INTERNATIONAL SOIL AND WATER ASSESSMENT TOOL CONFERENCE

SWAT 2018

VUB VRIJE UNIVERSITEIT BRUSSEL

SESSION – H2: Hydrology

Integration of Automated SWAT and HEC-RAS Models in Real Time Data for Flood Forcasting in Vu Gia – Thu Bon River Basin, Vietnam

Nguyen Kim Loi, Nguyen Duy Liem, Vo Ngoc Quynh Tram, Le Hoang Tu, Nguyen Thi Hong, Cao Duy Truong, Tran Thong Nhat
Nong Lam University- HCM City, Vietnam
Email: ngkloi@hcmuaf.edu.vn

Jaehak Jeong
Texas A&M University

19-21 September / Brussels, Belgium

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General information

General information

- Project's name: **Decision Support System for Real-time Flood Warning in Vu Gia- Thu Bon river basin, Quang Nam province** *(in Vietnamese: Hệ hỗ trợ trực tuyến cảnh báo lũ cho lưu vực sông Vu Gia- Thu Bồn, tỉnh Quảng Nam)*
- Code: **KC.01.24/11-15** (under The National Program for Key Science & Technology "*Research, Application and Development of Information and Communication Technologies*")
- Project Leader: **Prof. Nguyen Kim Loi** *(Nong Lam University- Ho Chi Minh City)*
- Project funding: **Ministry of Science and Technology**
- Duration: **Feb 2011- Dec 2015**
- Study area: **Vu Gia- Thu Bon river basin, Quang Nam province**

General information

- Project office
  - ✓ Room RD405A, Rang Dong Building
  - ✓ Nong Lam University- Ho Chi Minh City

General information

- Equipment
  - ✓ Laptops
  - ✓ Handheld GPS
  - ✓ Servers
  - ✓ Softwares: ArcGIS Desktop, VizSWAT

International Expert Team


Prof. Raghavan Srinivasan
SWAT Expert, *Texas A&M University, USA*


Assoc. Prof. Jaehak Jeong
SWAT Expert, *Texas A&M University, USA*


Mr. Christopher R. Goodell
HEC-RAS Expert, *WEST Consultants, Inc., USA*

GIS – RS Team


Dr. Trần Thống Nhất[3]


Dr. Nguyễn Văn Trai[1]


Ms. Nguyễn Thị Huyền[1]


Mr. Lê Hoàng Tú[1]


Ms. Võ Ngọc Quỳnh Trâm[1]


Mr. Dương Ngọc Minh[1]


Mr. Nguyễn Lê Tấn Đạt[1]


Ms. Trần Thị Thi Thi[1]

Project Leader

Nguyễn Kim Lợi[1]

Modeling Team


Dr. Nguyễn Thị Hồng[2]


Mr. Nguyễn Duy Liêm[1]


Ms. Nguyễn Đỗ Ngọc Uyên[1]


Ms. Phan Thị Thanh Trúc[1]

Information Technology Team


Dr. Cao Duy Trường[3]


Mr. Lê Văn Phận[1]

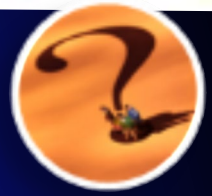

Ms. Trần Lê Như Quỳnh[1]


Ms. Trần Duy Long[4]


Mr. Đặng Xuân Tiến[1]

