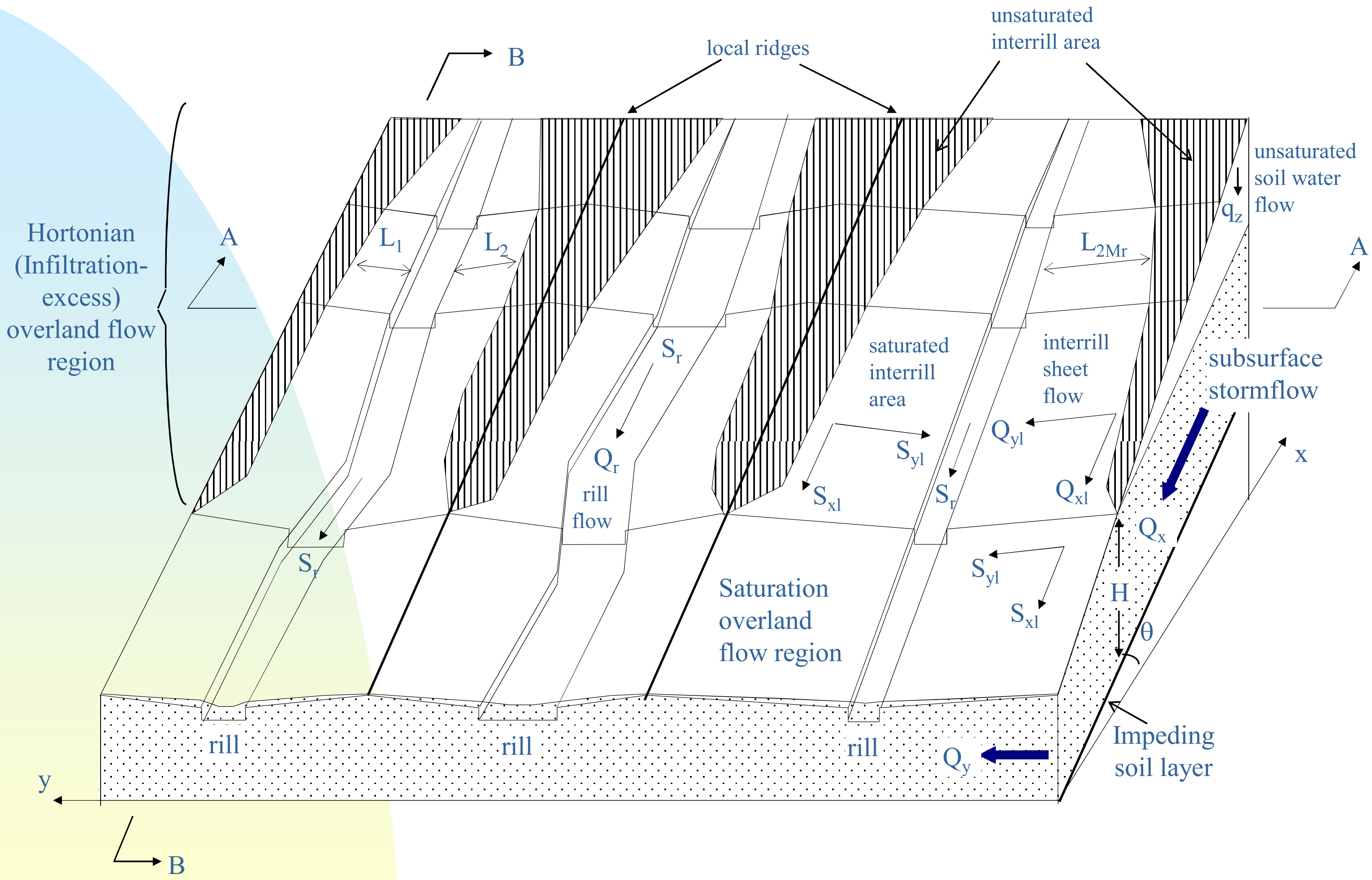
channel network flow and regional groundwater flow.

WEHY Model is a peer-reviewed and published watershed hydrology model (ASCE Journal of Hydrologic Engineering, Nov/Dec 2004 issue).

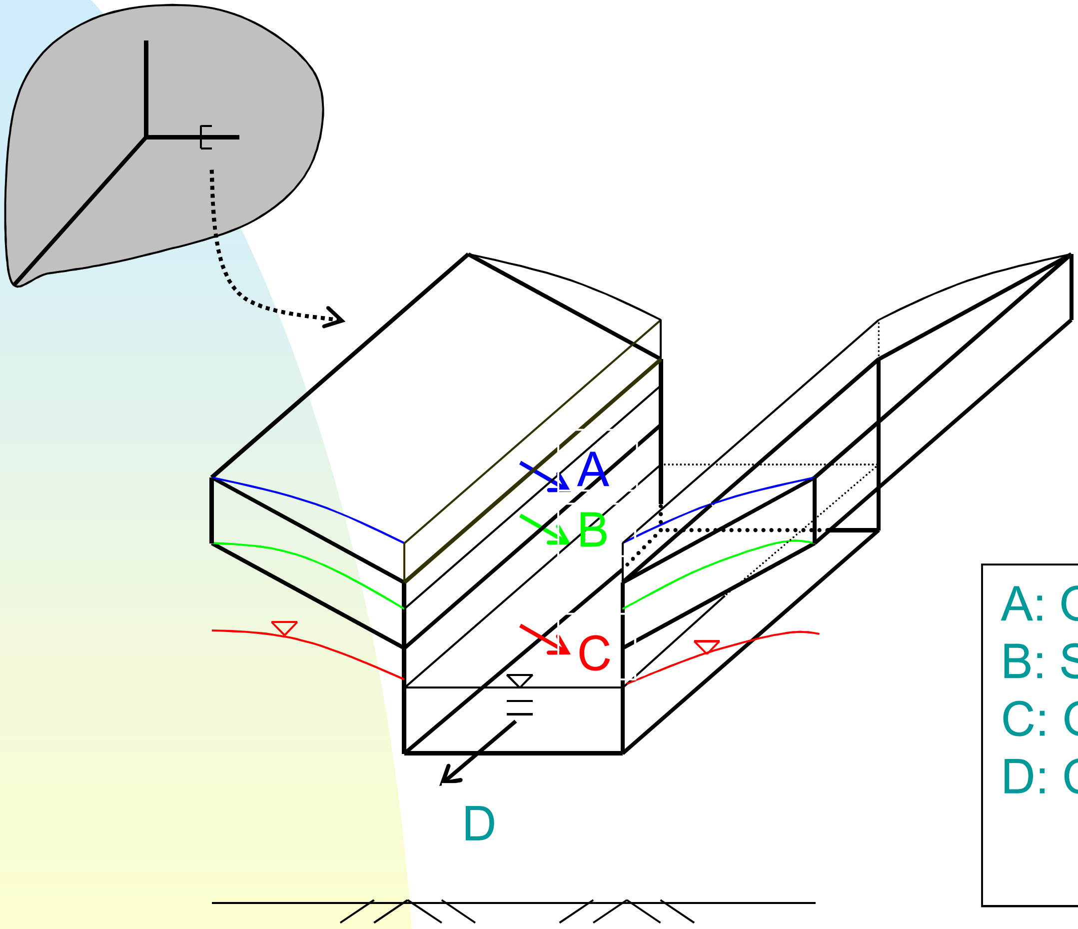
It can be used either for event-based runoff prediction, or for long-term continuous-time runoff prediction.


INPUT
Precipitation
Snowfall, Temperature, Wind Speed, Relative Humidity
Parameter values related to Topography, Soil, Land Use Land Cover characteristics
Rainfall
I. HYDROLOGIC MODULE
Interception and Evapotranspiration Model
Unsaturated flow and Infiltration Model (Vertical 1-Ds)
Solar Radiation + Snow Accumulation + Snowmelt Models
Hillslope Processes (Hybrid 1-Ds)
Subsurface Stormflow (Horizontal 1-D)
Overland flow (Sheet and Rill Flow) (1-Ds)
II. ENVIRONMENTAL MODULE
Hillslope Erosion/Sediment Transport (1-D)
Hillslope Nutrient Transport (1-D)
Stream and Regional Groundwater Processes (1-Ds and 2-D)
Regional Groundwater (2-D)
Stream Network Flow (1-D)
In-stream Erosion/Sediment Transport (1-D)
In-stream Nutrient Transport (1-D)
OUTPUT
Streamflow Hydrograph at any desired location within a watershed
Nutrient Load at any desired location within a watershed
Sediment Load at any desired location within a watershed


Sun
Precipitation
Interception by vegetation
Through Fall
Direct Evaporation of Intercepted Water
Transpiration of Root Zone Water
Bare Soil Evaporation
Snow cover
Snowmelt
Direct runoff
Infiltration
Infiltration
Root Zone
Unsaturated Zone
Groundwater Recharge
Groundwater Table

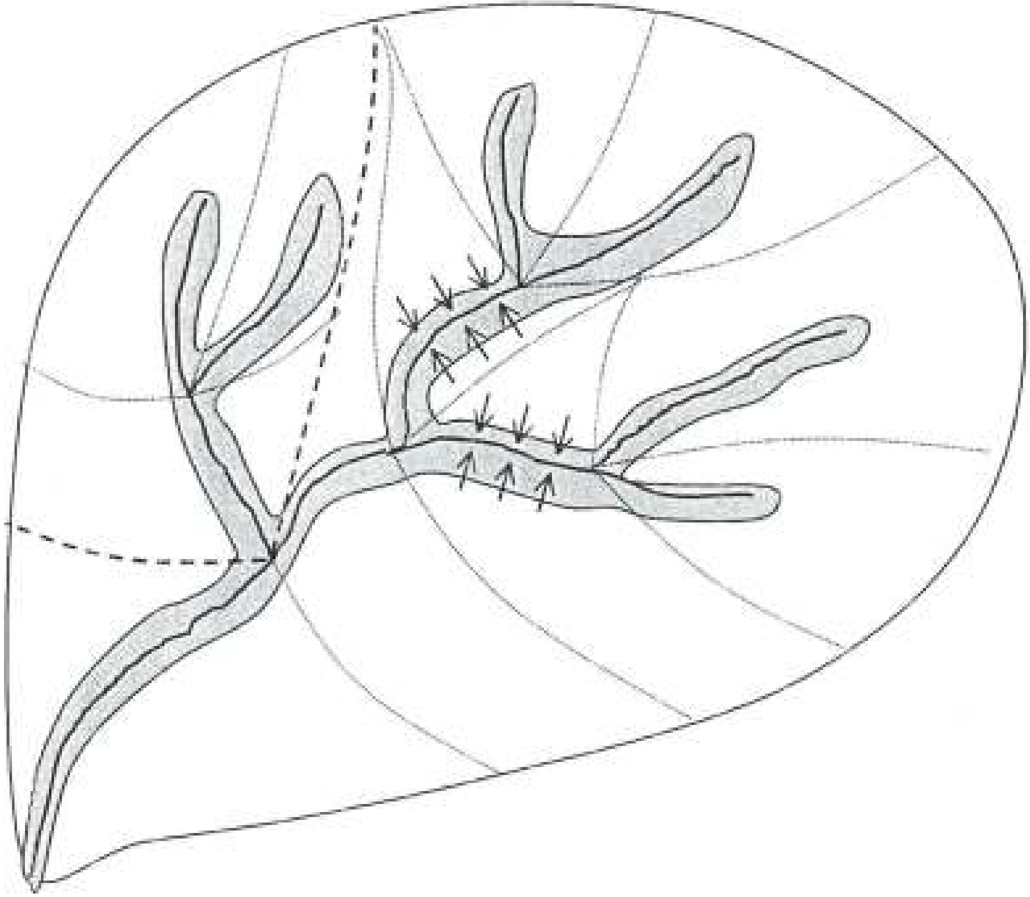

B
local ridges
unsaturated interrill area
unsaturated soil water flow
q_z
Hortonian (Infiltration-excess) overland flow region
A
L_1
L_2
L_{2Mr}
A
S_r
Q_r
rill flow
saturated interrill area
interrill sheet flow
subsurface stormflow
S_{yl}
Q_{yl}
S_{xl}
S_r
Q_{xl}
x
Q_x
S_r
S_{yl}
Saturation overland flow region
H
S_{xl}
θ
Impeding soil layer
rill
rill
rill
Q_y
y
B

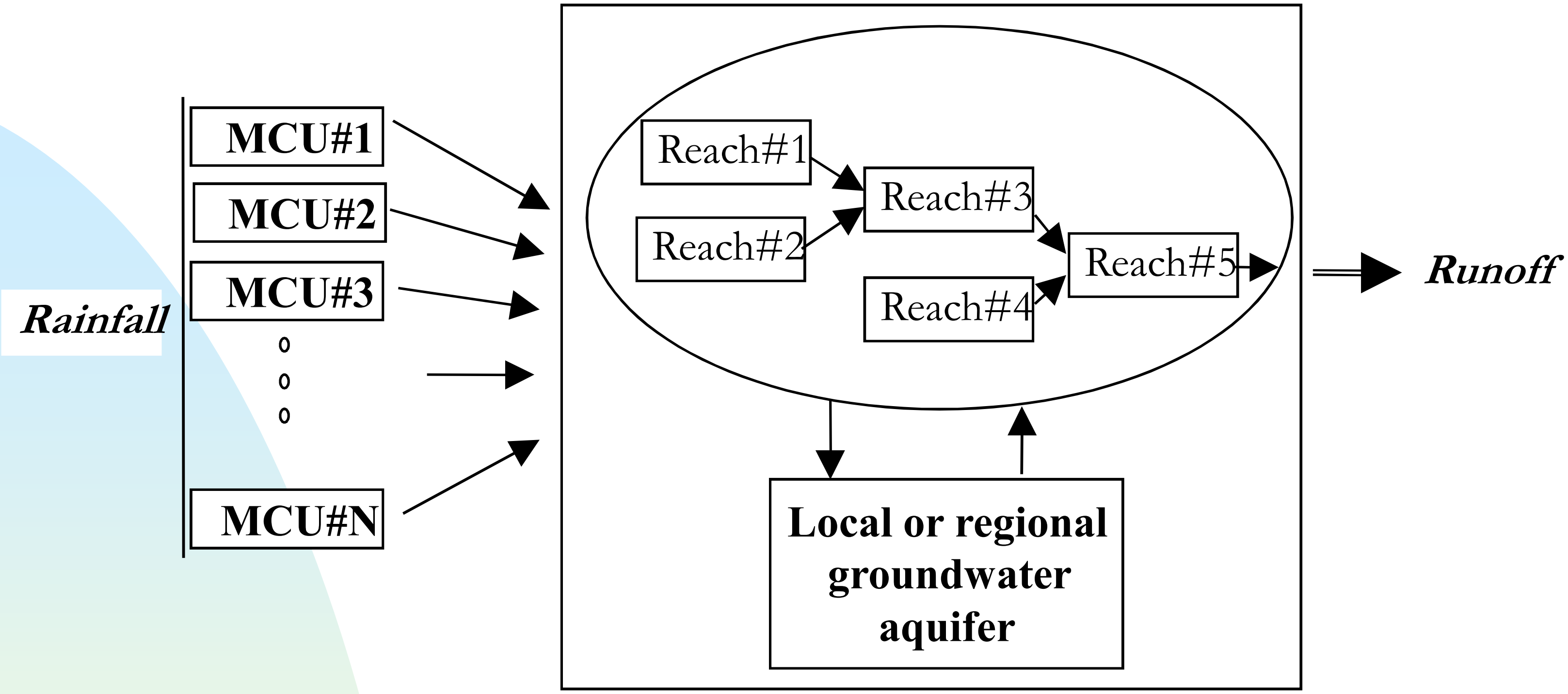
Schematic description of hillslope-stream interaction