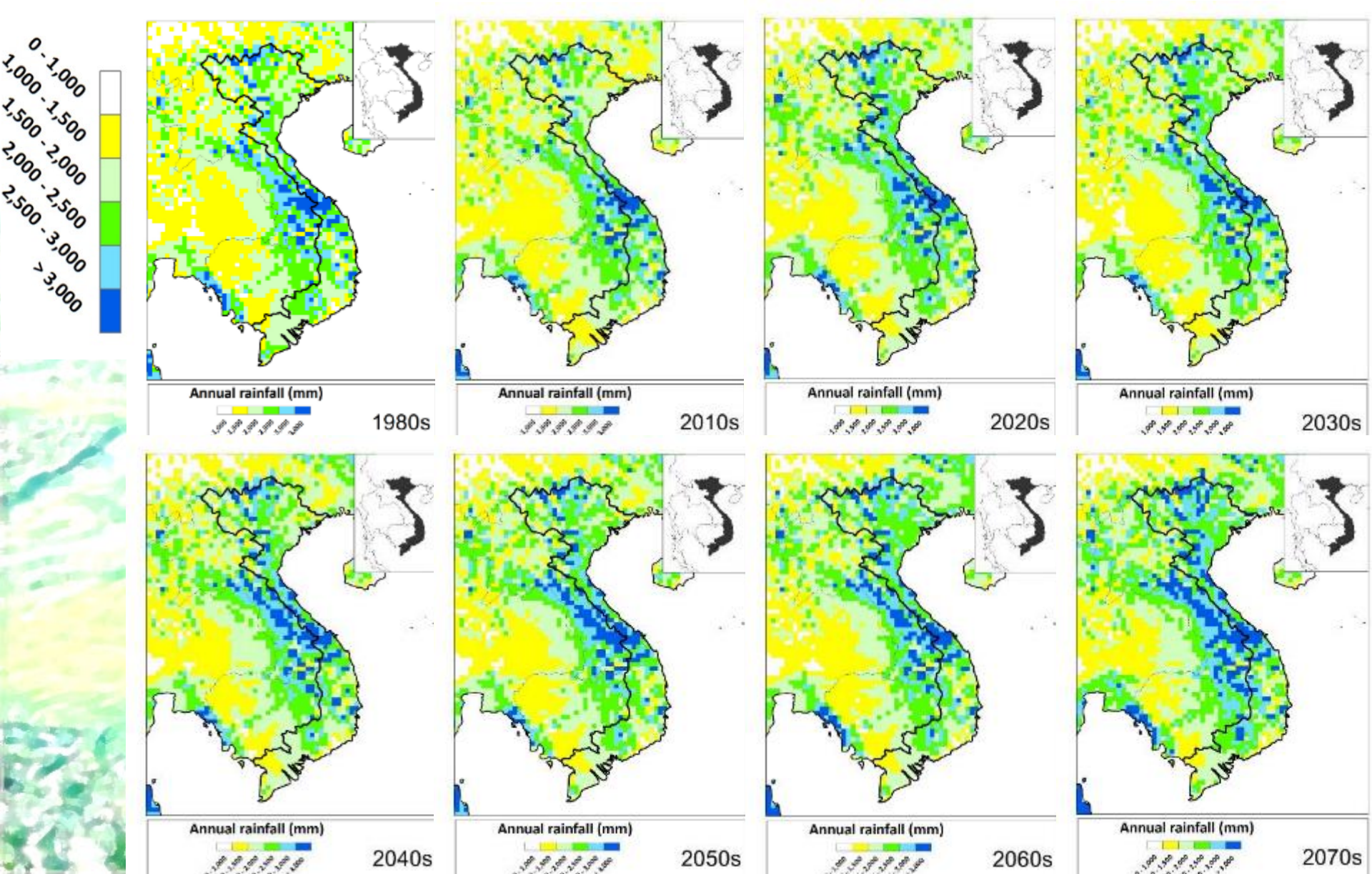
(1) Nong Lam University *(2) VNU_Ha Noi*
(3) University of Natural Resources and Environment *(4) DONRE Ho Chi Minh city*

Justifications



Prediction of rainfall in Vietnam from 2010s – 2070s

Source: SEA-START, RCCC (2009)



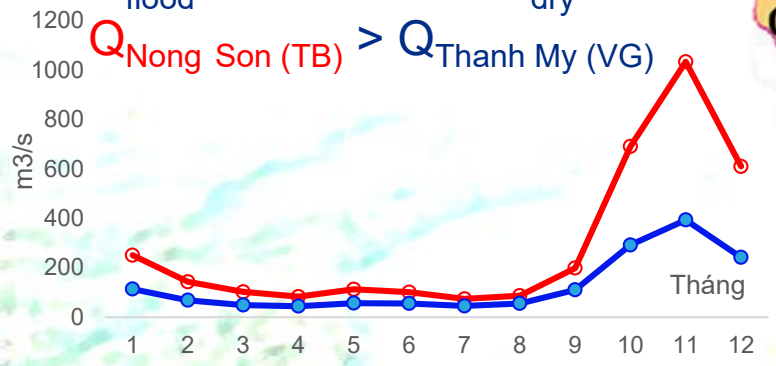
Where is Vu Gia- Thu Bon river basin?

W_{mean} = 20.1 billion cbm, Q_{mean} = 400 cms

Q (cms):