A: Overland flow
B: Subsurface stormflow
C: Groundwater flow
D: Channel flow

Schematic description of Subdivisions and Contributing Areas in a Watershed





Rainfall

MCU#1

MCU#2

MCU#3

MCU#N

Reach#1

Reach#2

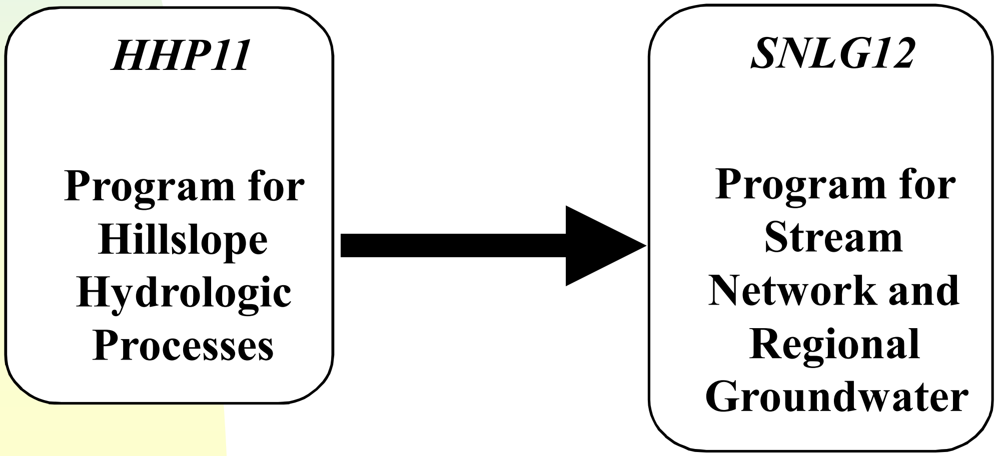
Reach#3

Reach#4

Reach#5

Local or regional groundwater aquifer

Runoff

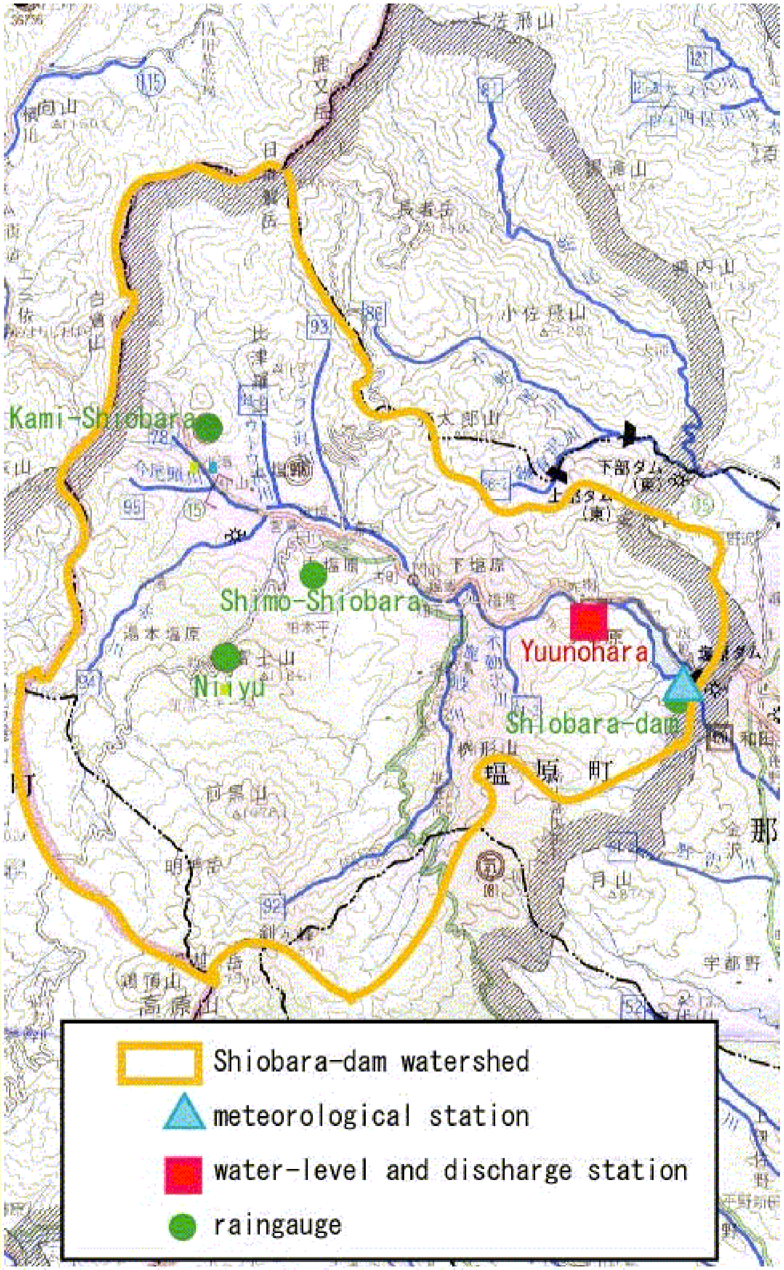


HHP11

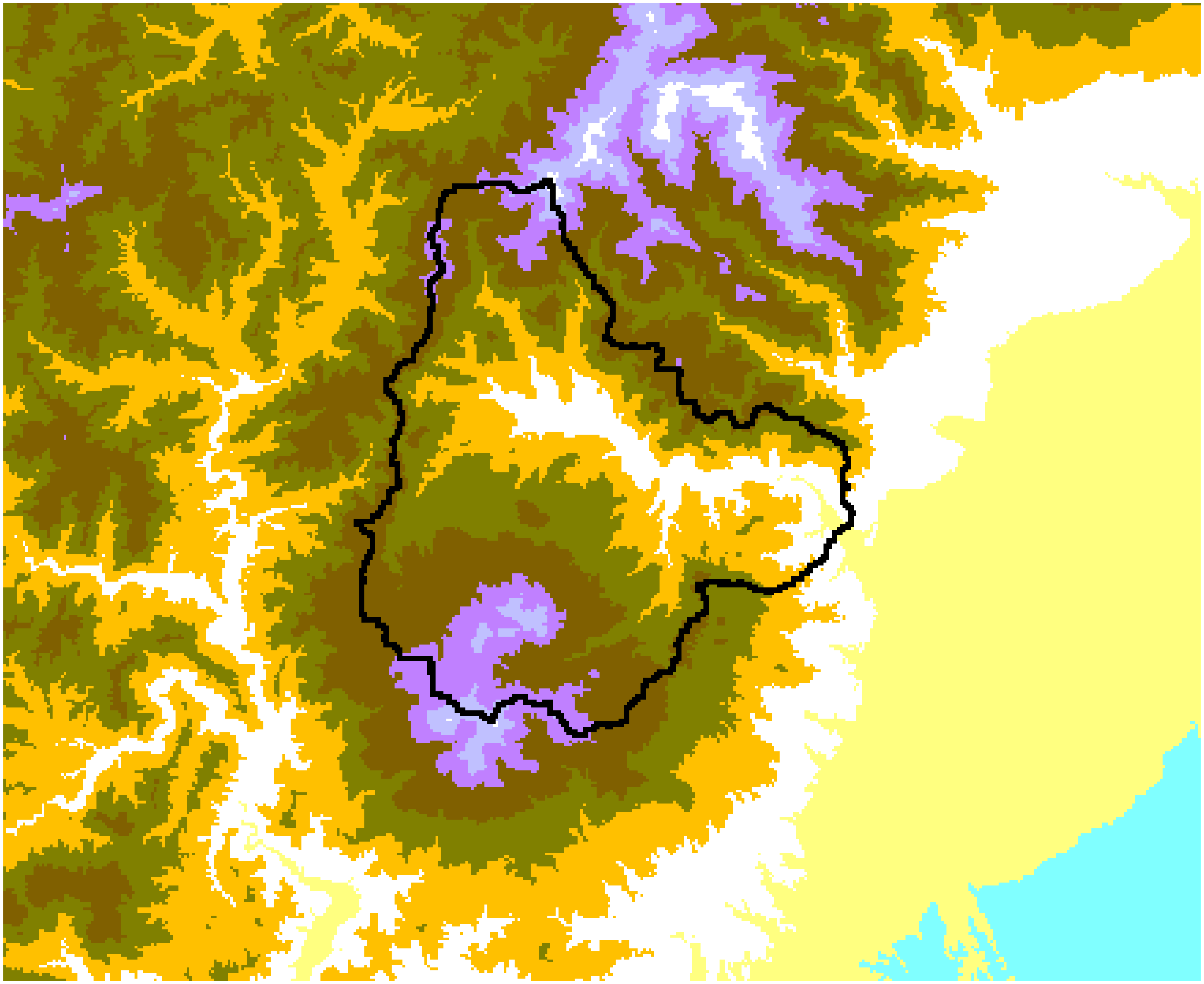
Program for Hillslope Hydrologic Processes

SNLG12

Program for Stream Network and Regional Groundwater


Kami-Shiobara
Shimo-Shiobara
Niiyu
Yuunohara
Shiobara-dam
塩原町
Shiobara-dam watershed
meteorological station
water-level and discharge station
raingauge

Shiobara-Dam Region

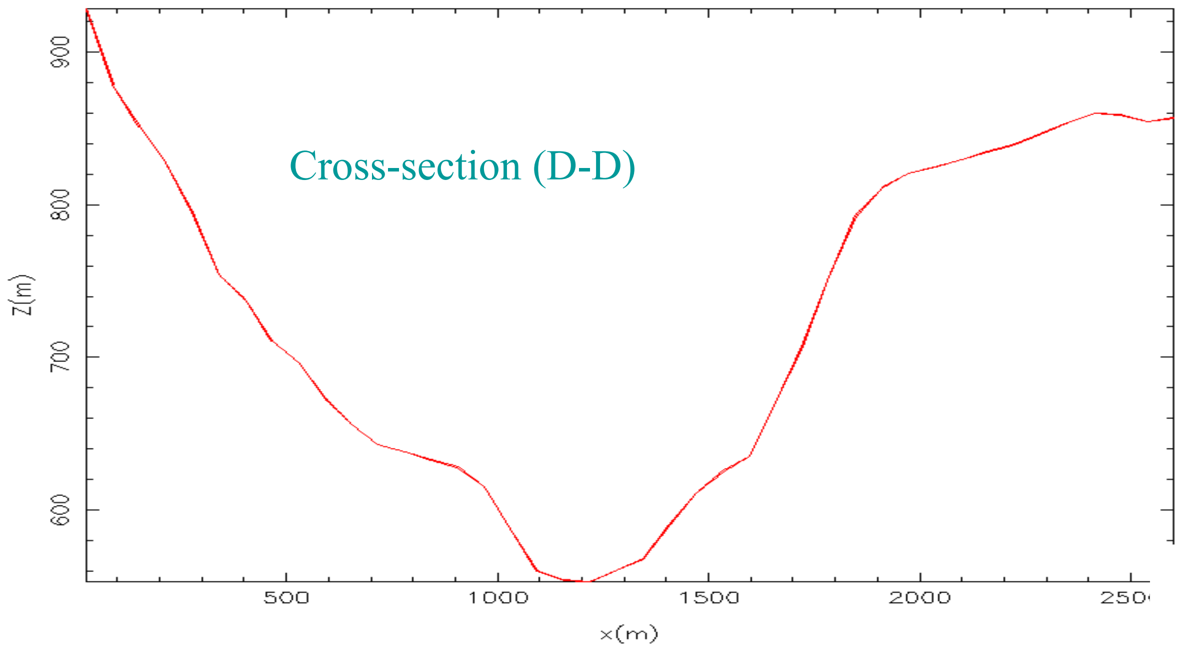


Different

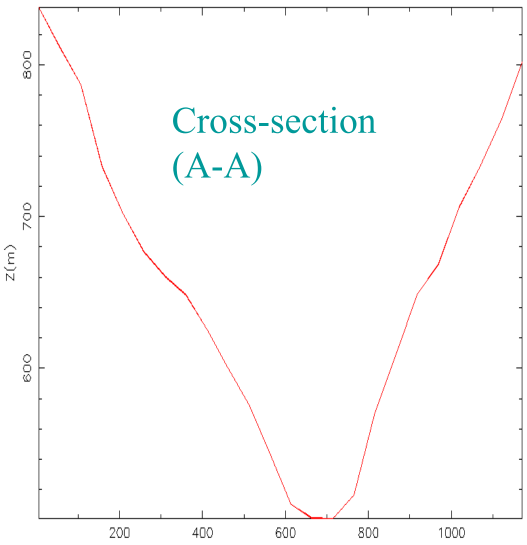
local geomorphological conditions

demand

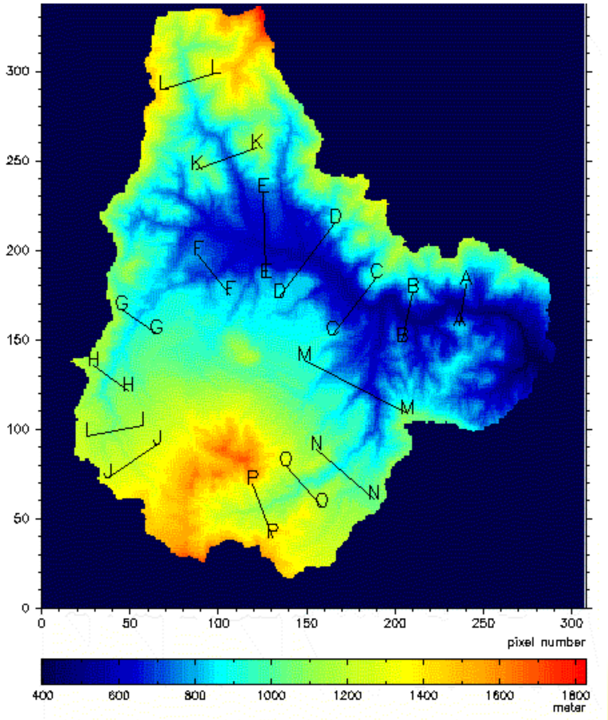
different model treatments

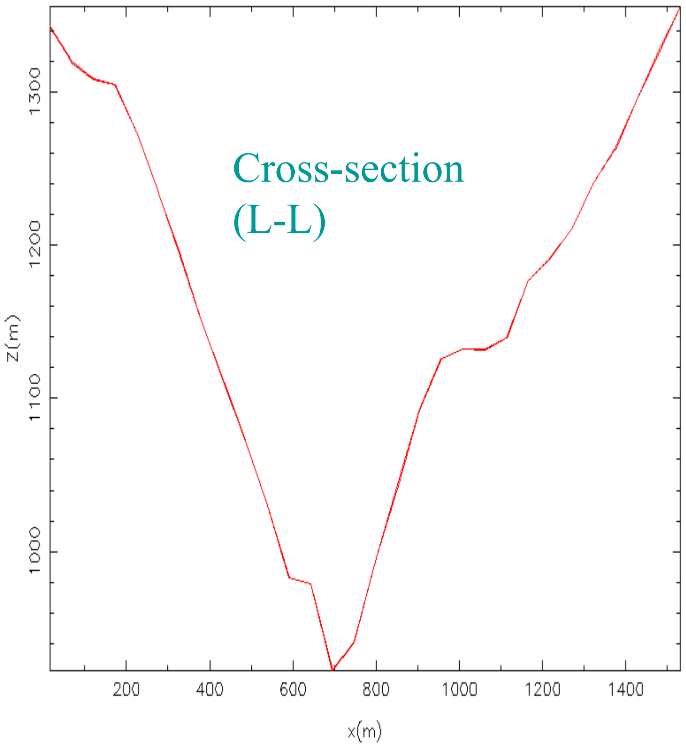


Cross-section (D-D)



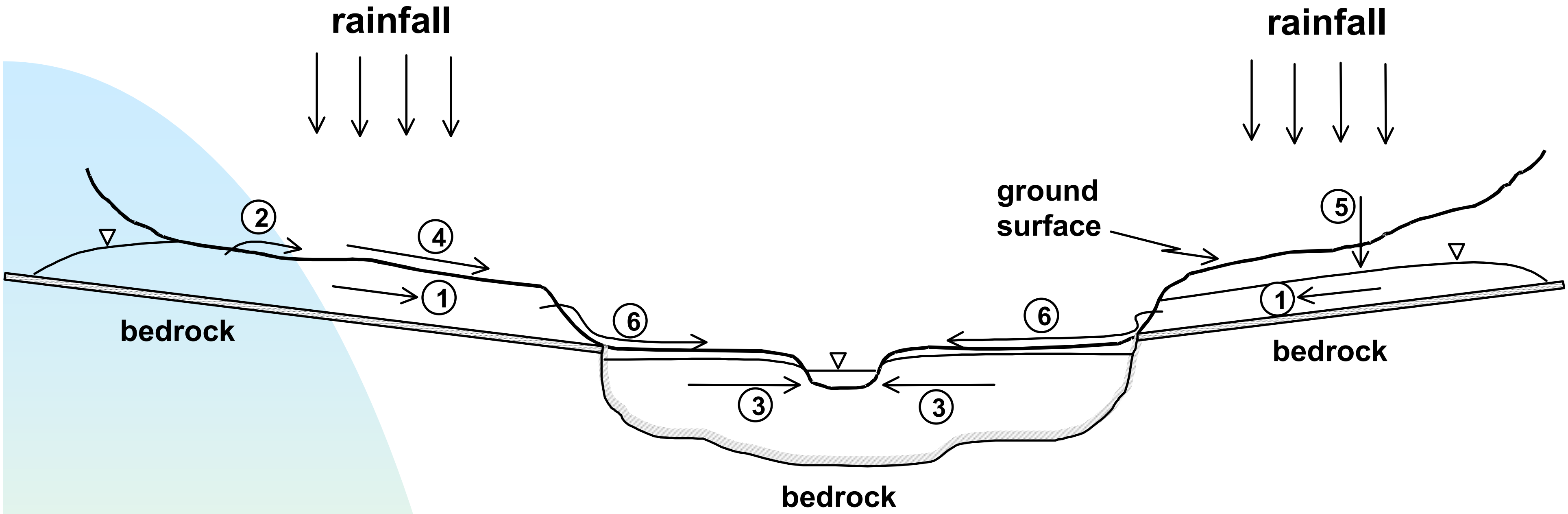
Cross-section (A-A)





Cross-section (L-L)


2 12 '00



1. Subsurface stormflow

2. Return flow

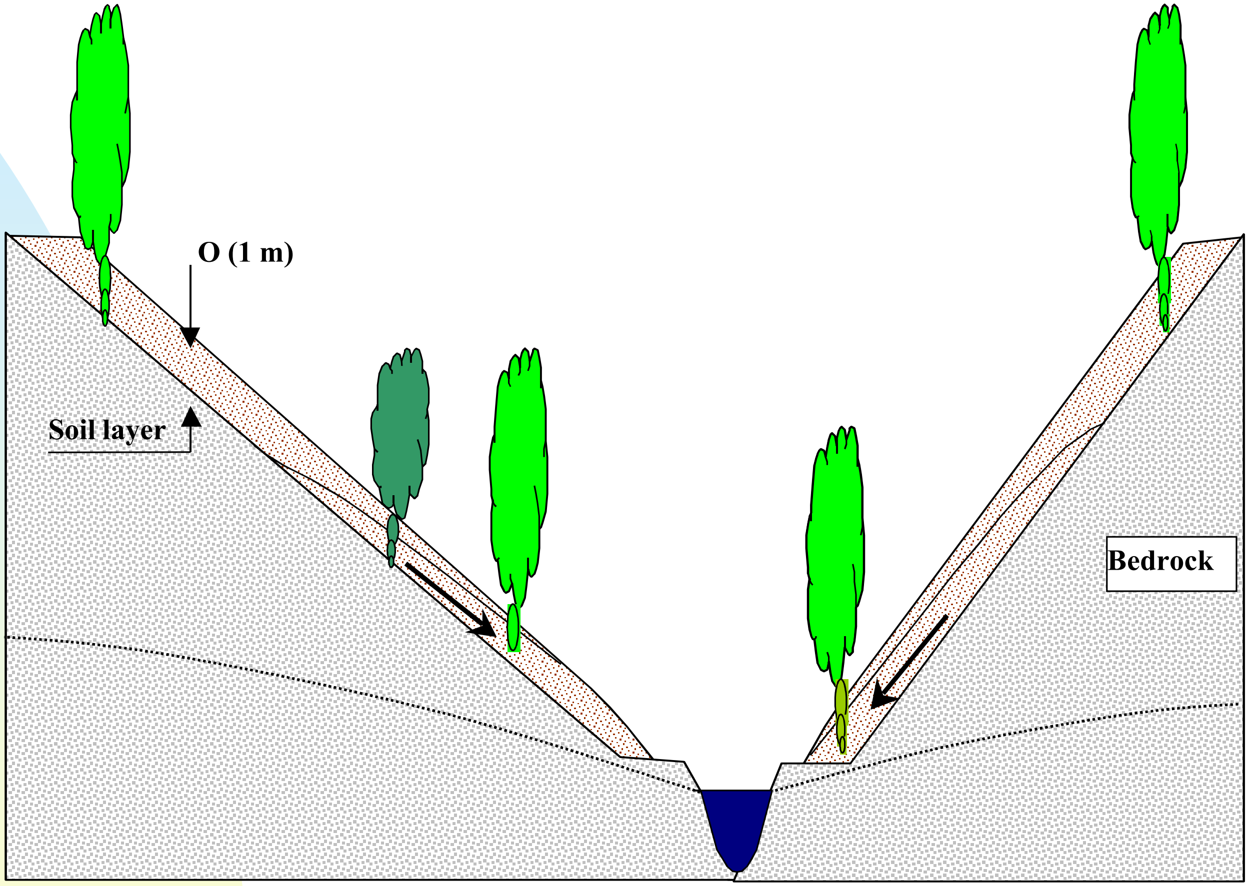
3. Groundwater flow

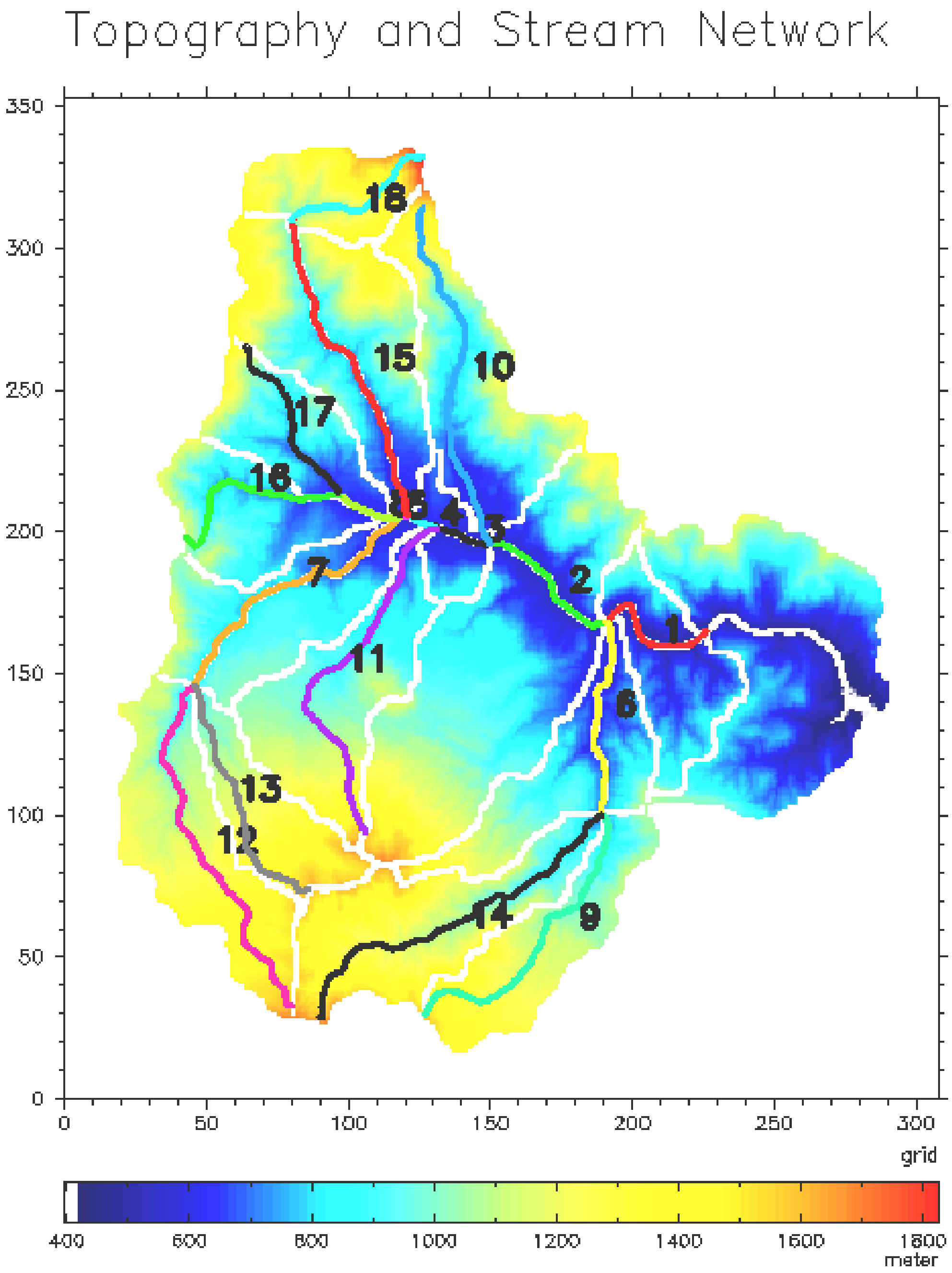
4. Overland flow (interacting rill and sheet flow)