Q_{flood}= 309 - 778 > Q_{dry}= 60 - 130

$Q_{Nong\ Son\ (TB)}$ > $Q_{Thanh\ My\ (VG)}$



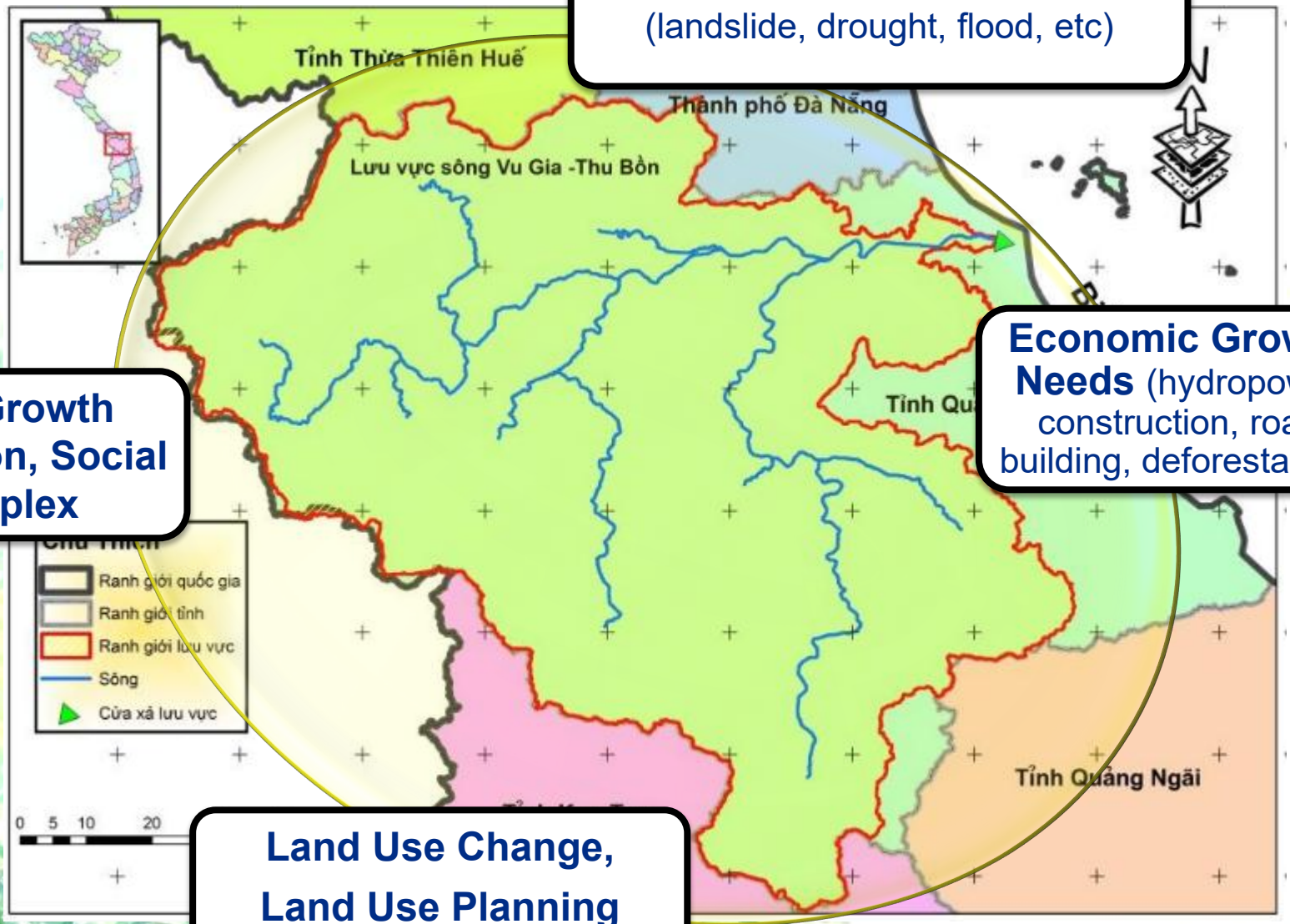
S = 10,350 sq.km

3 province/ city: Kon Tum + Quang Nam + Da Nang City

→ It has important role in the socio-economic development of Quang Nam, Da Nang city.

The 4 greatest problems facing managers!

Water Problems/Disasters (landslide, drought, flood, etc)