5. Vertical unsaturated soil water flow

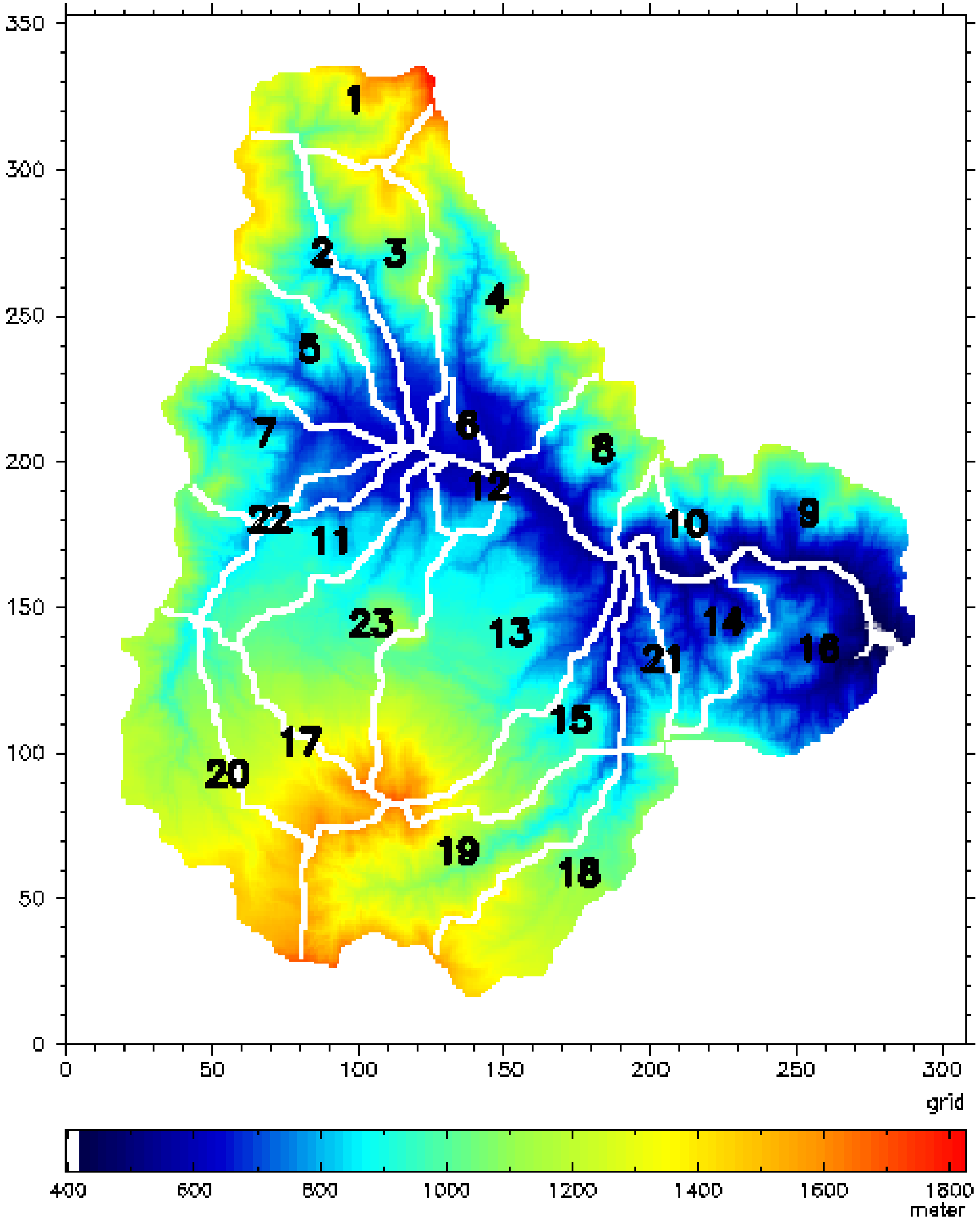
6. Overland flow from seepage face

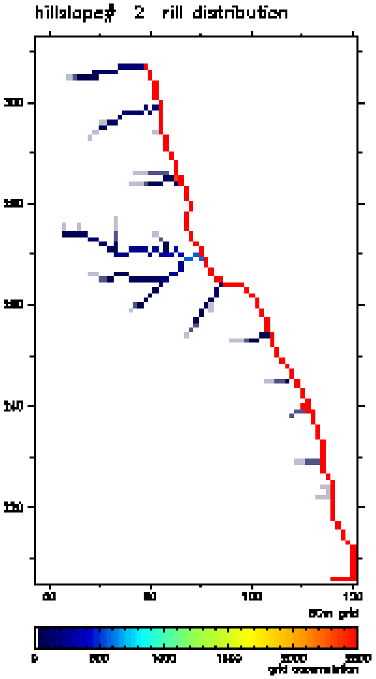

2 12 00

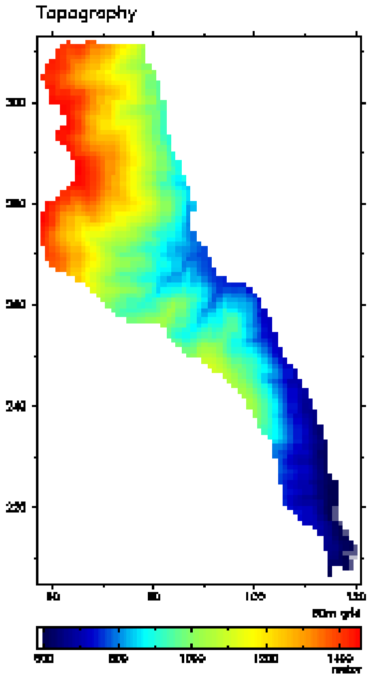

O (1 m)
Soil layer
Bedrock

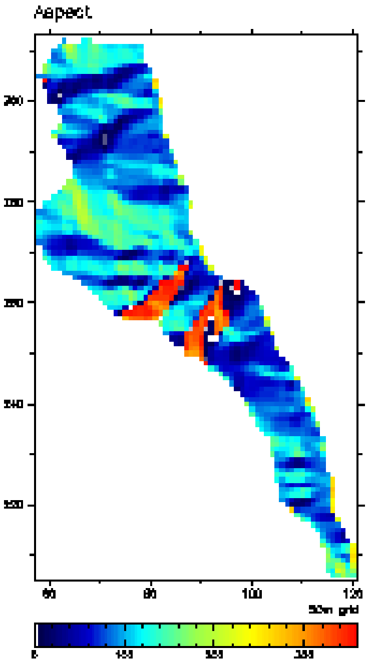

Topography and Stream Network
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
grid
1
2
3
4
5
6
7
9
10
11
12
13
14
15
16
17
18
400
600
800
1000
1200
1400
1600
1800
meter

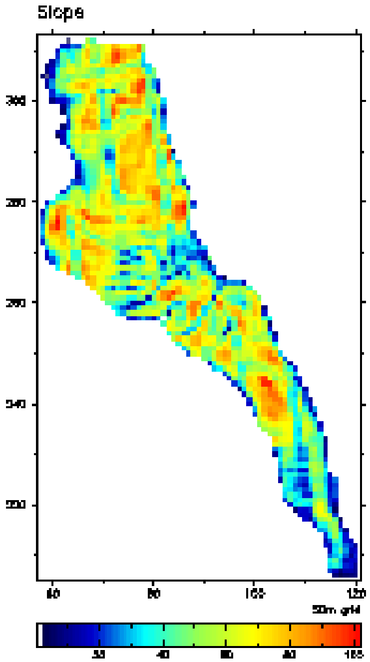
Hillslope MCUs

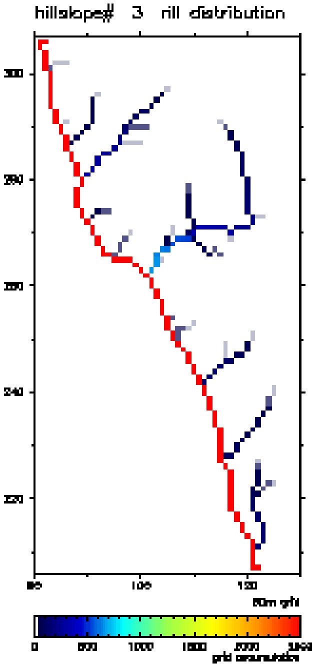


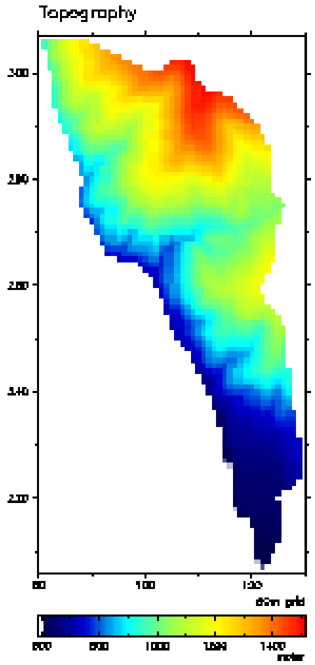

hillslope# 2 rill distribution
300
280
260
240
220
60
80
100
120
50m grid
0
600
1200
1800
2400
3000
grid accumulation

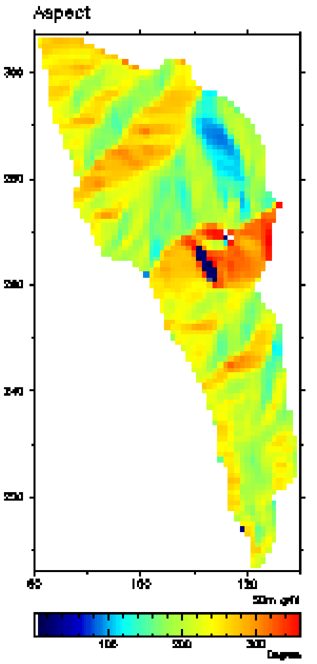

Topography
300
280
260
240
220
60
80
100
120
50m grid
600
800
1000
1200
1400
meter

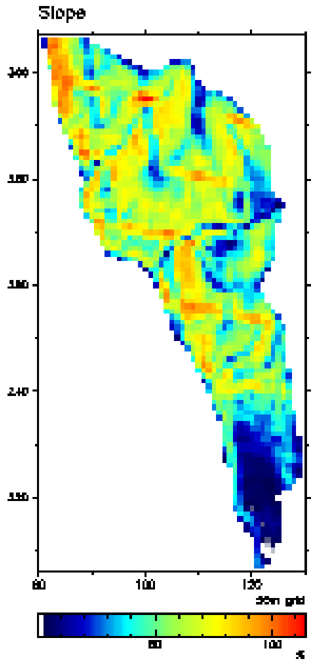

Aspect
300
280
260
240
220
60
80
100
120
50m grid
0
100
200
300


Slope
300
280
260
240
220
60
80
100
120
50m grid
20
40
60
80
100


hillslope# 3 rill distribution


Topography

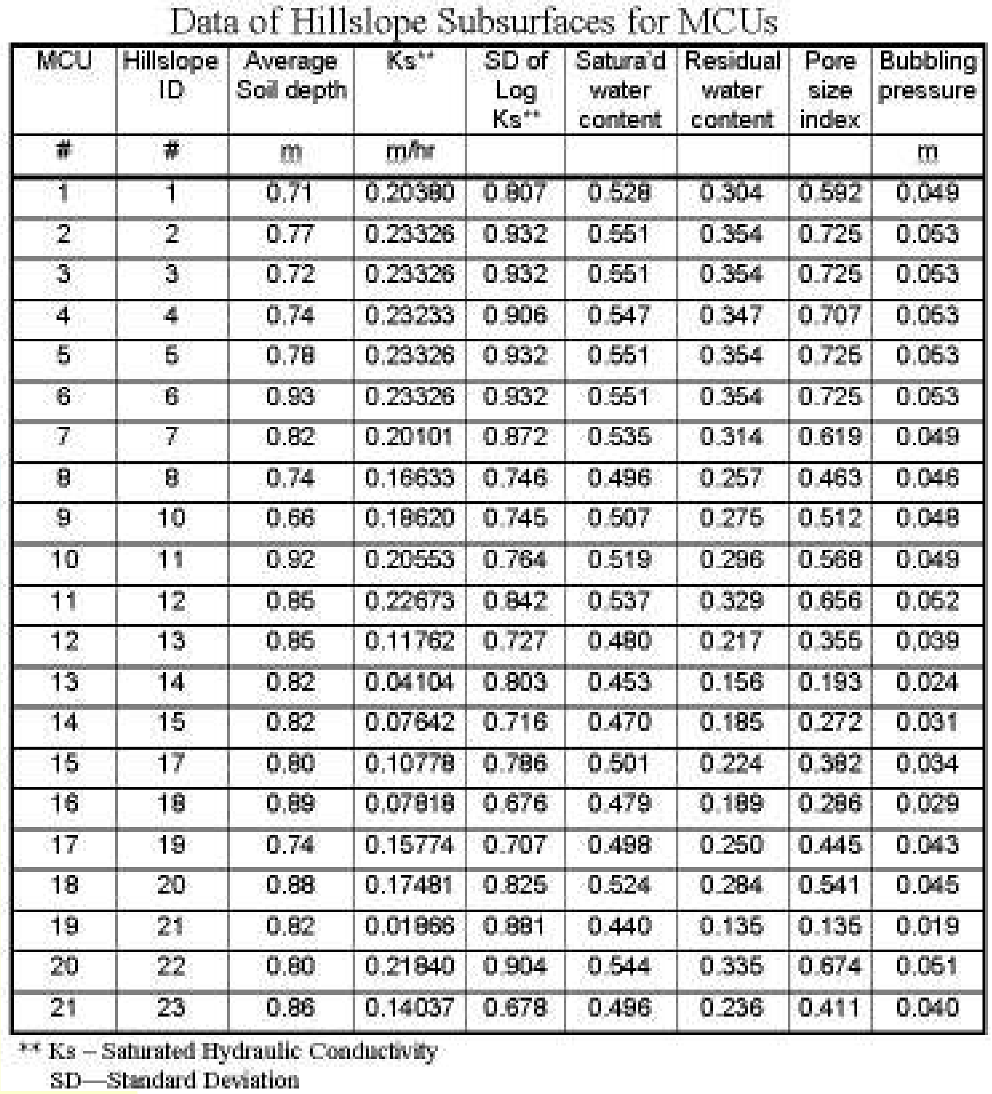

Aspect


Slope

Data of Hillslope Surfaces for MCUs Computed From DEM

MCU	Hillslope ID	Receiving stream reach ID	MCU Area	Hillslope base width	Slope near stream	Interrill area slope	Rill slope	MCU mean slope**	Rill length	Rill density
#	#	#	km^2	m	%	%	%	%	m	m^{-2}
1	1	18	4.005	2850	36.686	60.478	41.415	58.438	8550	0.0028
2	2	15	5.110	3700	19.752	55.088	42.232	52.835	10500	0.0022
3	3	15	5.443	1750	25.416	54.514	40.691	52.699	11750	0.0013
4	4	10	8.570	5900	26.168	55.750	35.871	53.422	20050	0.0033
5	5	17	4.802	4350	27.118	52.636	35.441	50.402	10600	0.0030
6	6	3	0.870	1200	13.415	17.621	12.803	16.830	1650	0.0019
7	7	16	5.385	3300	26.158	45.478	25.944	43.226	12100	0.0033
8	8	2	4.264	1550	12.172	57.009	38.049	54.270	8650	0.0037
9	10	1	1.615	1300	10.134	57.831	50.353	55.286	2700	0.0012
10	11	7	4.382	2150	16.467	24.487	18.264	23.645	8850	0.0016
11	12	3	1.207	400	11.040	32.887	25.210	31.635	2800	0.0010
12	13	2	13.380	1000	12.493	30.861	20.732	29.454	34350	0.0110
13	14	1	3.642	800	11.471	50.036	30.607	47.573	7650	0.0046
14	15	6	4.382	2150	17.483	39.300	28.781	37.727	8650	0.0033
15	17	13	4.625	4450	20.794	29.514	19.837	28.069	13800	0.0030
16	18	9	6.265	5250	20.172	30.863	20.830	29.547	16350	0.0025
17	19	14	8.957	6500	25.657	52.888	32.954	50.520	18750	0.0027
18	20	12	8.640	6250	19.347	27.718	21.196	26.843	21600	0.0035
19	21	6	2.297	1500	18.359	48.223	33.515	45.902	4150	0.0011
20	22	7	3.062	3100	15.511	39.549	25.597	37.073	5450	0.0010
21	23	11	8.207	6050	21.328	26.887	19.700	25.817	23250	0.0033

**mean slope – average of flow direction slopes over all grid cells.



Data of Hillslope Subsurfaces for MCUs

MCU	Hillslope ID	Average Soil depth	Ks**	SD of Log Ks**	Satura'd water content	Residual water content	Pore size index	Bubbling pressure
#	#	m	m/hr					m
1	1	0.71	0.20380	0.807	0.528	0.304	0.592	0.049
2	2	0.77	0.23326	0.932	0.551	0.354	0.725	0.053
3	3	0.72	0.23326	0.932	0.551	0.354	0.725	0.053
4	4	0.74	0.23233	0.906	0.547	0.347	0.707	0.053
5	5	0.78	0.23326	0.932	0.551	0.354	0.725	0.053
6	6	0.93	0.23326	0.932	0.551	0.354	0.725	0.053
7	7	0.82	0.20101	0.872	0.535	0.314	0.619	0.049
8	8	0.74	0.16633	0.746	0.496	0.257	0.463	0.046
9	10	0.66	0.18620	0.745	0.507	0.275	0.512	0.048
10	11	0.92	0.20553	0.764	0.519	0.296	0.568	0.049
11	12	0.85	0.22673	0.842	0.537	0.329	0.656	0.052
12	13	0.85	0.11762	0.727	0.480	0.217	0.355	0.039
13	14	0.82	0.04104	0.803	0.453	0.156	0.193	0.024
14	15	0.82	0.07642	0.716	0.470	0.185	0.272	0.031
15	17	0.80	0.10778	0.786	0.501	0.224	0.382	0.034
16	18	0.89	0.07818	0.676	0.479	0.189	0.286	0.029
17	19	0.74	0.15774	0.707	0.498	0.250	0.445	0.043
18	20	0.88	0.17481	0.825	0.524	0.284	0.541	0.045
19	21	0.82	0.01866	0.881	0.440	0.135	0.136	0.019
20	22	0.80	0.21840	0.904	0.544	0.335	0.674	0.051
21	23	0.86	0.14037	0.678	0.496	0.236	0.411	0.040