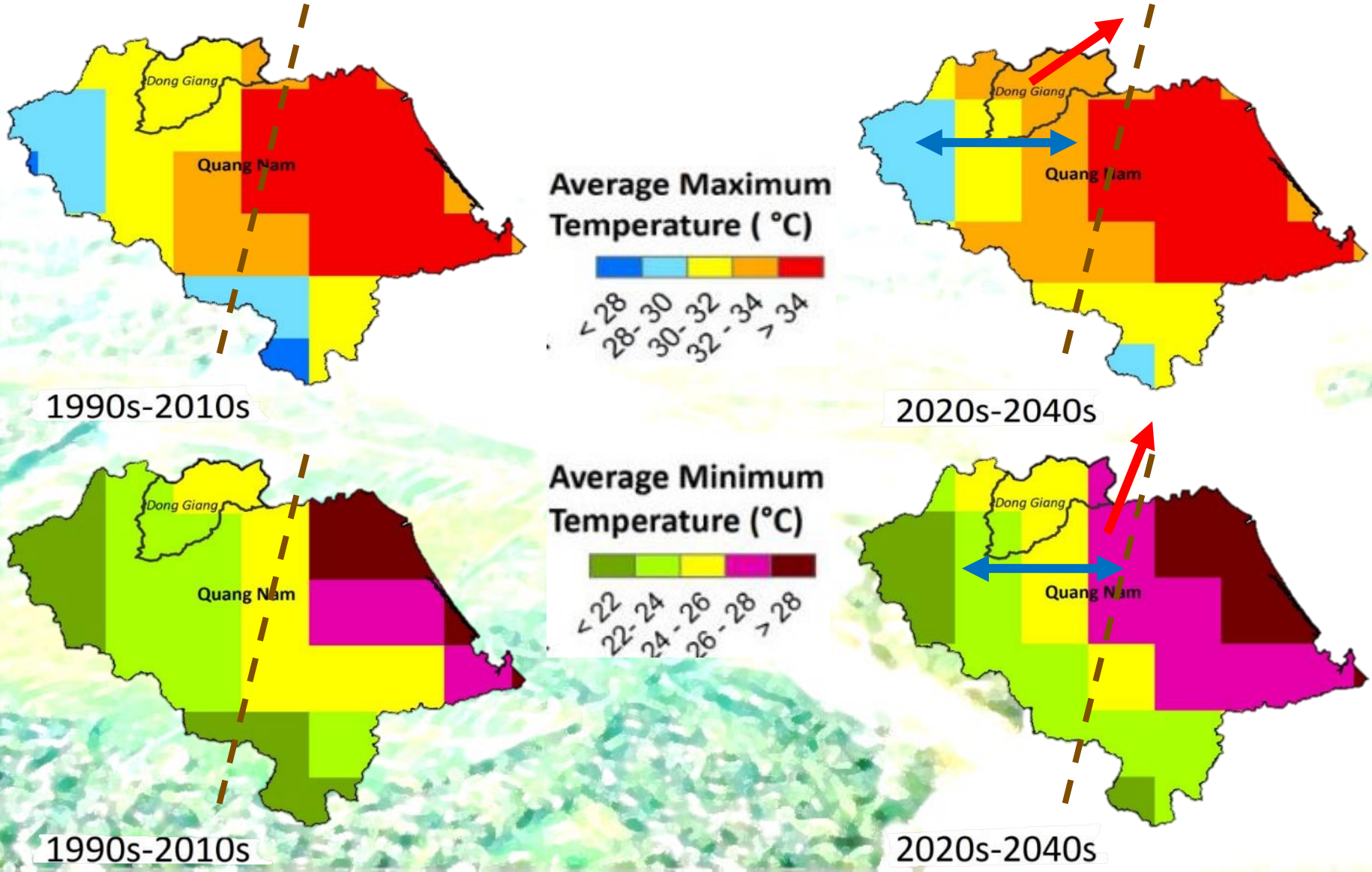
High Growth Population, Social Complex

Economic Growth Needs (hydropower construction, road building, deforestation)

Land Use Change, Land Use Planning

Temperature trend in Vu Gia- Thu Bon river basin

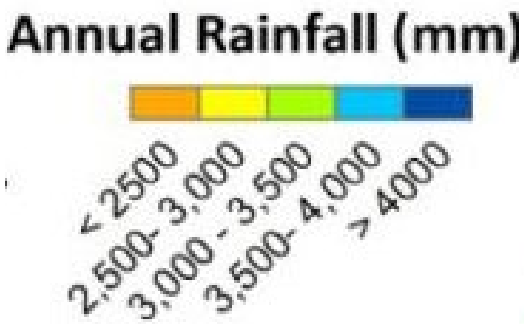
Source: SEA-START Center, RCCC-NLU, Dragon Inst.