** Ks – Saturated Hydraulic Conductivity

SD—Standard Deviation

Since all the parameters of WEHY Model are physically-based,

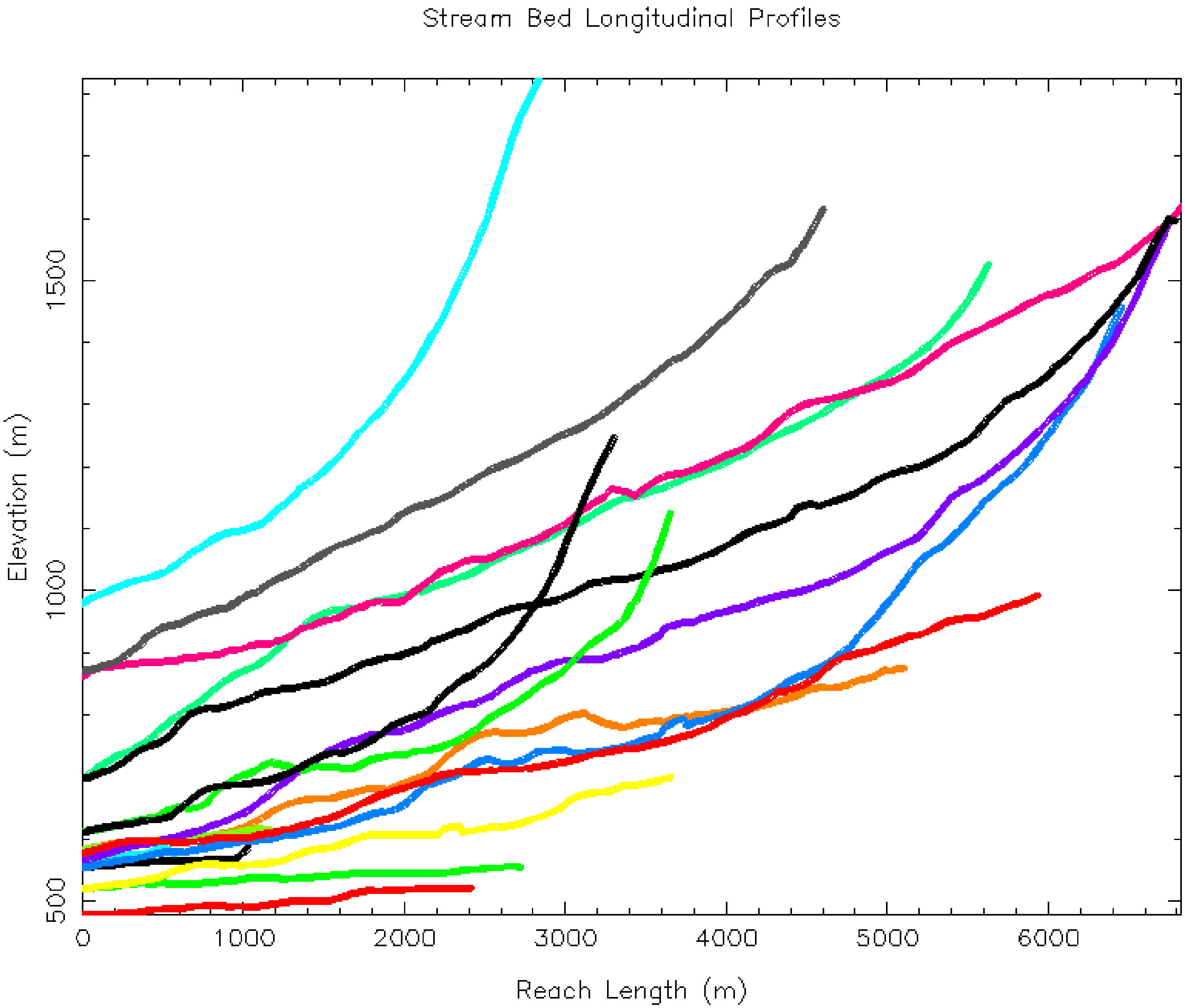
they are estimated directly from

the land use/land cover, soil, vegetation, topographic and geologic data

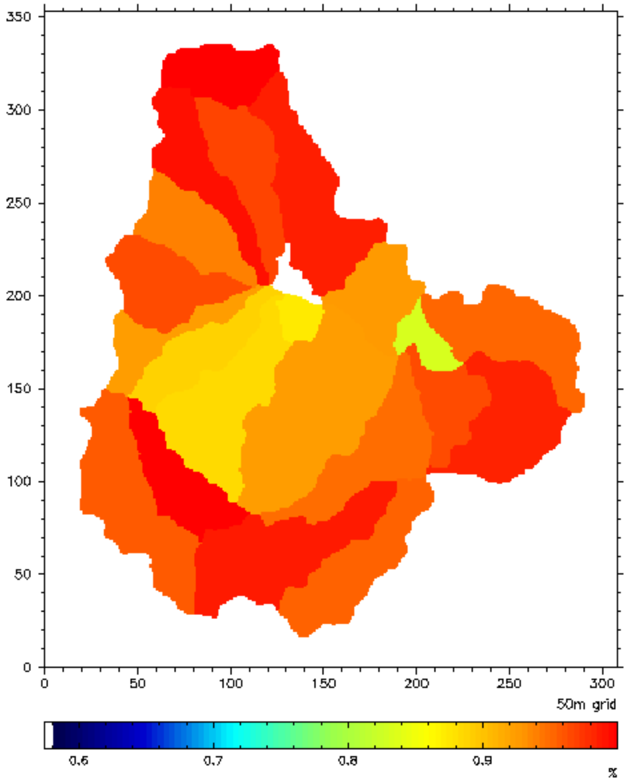
and

not from fitting the model to observed runoff hydrographs.

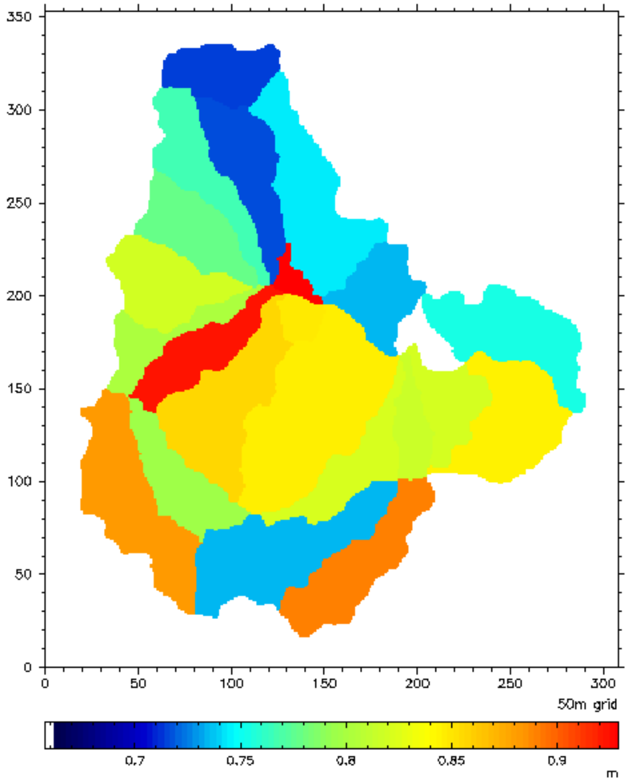
Therefore, **it is possible**
to calibrate and apply the WEHY Model at ungaged watersheds.

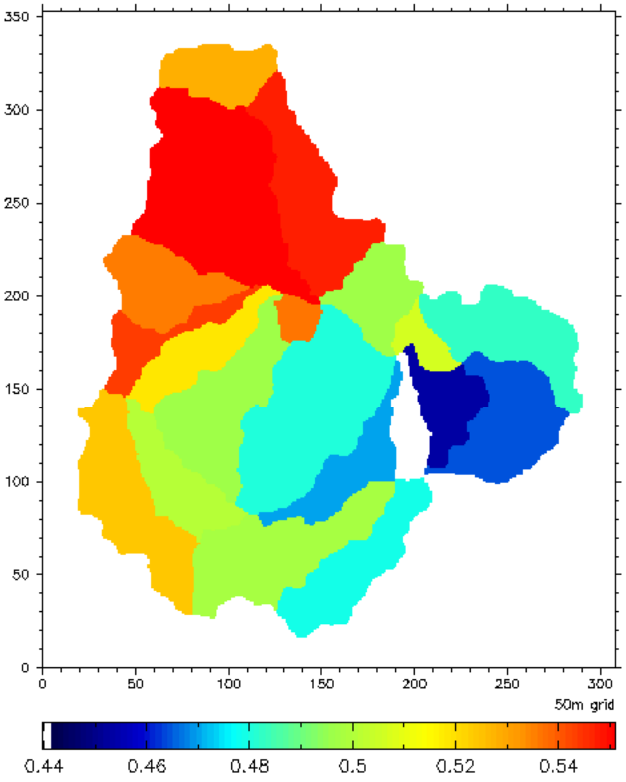

Stream Bed Longitudinal Profiles
Elevation (m)
500
1000
1500
0
1000
2000
3000
4000
5000
6000
Reach Length (m)

Forest Coverage

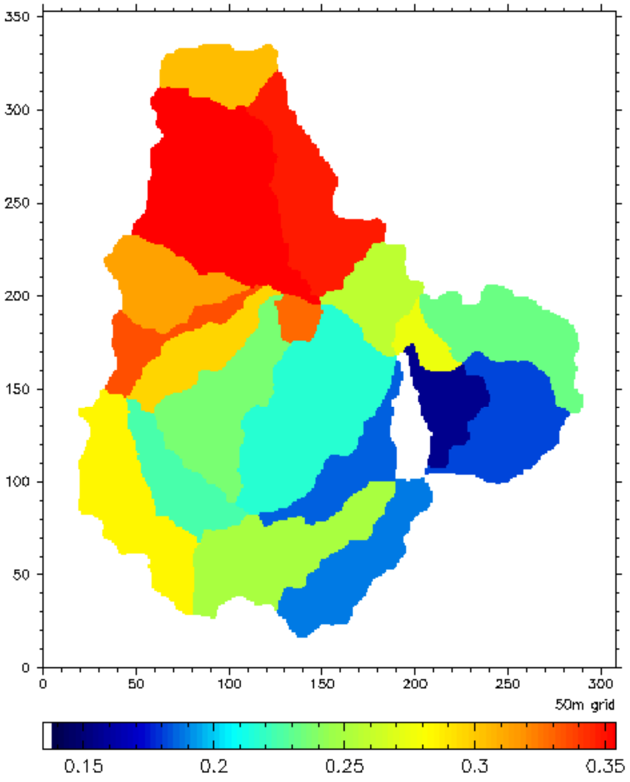


Soil Depth

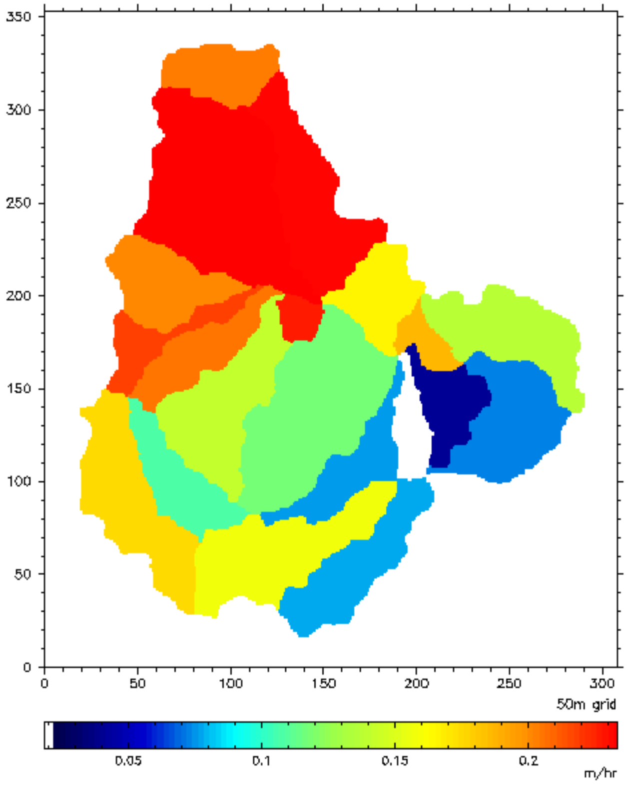




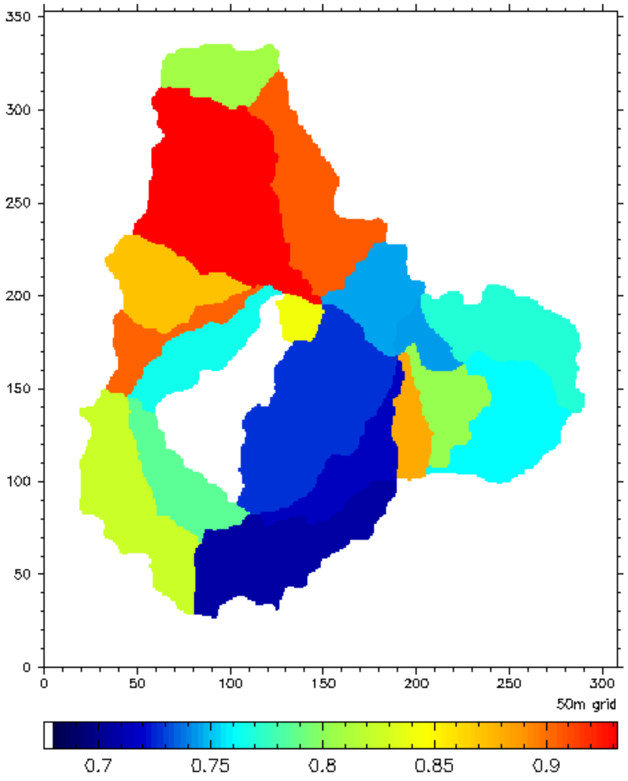
Soil Porosity



Soil Residual Water Content

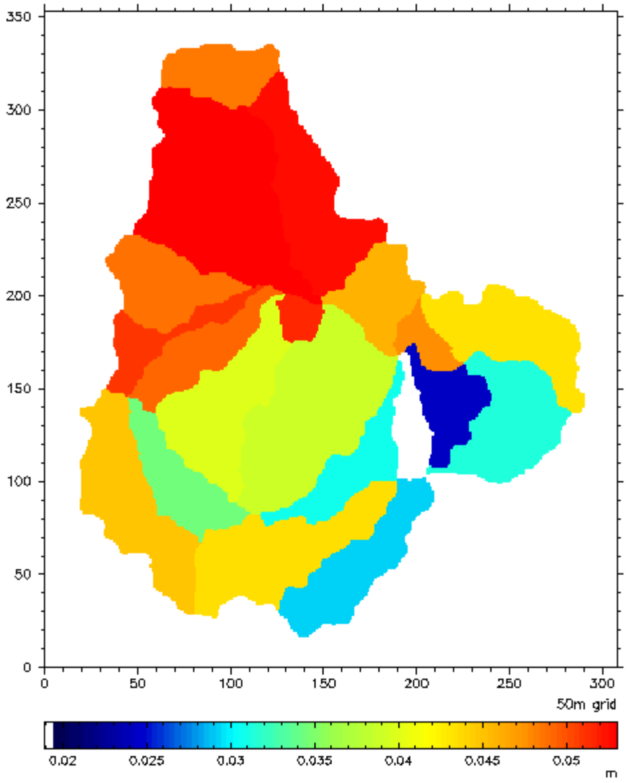


Soil Hydraulic Conductivity(median)

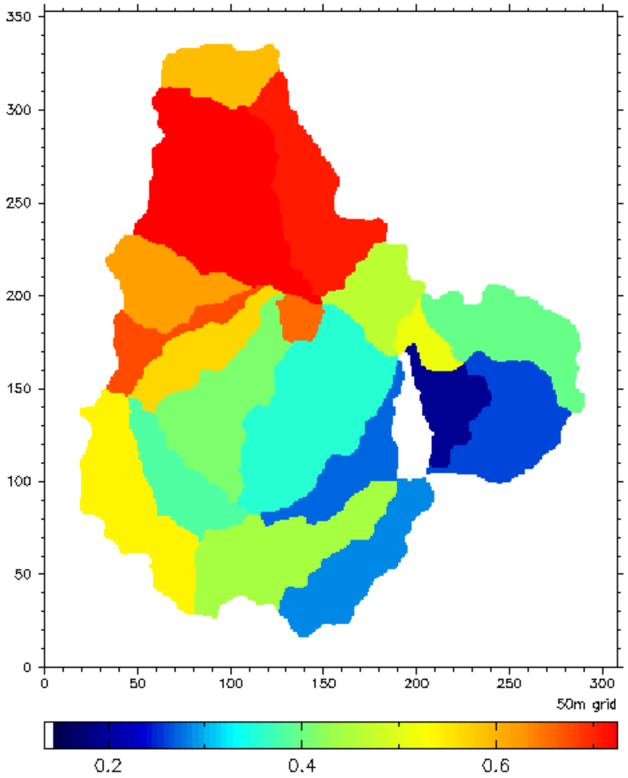


SD of Log Hydraulic Conductivity

Normalized Bubbling Pressure

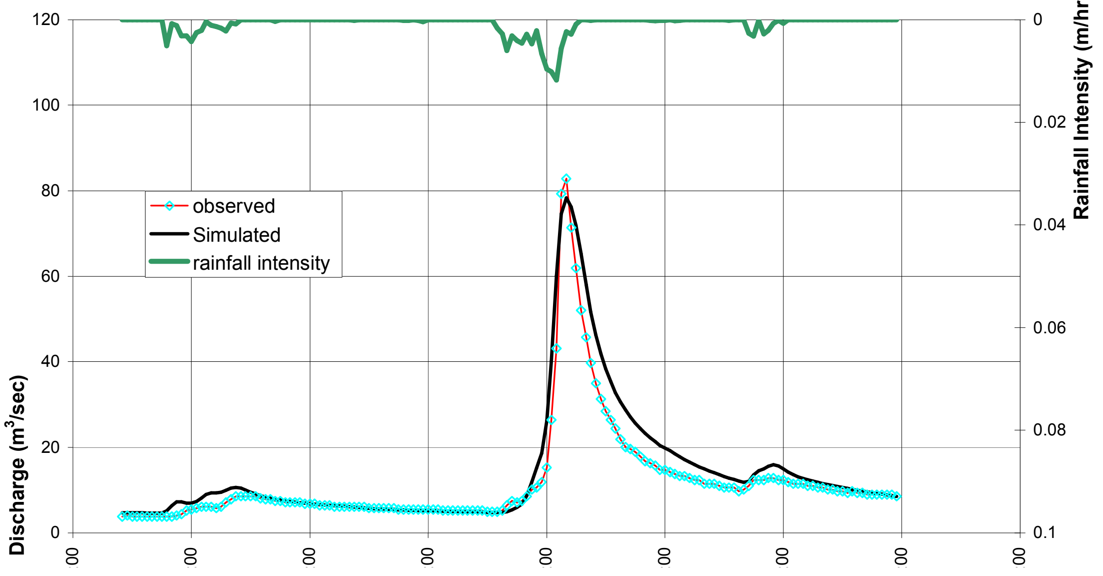


Pore Size Index



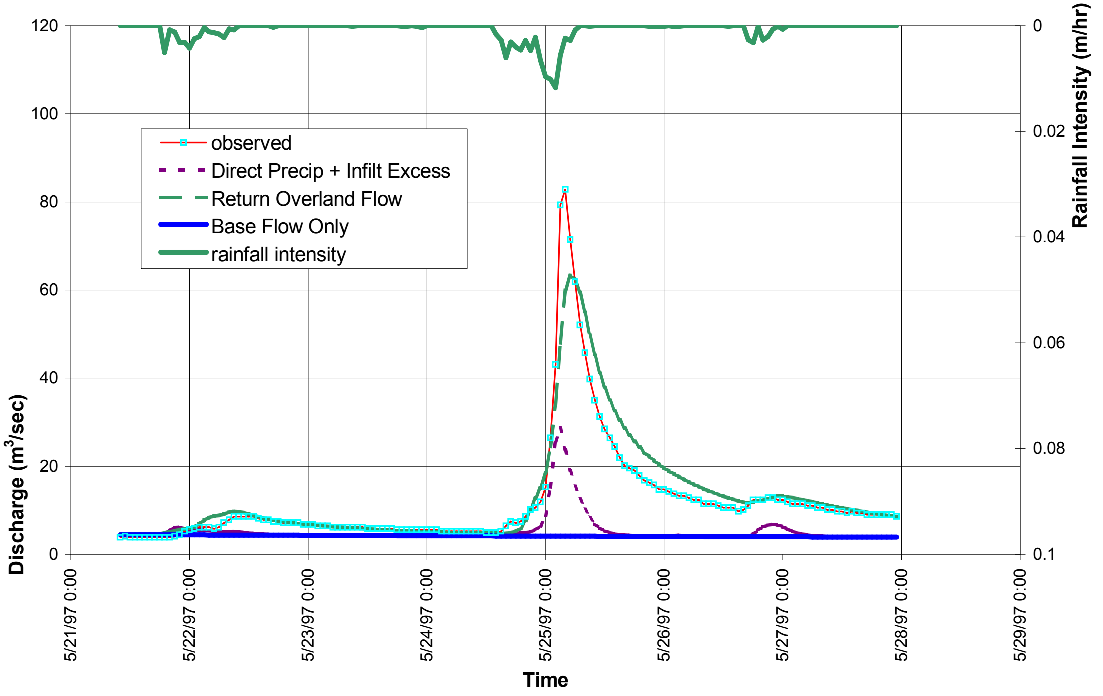
Discharge at Yuunohara

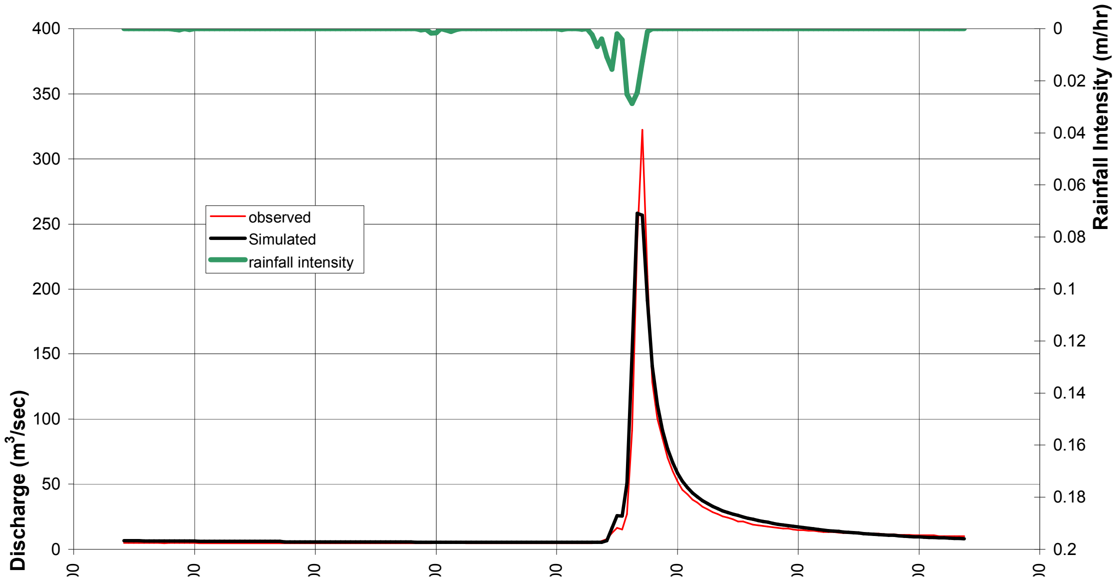
5/21/97--5/28/97



Contributions from Different Flow Processes to Discharge at Yuunohara

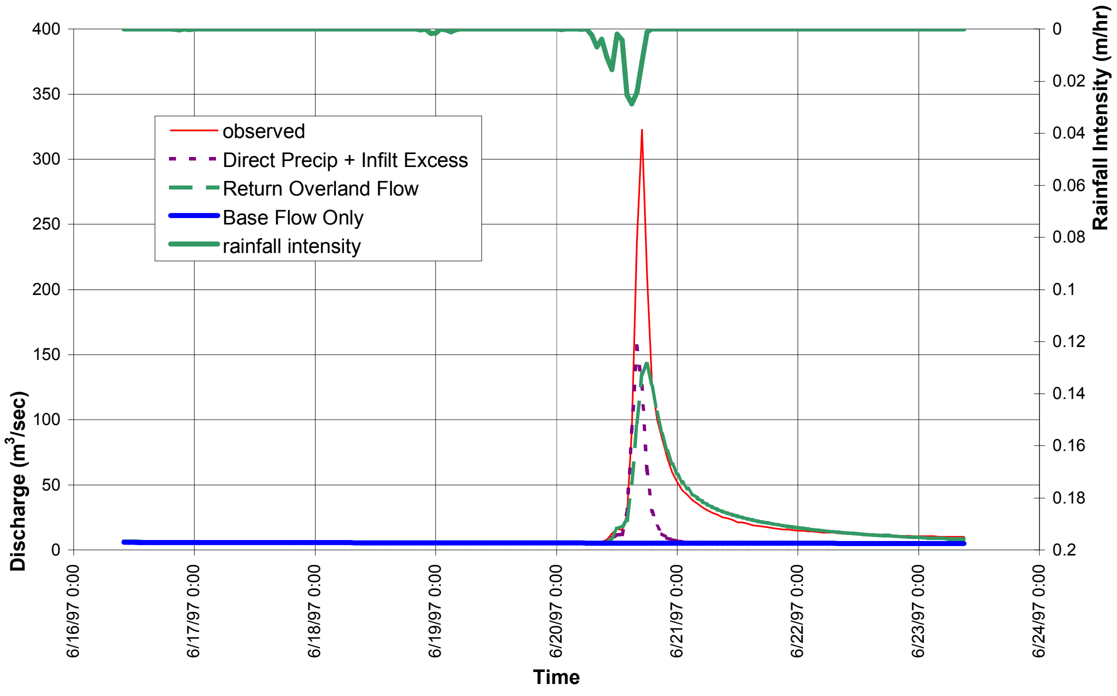
5/21/97--5/28/97





Discharge at Yuunohara

6/17/97--6/23/97

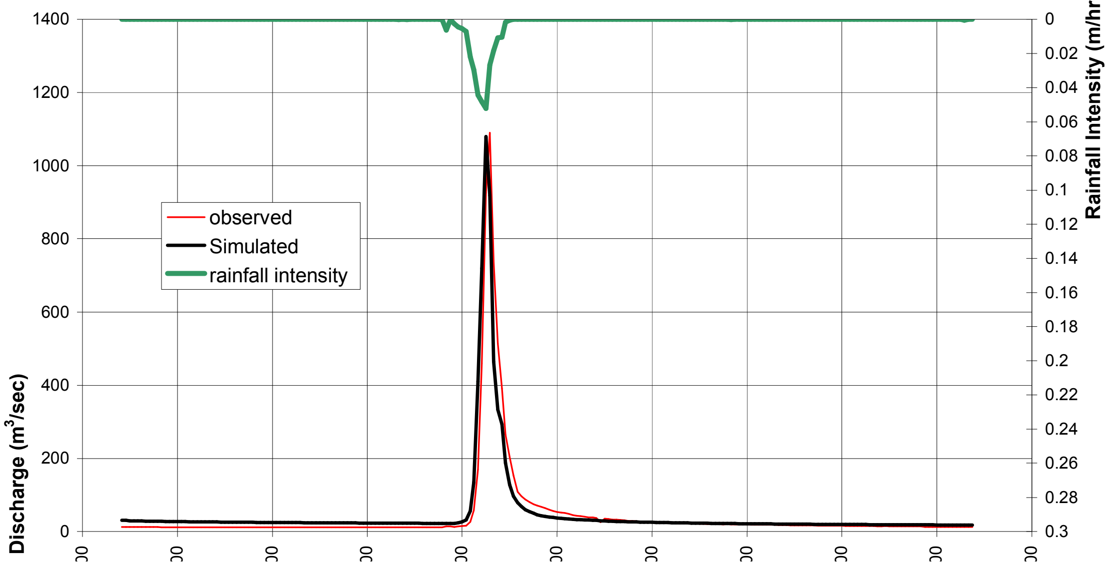


Contributions from Different Flow Processes to Discharge at Yuunohara

6/17/97--6/23/97

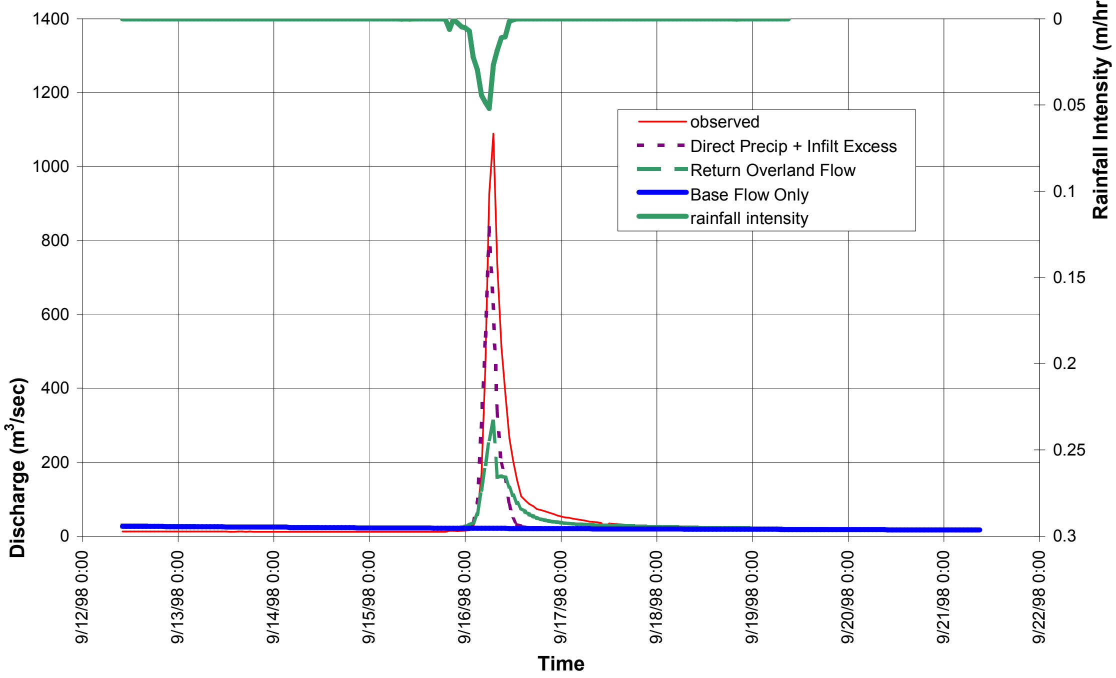
Discharge at Yuunohara

9/12/98--9/21/98



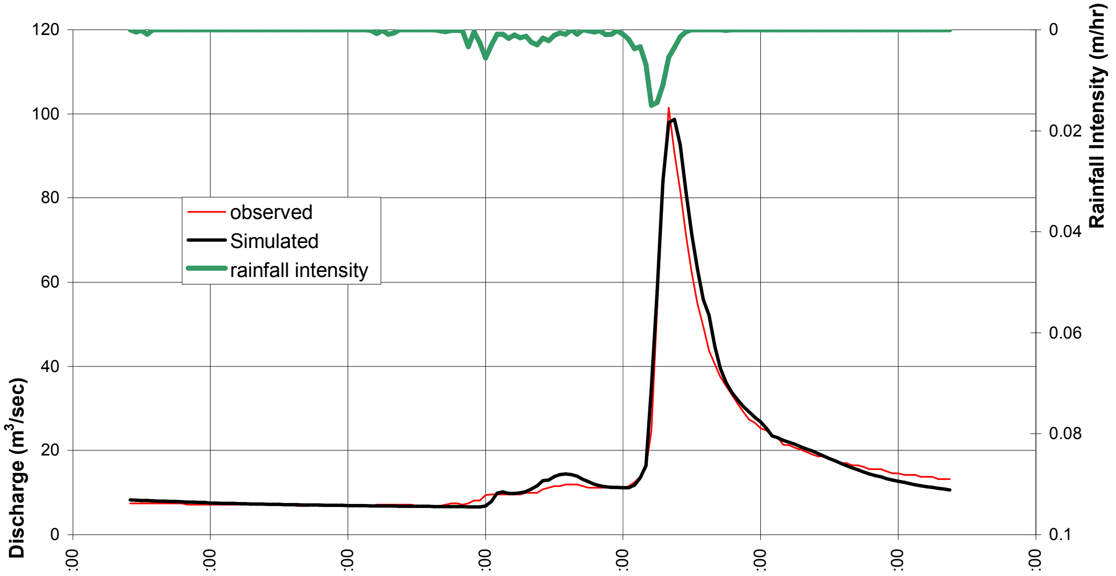
Contributions from Different Flow Processes to Discharge at Yuunohara

9/12/98--9/21/98



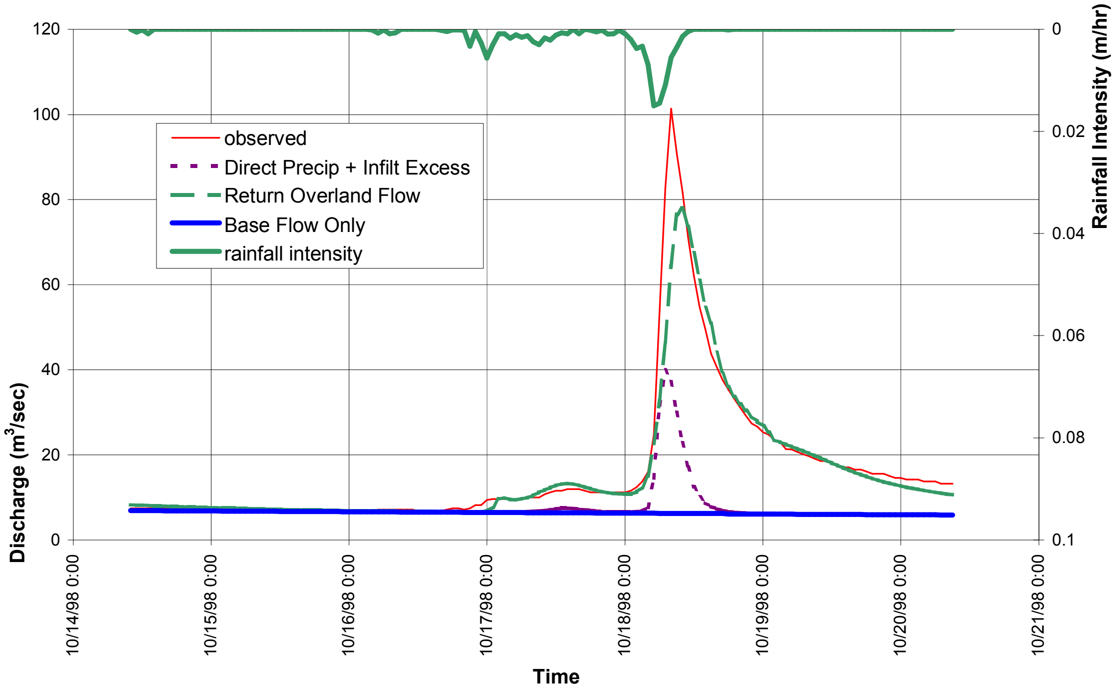
Discharge at Yuunohara

10/14/98 -- 10/21/98



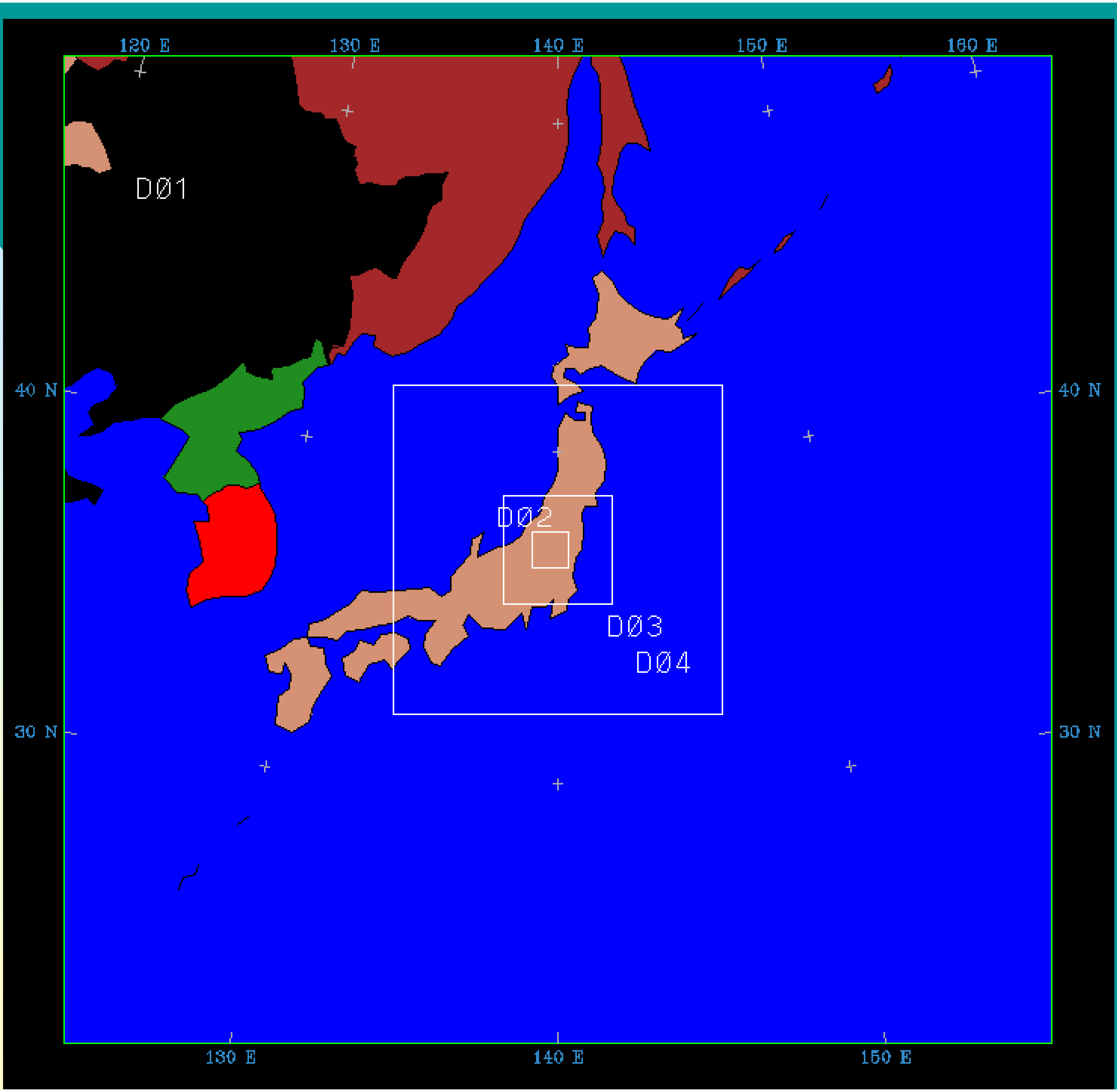
Contributions from Different Flow Processes to Discharge at Yuunohara

10/14/98 -- 10/20/98

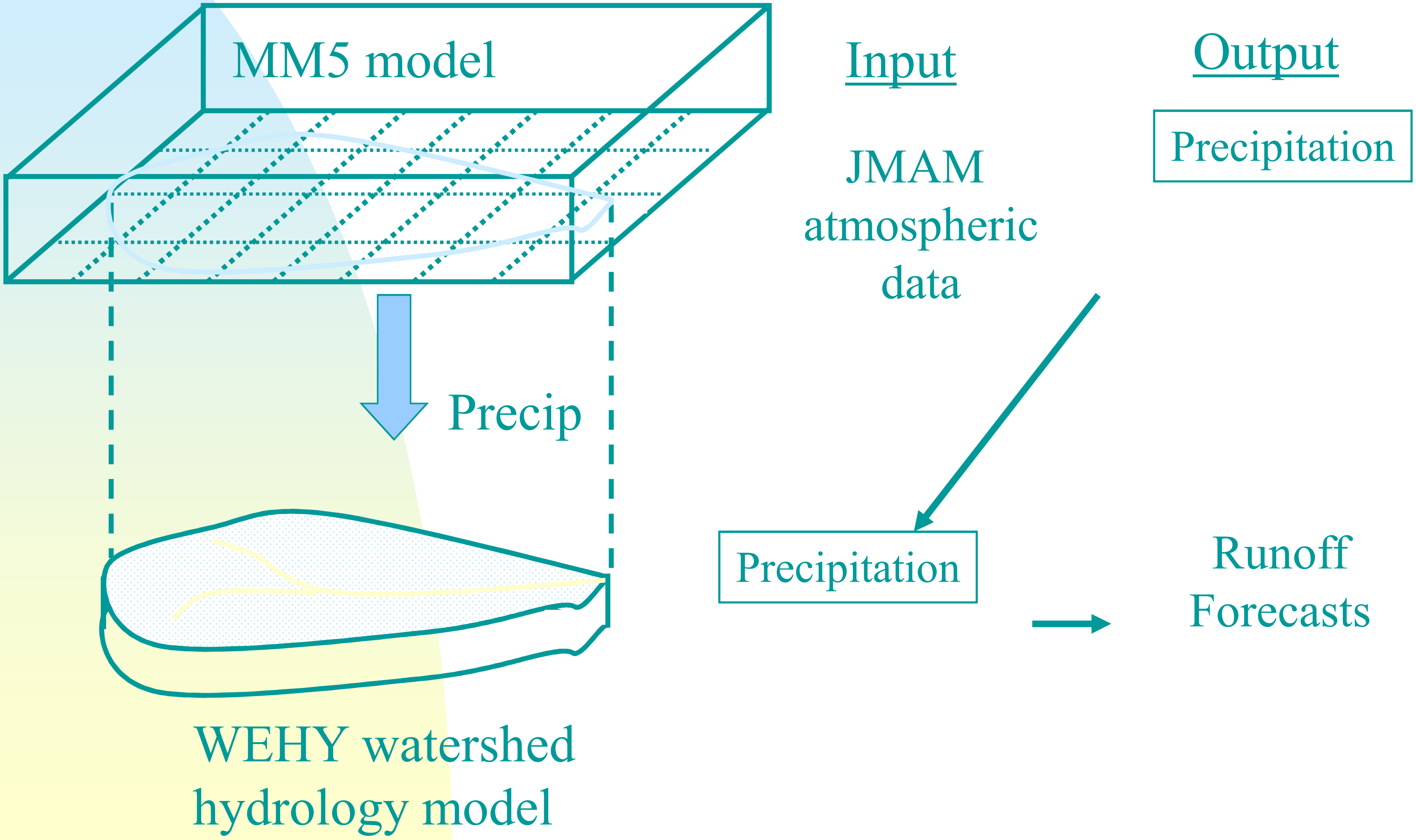


MM5 Precipitation Forecasts at Shiobara Dam Watershed

- Double-nested grid
- 34 x 34 outer grid mesh with 6 km resolution = 204km x 204km outer domain area;
- 31 x 31 inner grid mesh with 2 km resolution = 62km x 62km inner domain area;
- The initial and boundary conditions are obtained from the weather forecasts of JMAM.
- Computational time increments are 20 seconds.
- Precipitation forecasts are given for a 48-hour period with one-hour intervals.