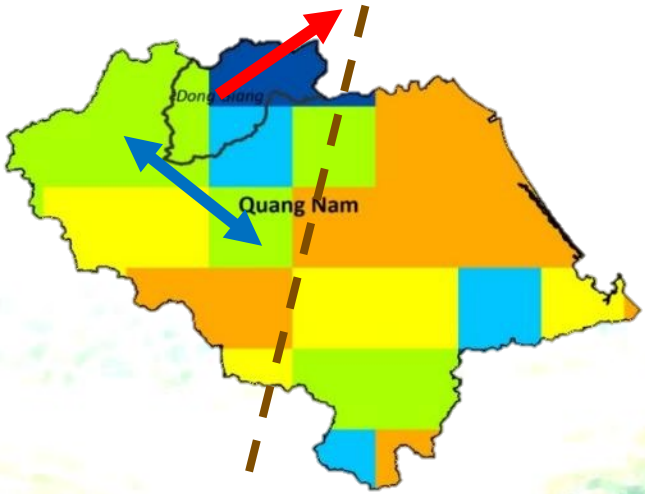


Rainfall trend in Vu Gia- Thu Bon river basin

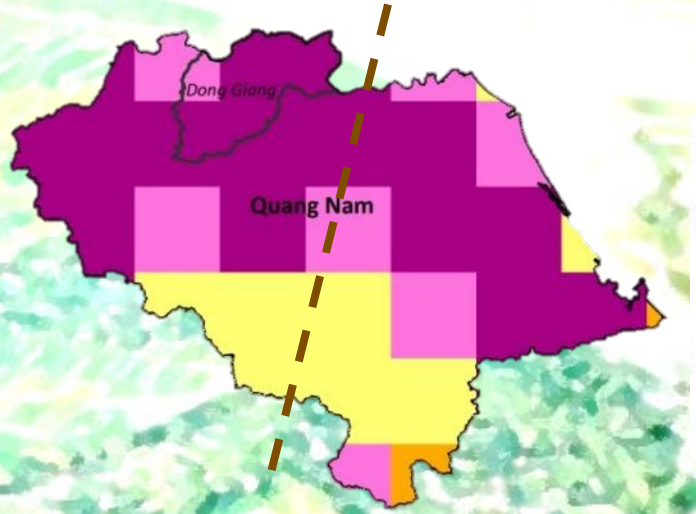
Source: SEA-START Center, RCCC-NLU, Dragon Inst.

1990s-2010s

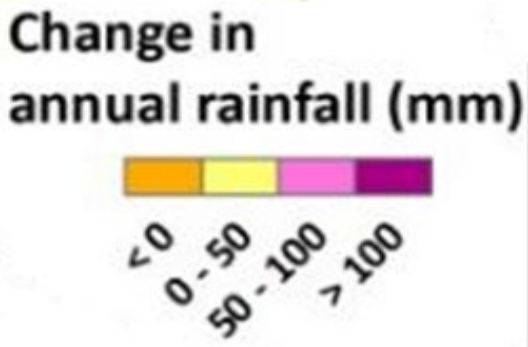




2020s-2040s



2020s-2040s



Objectives

Objectives

Develop a real-time flood warning system using GIS, Information and Communication Technology, SWAT (Soil and Water Assessment Tool) and HEC-RAS (Hydrologic Engineering Centers- River Analysis System) in Vu Gia - Thu Bon river basin

Building a meteo-hydrological data monitoring network in the river basin

Develop a suitable flood warning model for the river basin

Provide flood warning timely to flood-prone households in the river basin

Methods

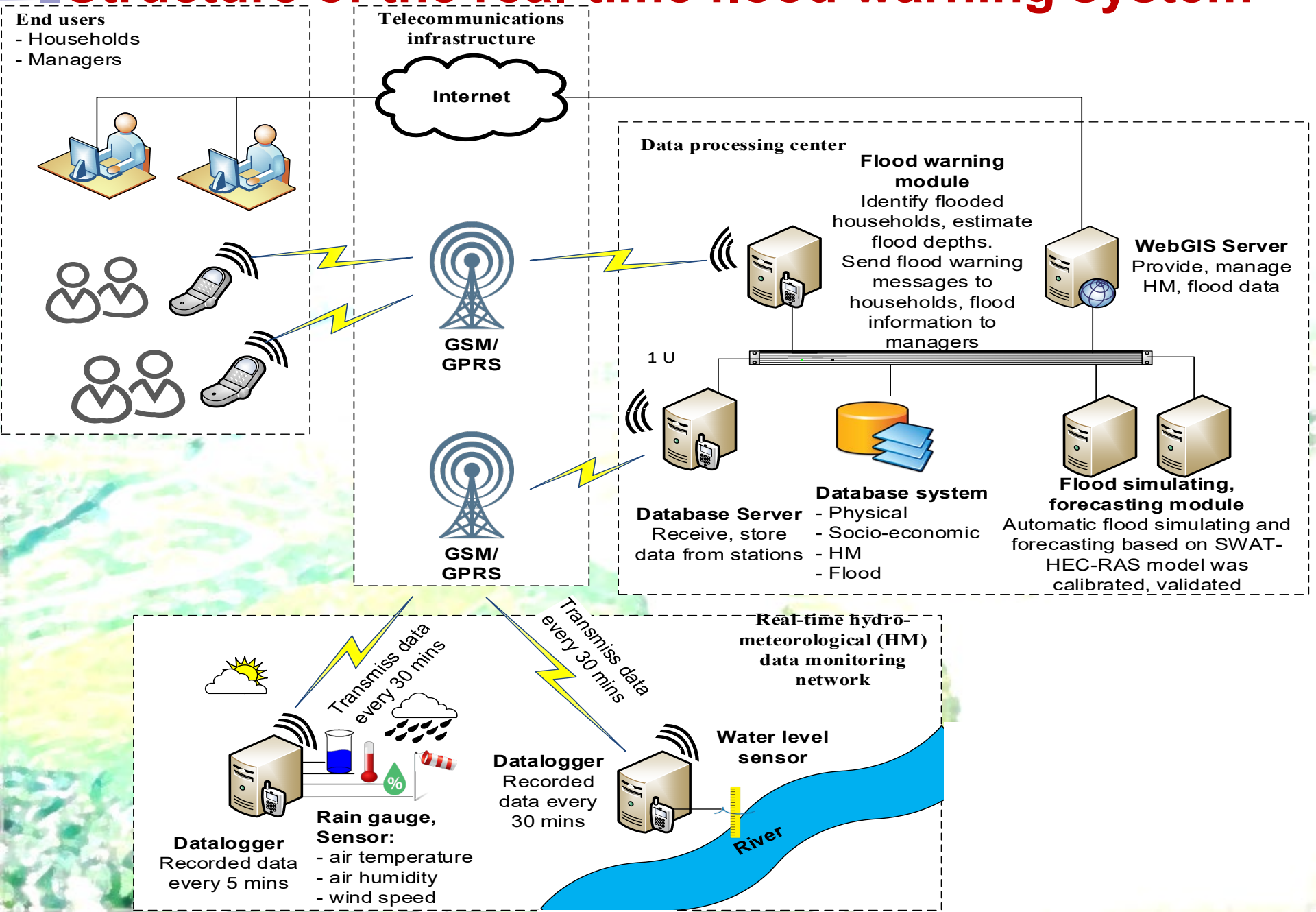
Materials

- Servers:
  - ✓ Database Server
  - ✓ WebGIS Server
- Real-time meteo-hydrological data monitoring network:
  - ✓ 20 weather stations
  - ✓ 5 hydrological stations
- Softwares:
  - ✓ Visual Studio .NET
  - ✓ PostgreSQL/PostGIS, Microsoft SQL Server
  - ✓ VisualSVN on Windows Server
  - ✓ ArcGIS Desktop, ArcSWAT, VizSWAT, SWAT-CUP, HEC-RAS
- Others:
  - ✓ UPS
  - ✓ Handheld GPS
  - ✓ GSM/GPRS, Internet

Data collection

ID	Data types	Data sources
Primary data		
1	Socio-economic data	Participatory Rural Appraisal- PRA
2	Real-time meteo-hydrological data	20 weather stations, 5 hydrological stations
Secondary data		
1	Topographic map	Department of Natural Resources and Environment of Quang Nam province
2	2010 land use map	
3	Soil map	Central Sub-Institute of Agricultural Planning and Design
4	Reservoir data (hydropower, irrigation)	Department of Natural Resources and Environment of Quang Nam province
5	Meteo-hydrological data (1980- 2013)	Middle-Middle Region Hydro-Meteorological Centre
6	Socio-economic data (2012- 2014)	Quang Nam Statistical Yearbook
7	Floods data (1998- 2015)	Irrigation Department of Quang Nam province
8	Satellite imagery (2004, 2006, 2011, 2012)	Vietnam Remote Sensing Center

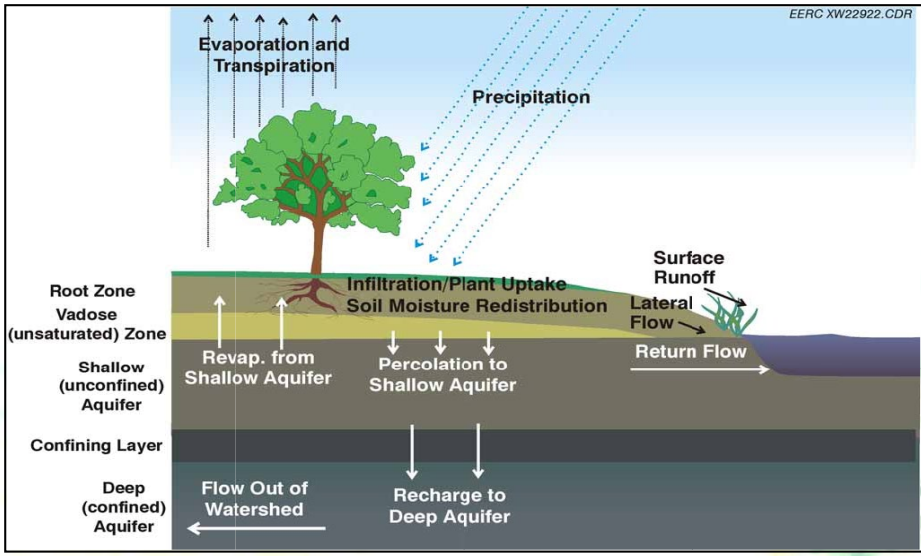
Structure of the real-time flood warning system