120 E
130 E
140 E
150 E
160 E
D01
40 N
40 N
D02
D03
D04
30 N
30 N
130 E
140 E
150 E

Runoff Forecasts by WEHY Model with Atmospheric Inputs from MM5 Model



MM5 model

Precip

WEHY watershed hydrology model

Input

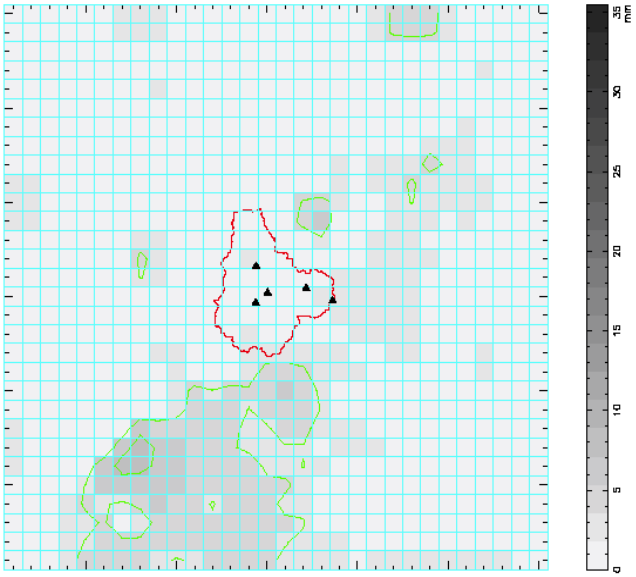
JMAM atmospheric data

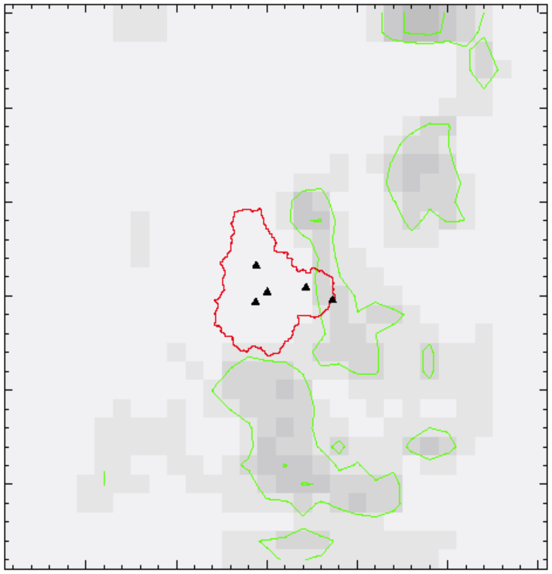
Precipitation

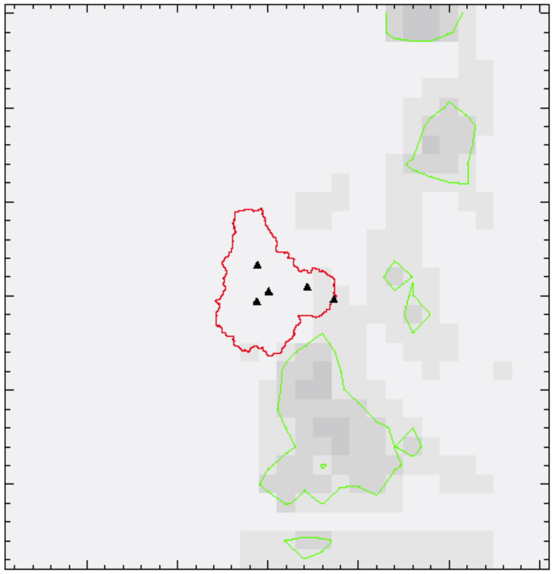
Output

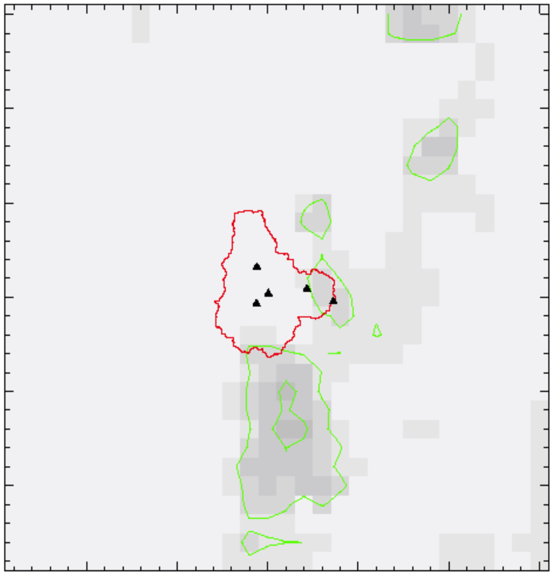
Precipitation

Runoff Forecasts


Hourly Precipitation ended at 98082613UTC (MM5 2km grid)


Hourly Precipitation ended at 98082614UTC (MM5 2km grid)


Hourly Precipitation ended at 98082615UTC (MM5 2km grid)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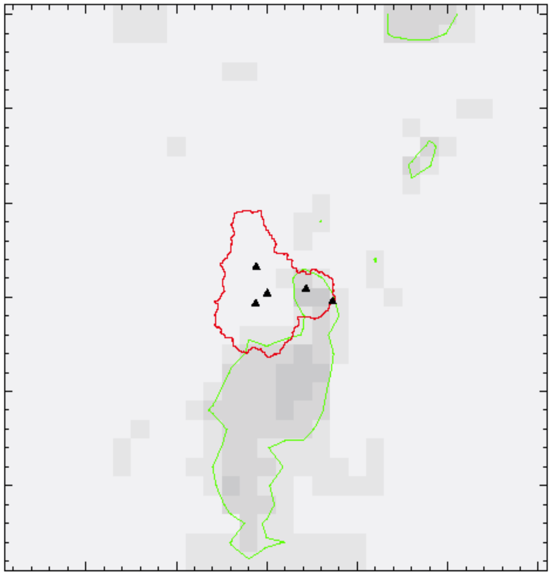
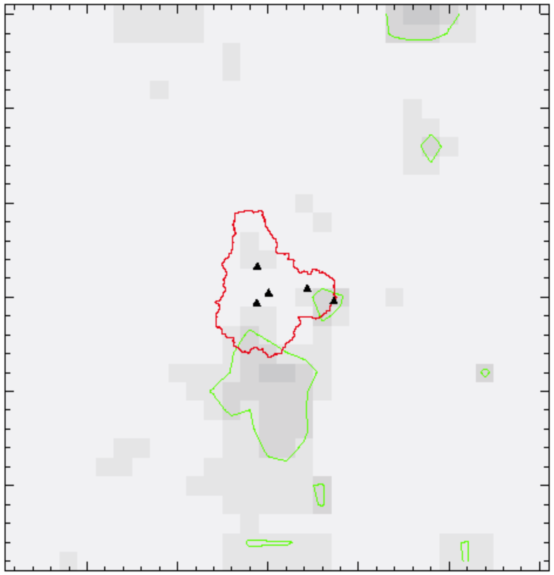
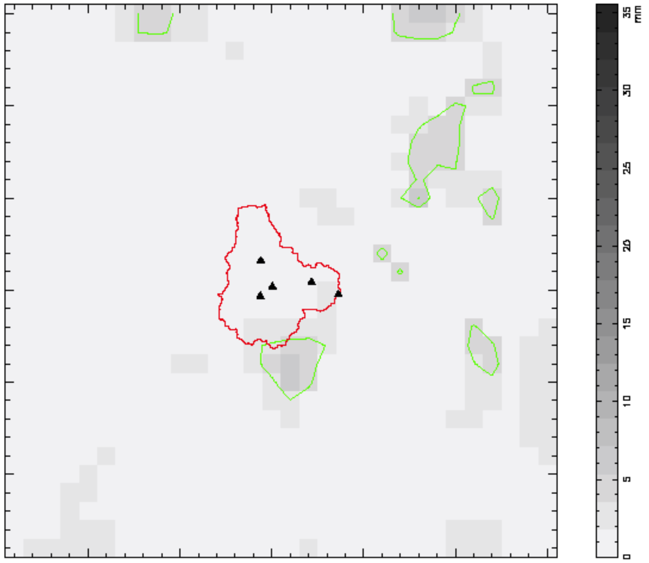
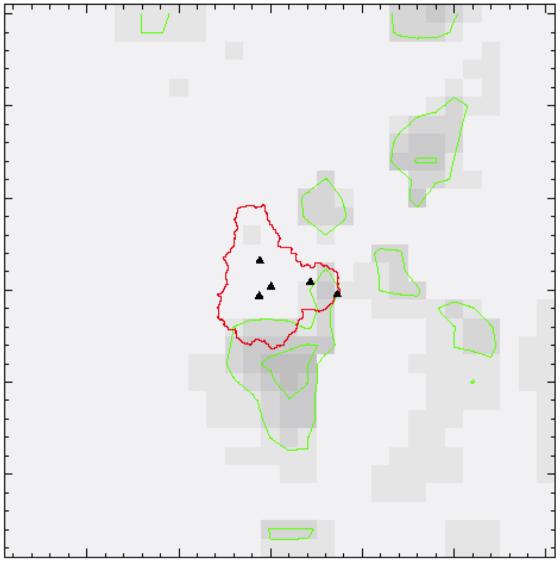
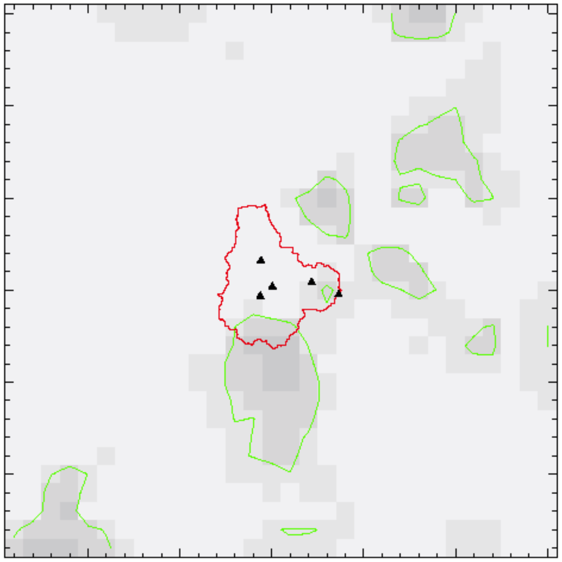

Hourly Precipitation ended at 98082617UTC (MM5 2km grid)

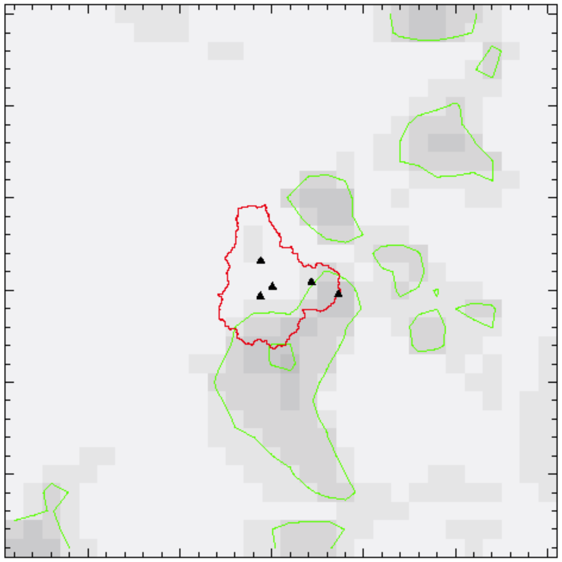

Hourly Precipitation ended at 98082618UTC (MM5 2km grid)

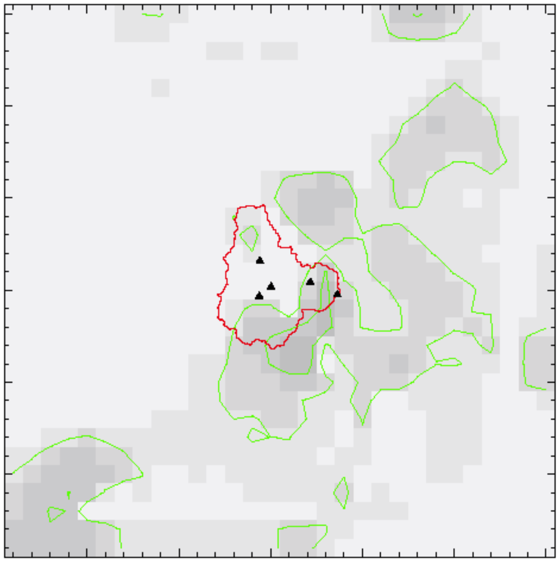
The simulation started at 1998-08-26_12:00Z.


Hourly Precipitation ended at 98082619UTC (MM5 2km grid)


Hourly Precipitation ended at 98082620UTC (MM5 2km grid)


Hourly Precipitation ended at 98082621UTC (MM5 2km grid)


Hourly Precipitation ended at 98082622UTC (MM5 2km grid)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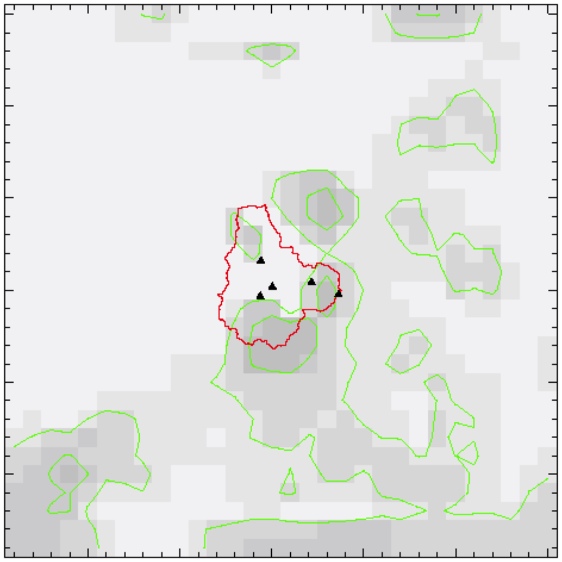
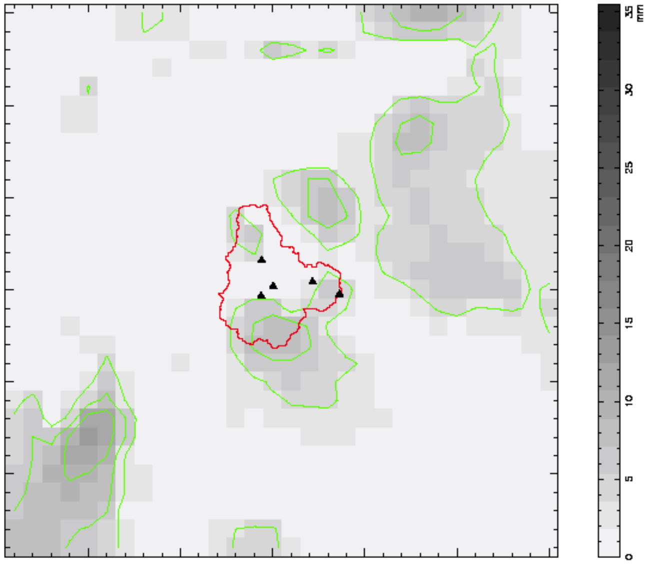
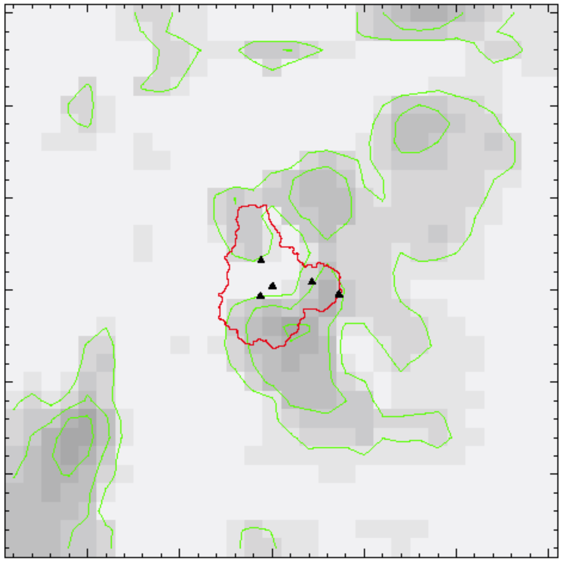

Hourly Precipitation ended at 98082624UTC (MM5 2km grid)

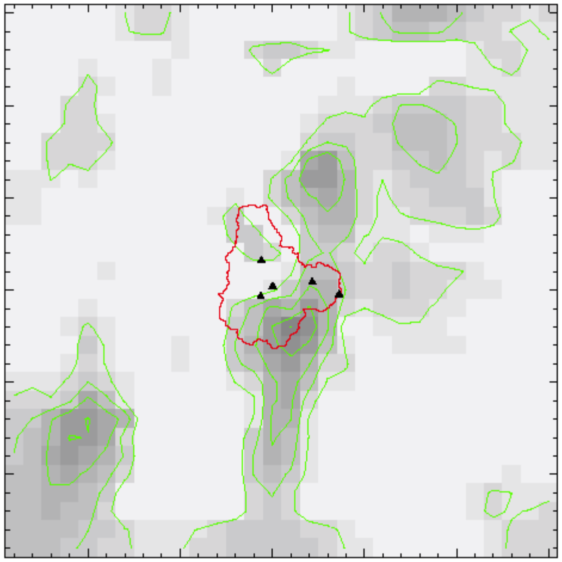
Hourly Precipitation ended at 98082701UTC (MM5 2km grid)



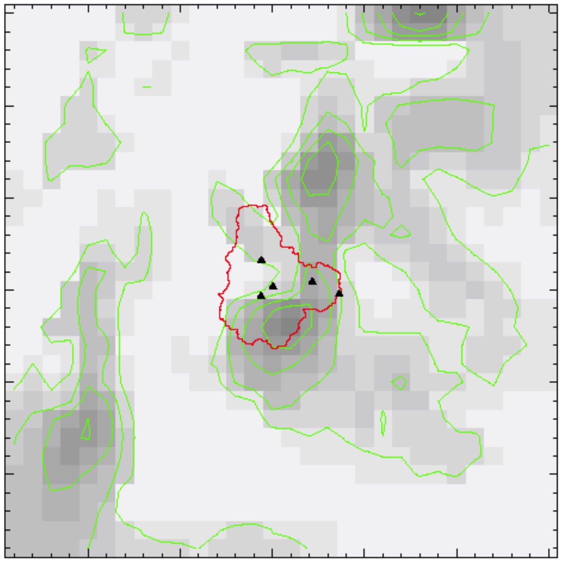
Hourly Precipitation ended at 98082702UTC (MM5 2km grid)



Hourly Precipitation ended at 98082703UTC (MM5 2km grid)



Hourly Precipitation ended at 98082704UTC (MM5 2km grid)



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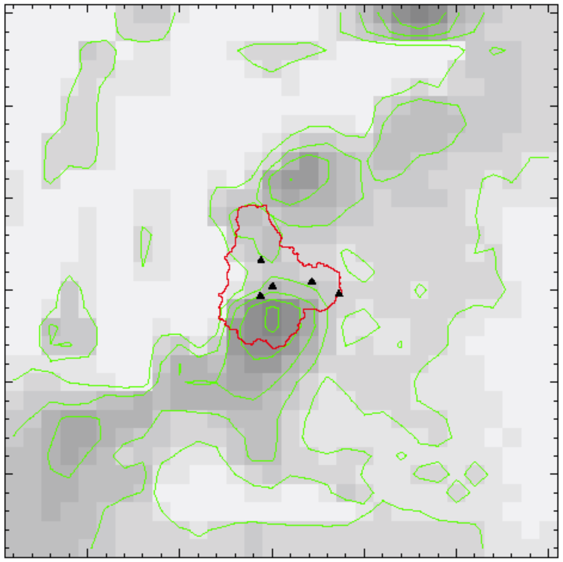
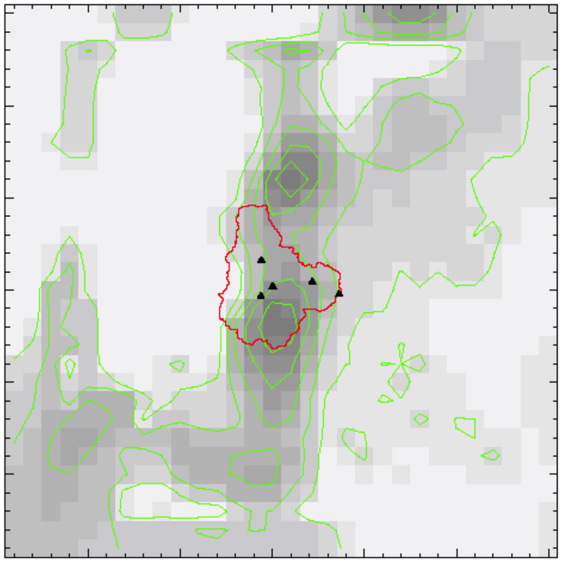
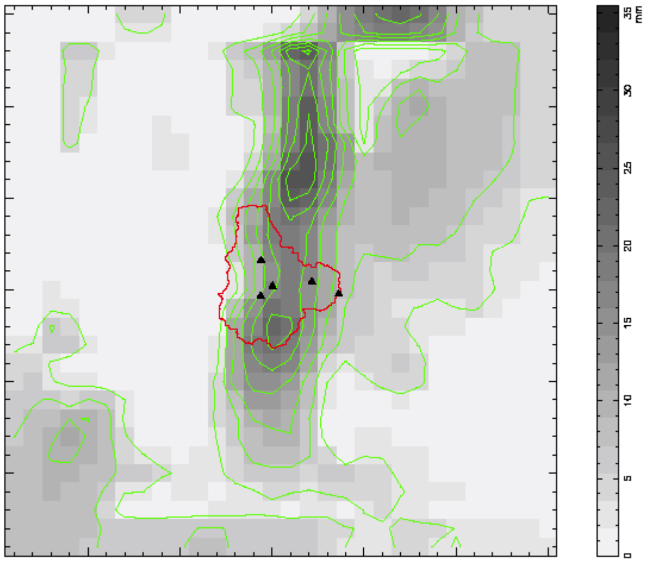