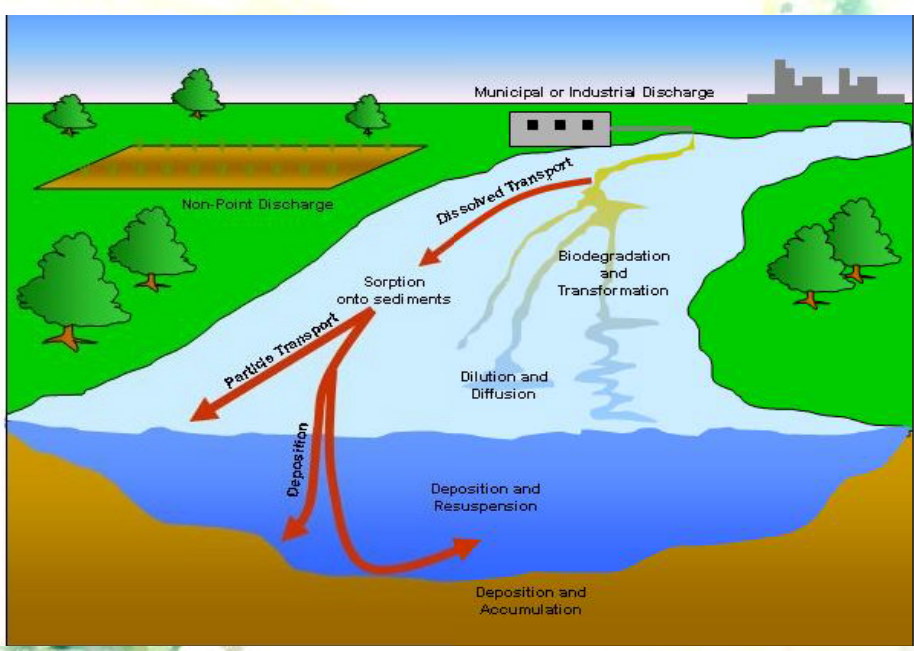


Data required to set-up SWAT model

- Spatial data
  - ✓ DEM (Digital Elevation Model)
  - ✓ Land use/cover map
  - ✓ Soil classification map
  - ✓ Reservoir (characteristics, release data)
  - ✓ Crop calendar
- Time series data
  - ✓ Maximum/ Minimum temperature
  - ✓ Rainfall
  - ✓ Relative humidity
  - ✓ Evaporation
  - ✓ Solar radiation
  - ✓ Wind speed
  - ✓ Water discharge (for calibrating the model)

(including the locations of stations)



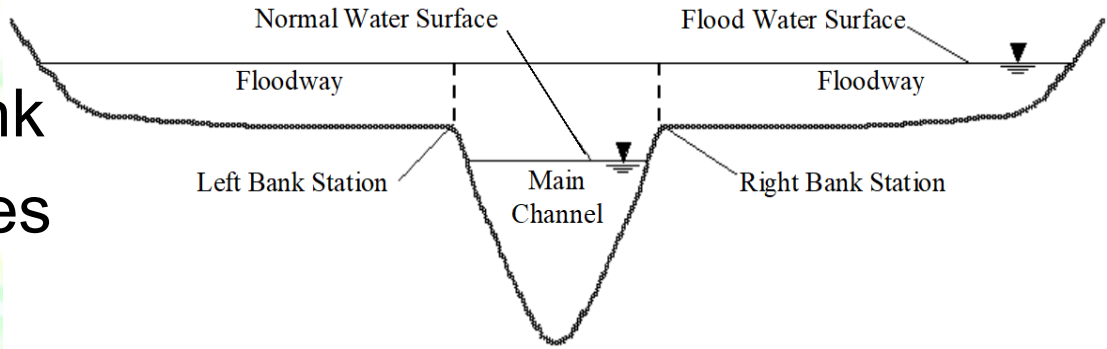


Model philosophy

- HEC-RAS: **H**ydrologic **E**ngineering **C**enter's **R**iver **A**nalysis **S**ystem.
- Developed by The U.S. Army Corps of Engineers' River Analysis System.
- Perform one-dimensional steady and unsteady flow river hydraulics calculations for a full network of natural and constructed channels.

Data required to set-up HEC-RAS Model

- Topographic data
  - ✓ Digital Elevation Data
- Land use/cover map
- Geometric data
  - ✓ Stream Centerline
  - ✓ Right Bank, Left Bank
  - ✓ Flow Path Centerlines
  - ✓ Cross Section
- Hydrological data
  - ✓ Water discharge and stage

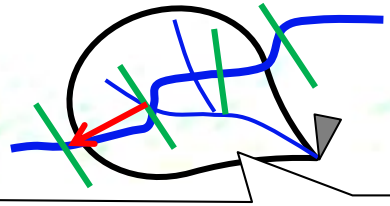


Can integrate SWAT and HEC-RAS?