Hourly Precipitation ended at 98082706UTC (MM5 2km grid)

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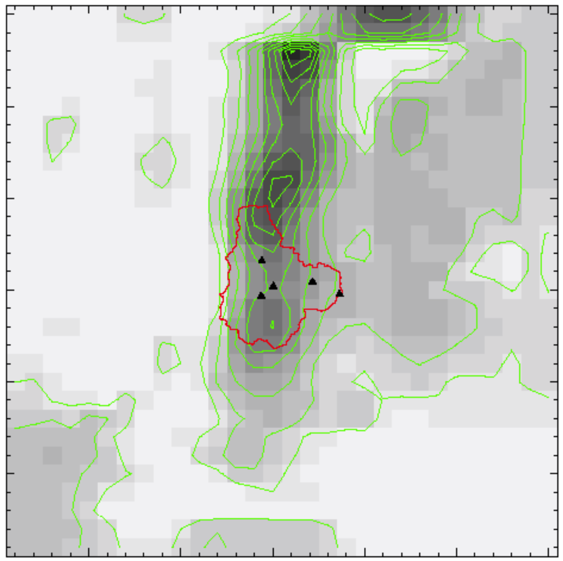
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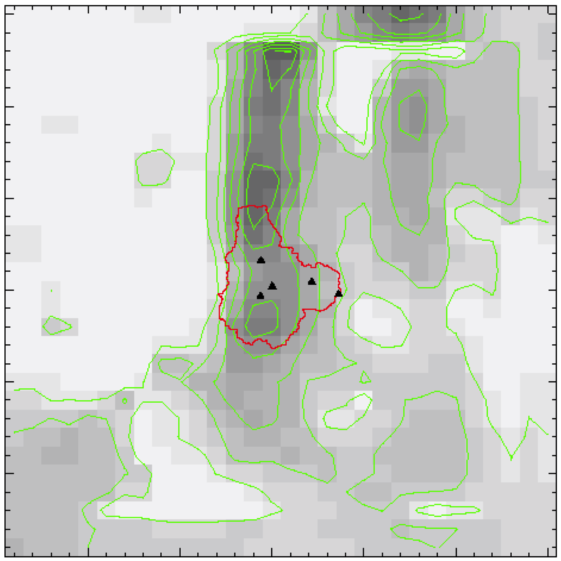
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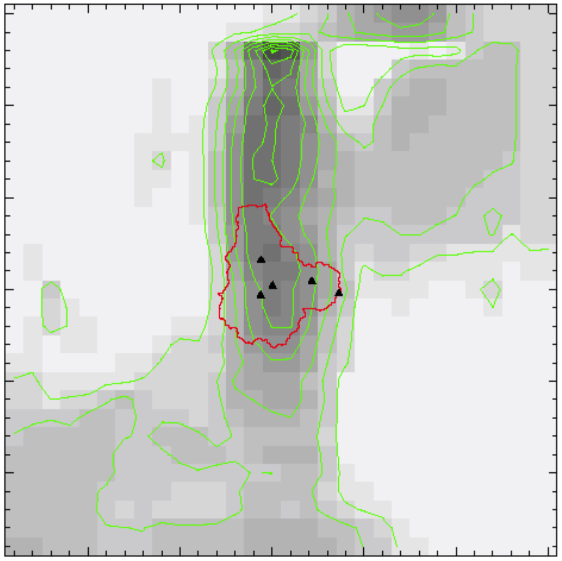
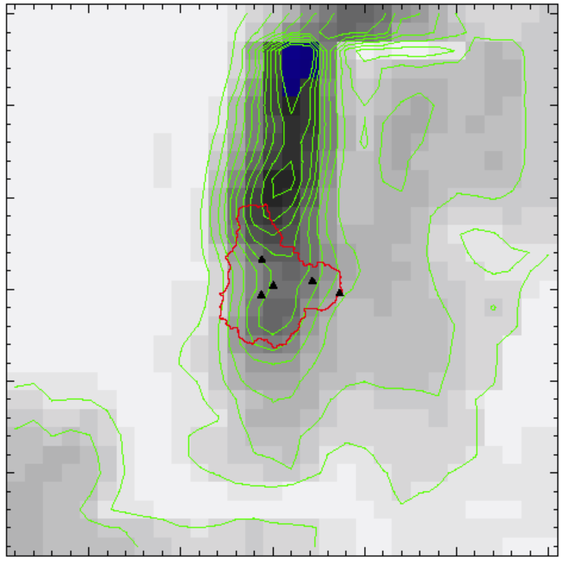

Hourly Precipitation ended at 98082710UTC (MM5 2km grid)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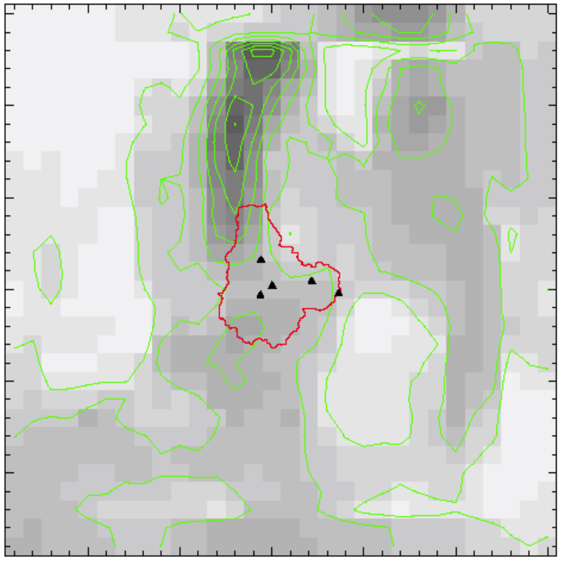
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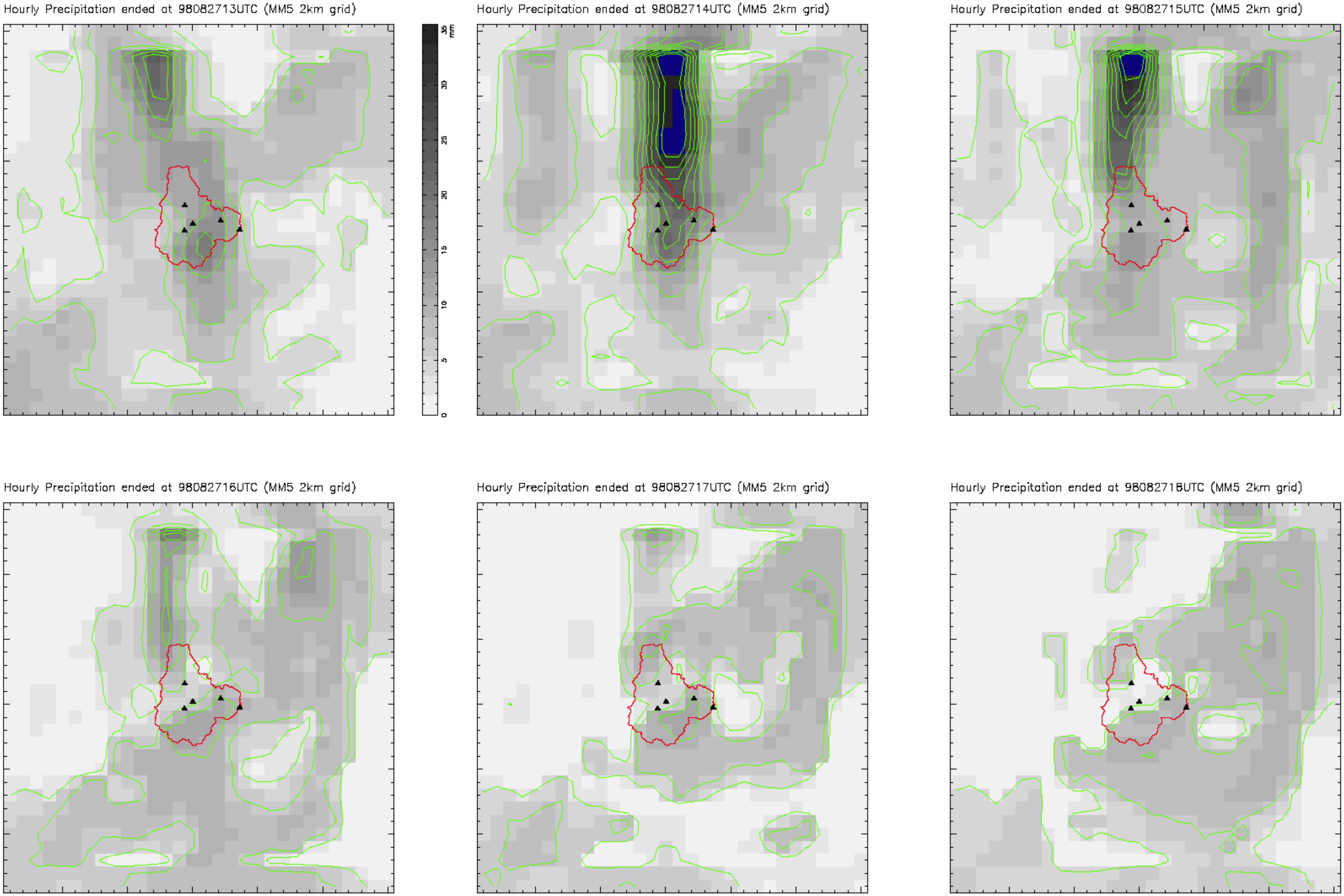

Hourly Precipitation ended at 98082713UTC (MM5 2km grid)

Hourly Precipitation ended at 98082714UTC (MM5 2km grid)

Hourly Precipitation ended at 98082715UTC (MM5 2km grid)

Hourly Precipitation ended at 98082716UTC (MM5 2km grid)

Hourly Precipitation ended at 98082717UTC (MM5 2km grid)

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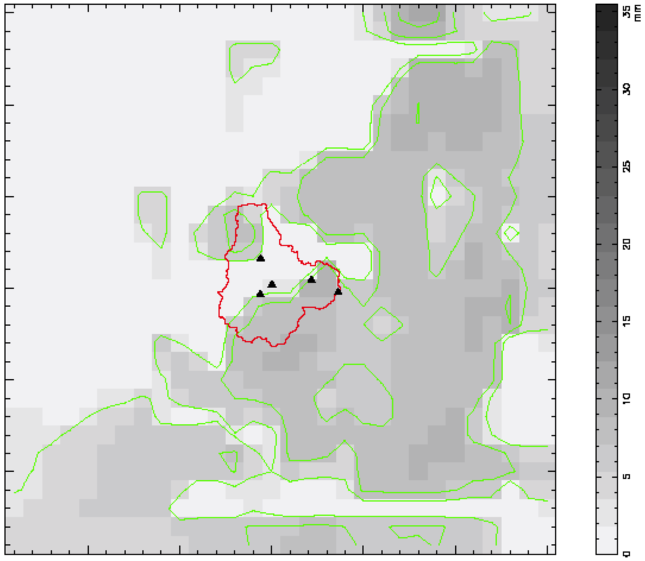
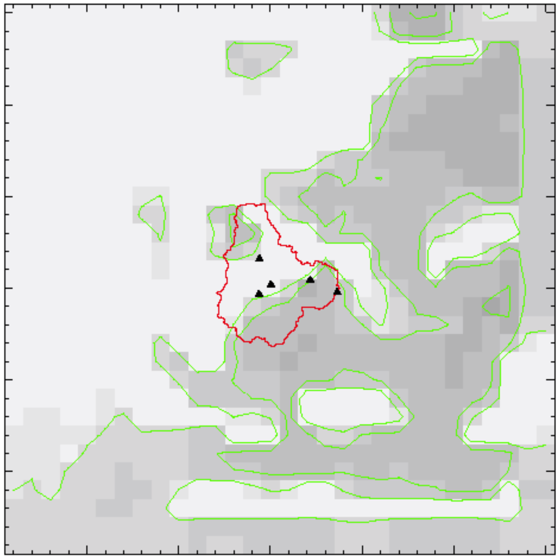
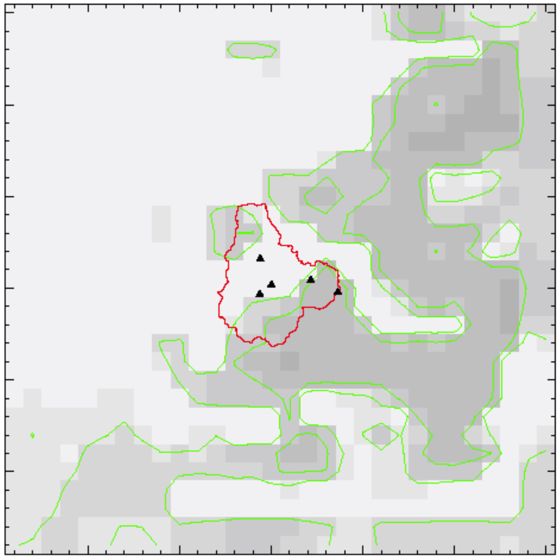


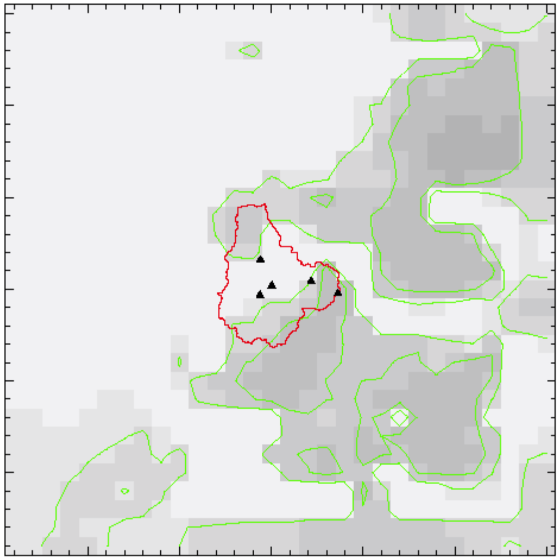
Hourly Precipitation ended at 98082720UTC (MM5 2km grid)



Hourly Precipitation ended at 98082721UTC (MM5 2km grid)



Hourly Precipitation ended at 98082722UTC (MM5 2km grid)



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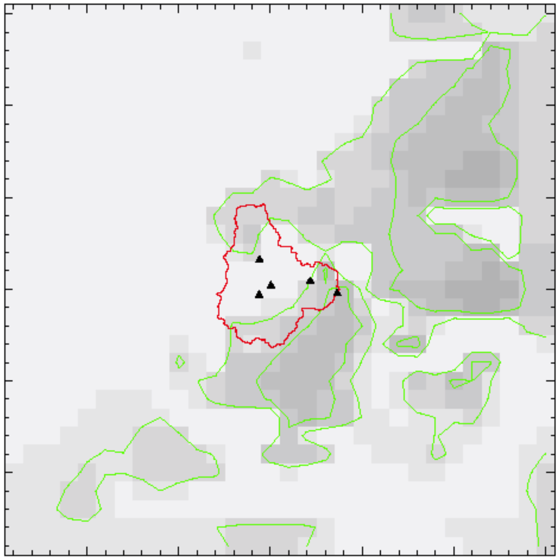
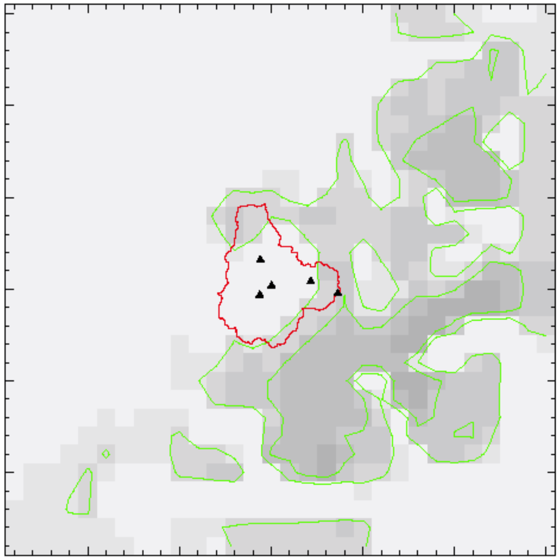
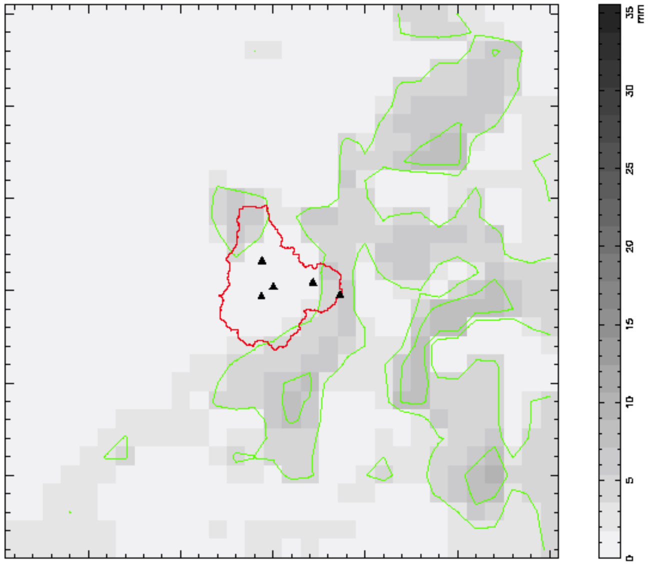


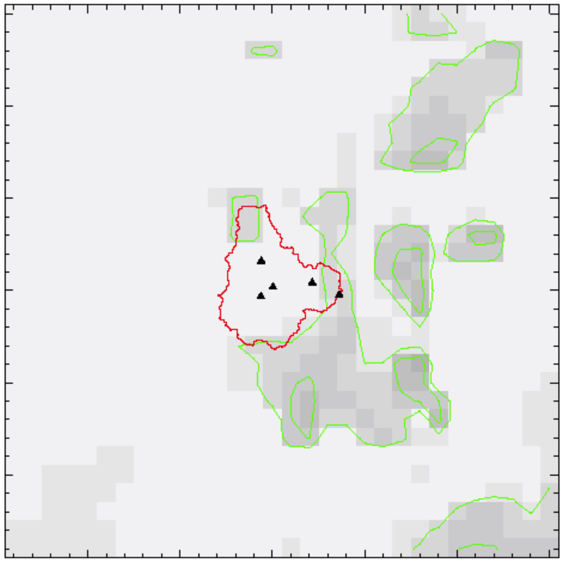
Hourly Precipitation ended at 98082800UTC (MM5 2km grid)



Hourly Precipitation ended at 98082801UTC (MM5 2km grid)



Hourly Precipitation ended at 98082802UTC (MM5 2km grid)



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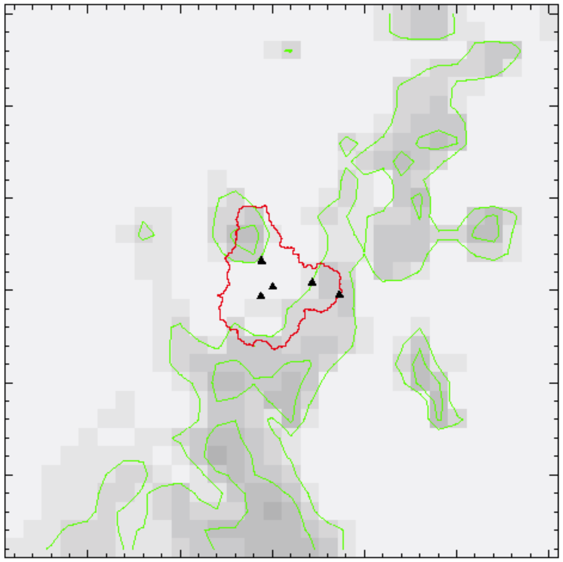

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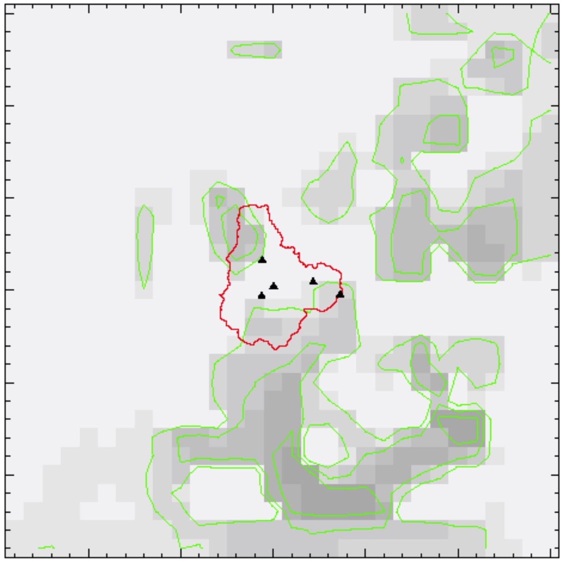

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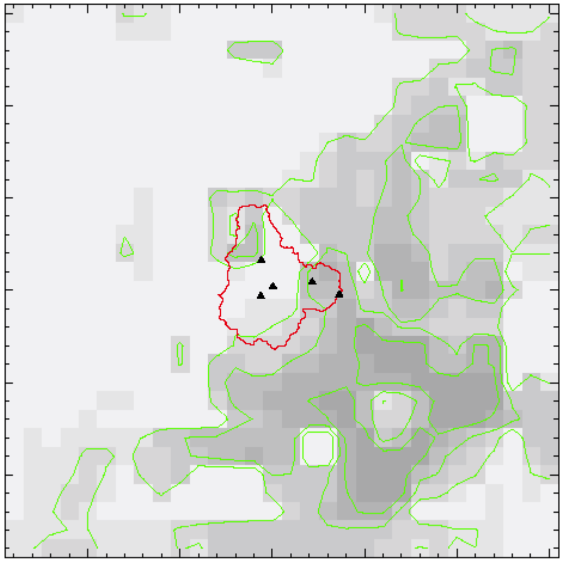

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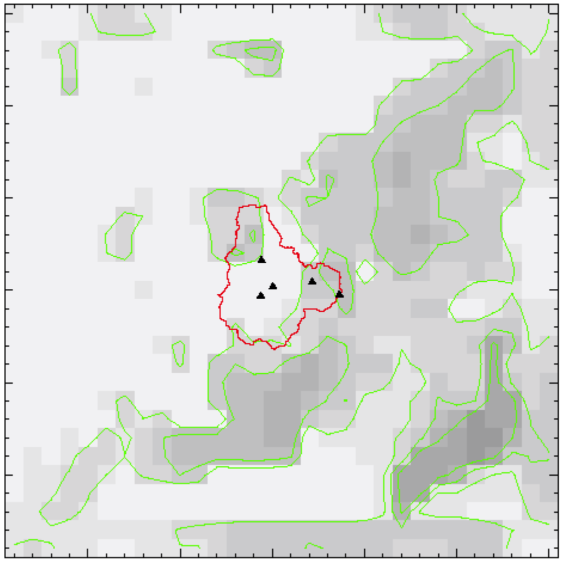

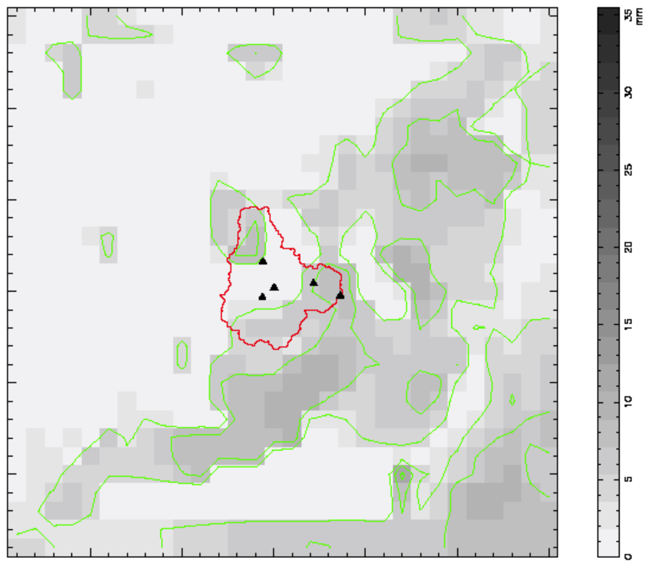

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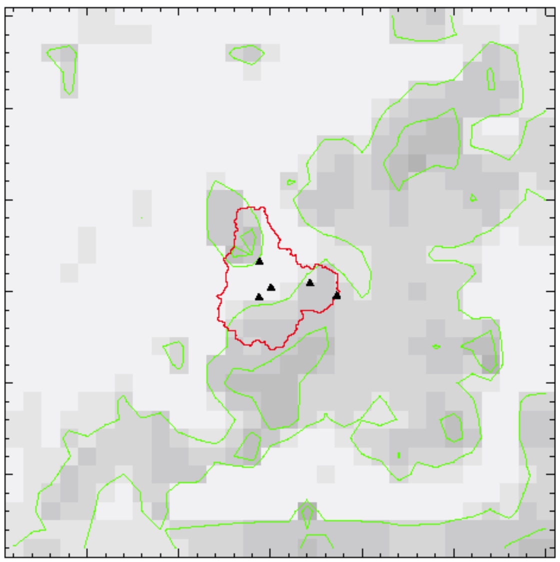
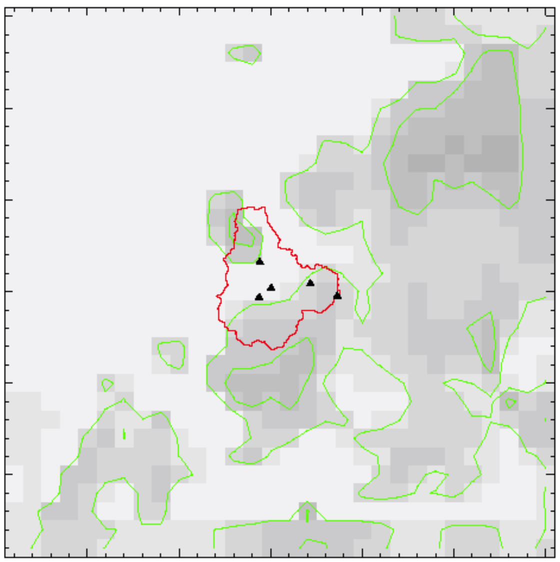
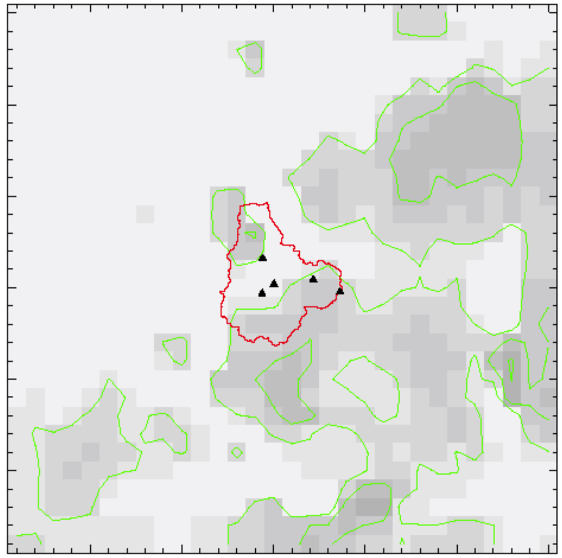


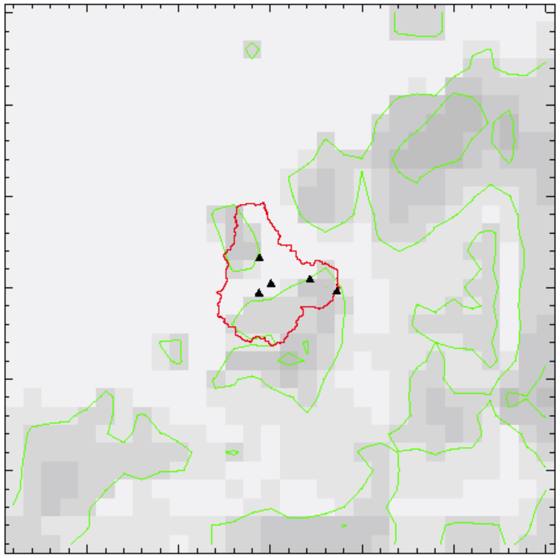
Hourly Precipitation ended at 98082808UTC (MM5 2km grid)



Hourly Precipitation ended at 98082809UTC (MM5 2km grid)



Hourly Precipitation ended at 98082810UTC (MM5 2km grid)



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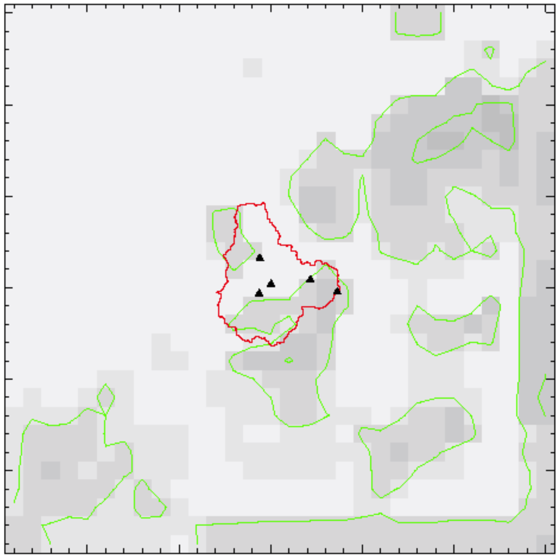
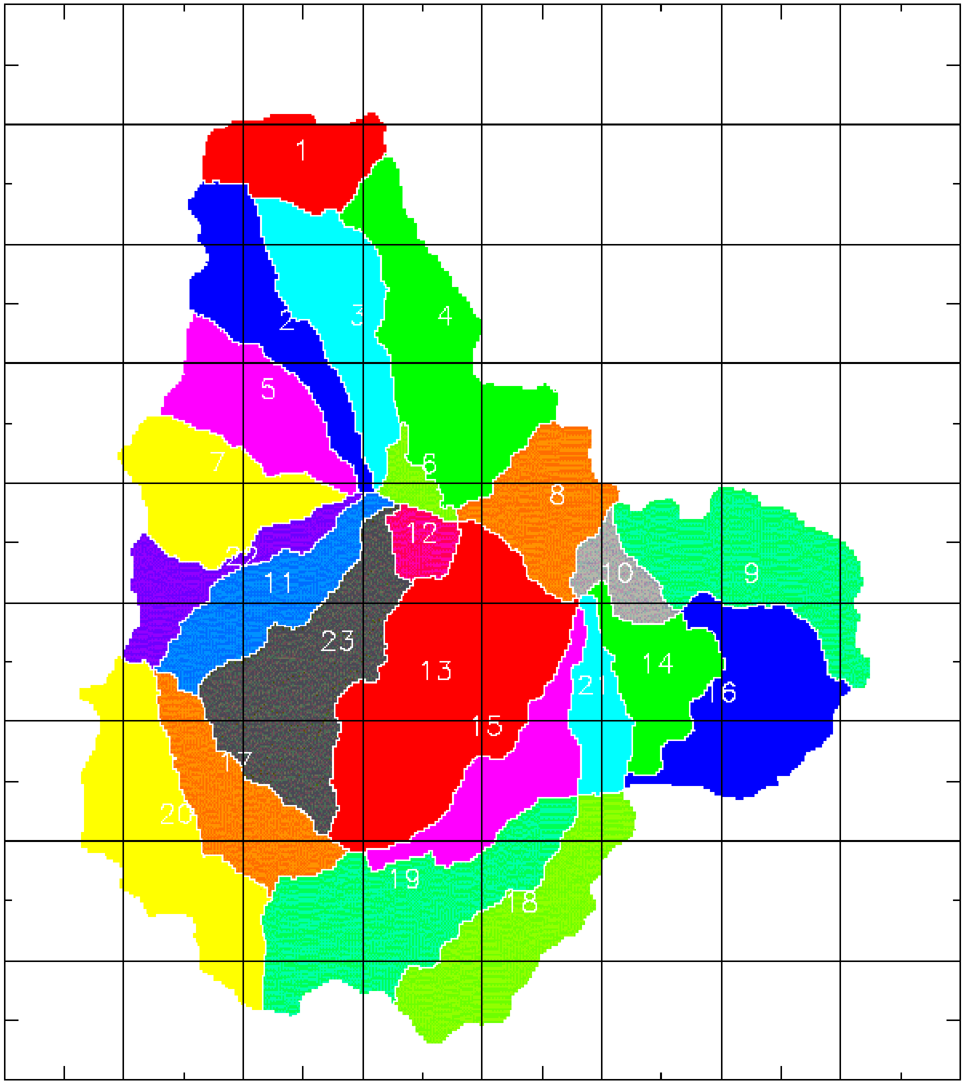
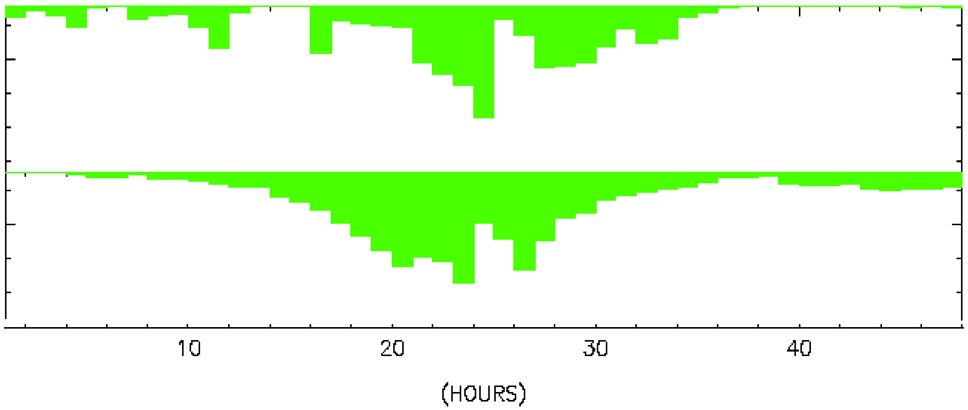


Hourly Precipitation ended at 98082812UTC (MM5 2km grid)



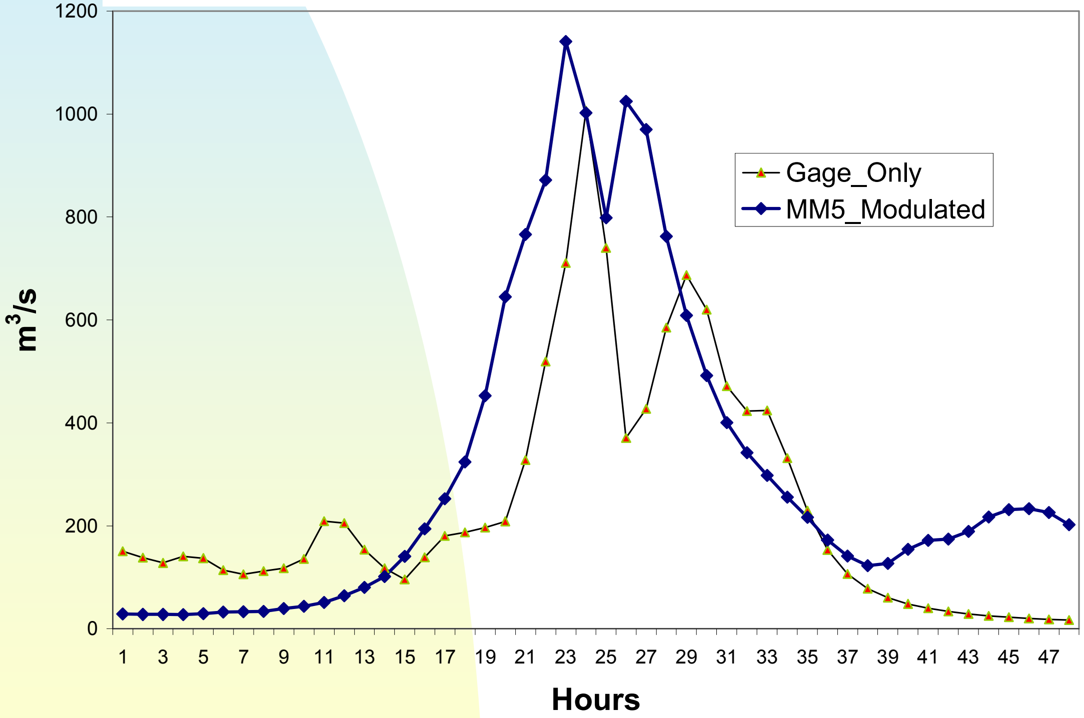
Transformation of spatially-distributed precipitation data from the MM5 grids to the computational units (MCUs) of WEHY model



Observed basin average rainfall

versus

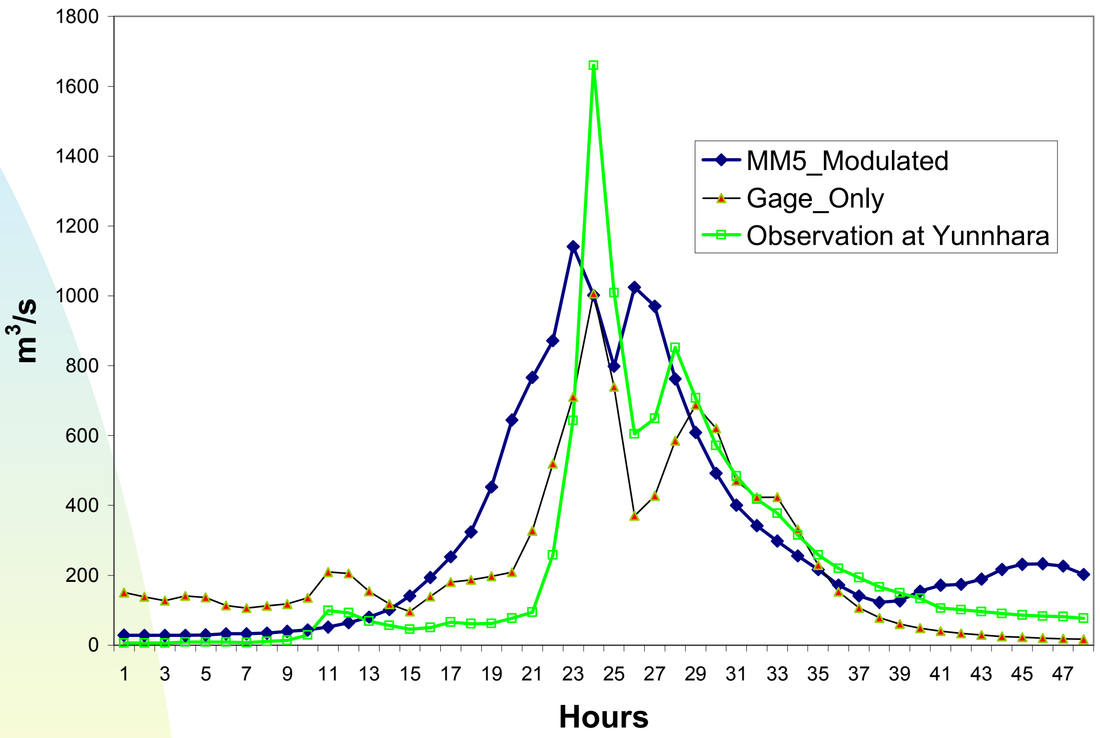
48-hour ahead predicted basin average rainfall by MM5



Comparison of runoff forecasts based upon raingage observations,

versus

runoff forecasts based upon MM5 predicted rainfall



Comparison of observed runoff at Yuunohara station versus

runoff forecasts based upon raingage observations and

runoff forecasts based upon MM5 rainfall forecasts

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CONCLUSIONS:

1. The runoff forecasts by a hydrologic model, based upon 48-hour-ahead precipitation forecasts by a fine resolution numerical atmospheric model, such as MM5, provides significant lead time for flood management decisions.

2. Technology is available for downscaling the routine weather forecasts of any global/continental scale atmosperic model (such as ECMRWF) at 6-hour time intervals and 40km spatial resolution over continental U.S.A. to any desired watershed at 1-hour time intervals and 2km spatial resolution by means of a sequence of nested MM5 models, coupled with a spatially-distributed hydrology model (such as WEHY Model).

3. Such a technology was applied successfully over California and Japanese watersheds.