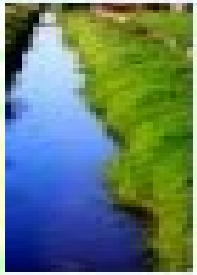
Real world → **Modeling**

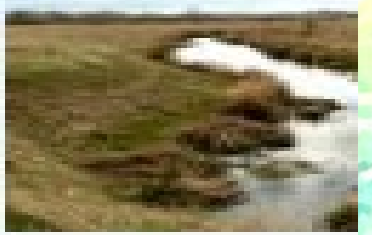
Watersed scale

SWAT



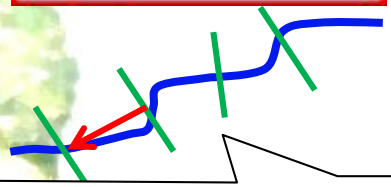
Simulate water discharge at the outlets of the basin.





In-stream scale

HEC-RAS



Simulate flow velocity, water level at the cross sections.

How to integrate SWAT and HEC-RAS?

SWAT

HEC-RAS

Extract River network, flow direction **to edit** → Geometric data

Extract Water discharge **to edit** → Boundary condition, initial condition

Time step (30 mins, 1 day) **synchronize** ↔ Time step (30 mins, 1 day)

Automated procedure for SWAT model

Prof. **Raghavan Srinivasan**
SWAT Expert, *Texas A&M University, USA*
Assoc. Prof. **Jaehak Jeong**
SWAT Expert, *Texas A&M University, USA*

Weather input files: rainfall (*.pcp), temperature(*.tmp), humidity (*.hmd), wind (*.wnd)

Master watershed file (*.cio)

Execution file (*.exe)

Output file of main reach (output.rch)

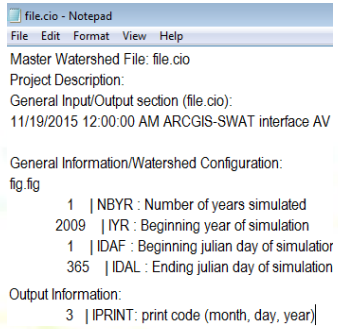
Automated procedure for SWAT model

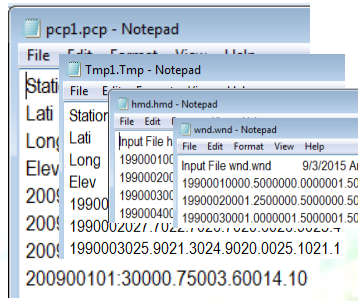
Create SWAT project ← *Manual*

Contains all input, output files on folder TxtInOut (30 mins, daily)

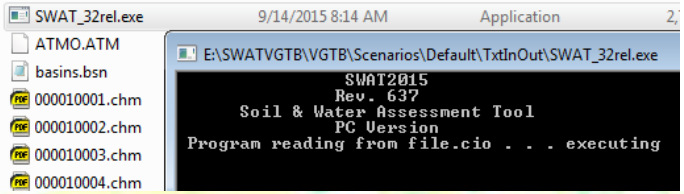
Aggregate all input files ← *Using read, write file commands*

- Master watershed file (*.cio): simulation duration, print output files (30 mins, daily).
- Weather input files (*.pcp, *.tmp, *.hmd, *.wnd): check the validation of data, update data.





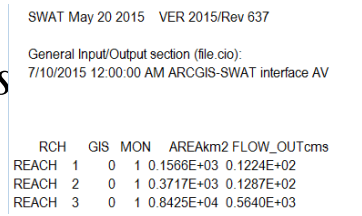
Automatically run execution file ← *Using command System.Diagnostics.Process.Star*

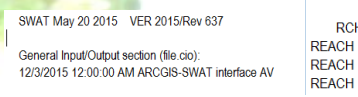


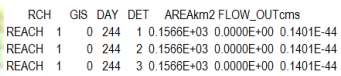

```
System.IO.Directory.SetCurrentDirectory(SWATFolder);
System.Diagnostics.Process p = System.Diagnostics.Process.Start(SWATFolder + @"\SWAT_32rel.exe");
p.WaitForExit();
p.Dispose();
```

Automatically process output file ← *Using read, write file commands*

Output file of main reach (output.rch): day, hour, water discharge (30 mins, daily)







Automated procedure for HEC-RAS model

Mr. **Christopher R. Goodell**
HEC-RAS Expert, *WEST Consultants, Inc., USA*

Unsteady flow input file (*.u01)

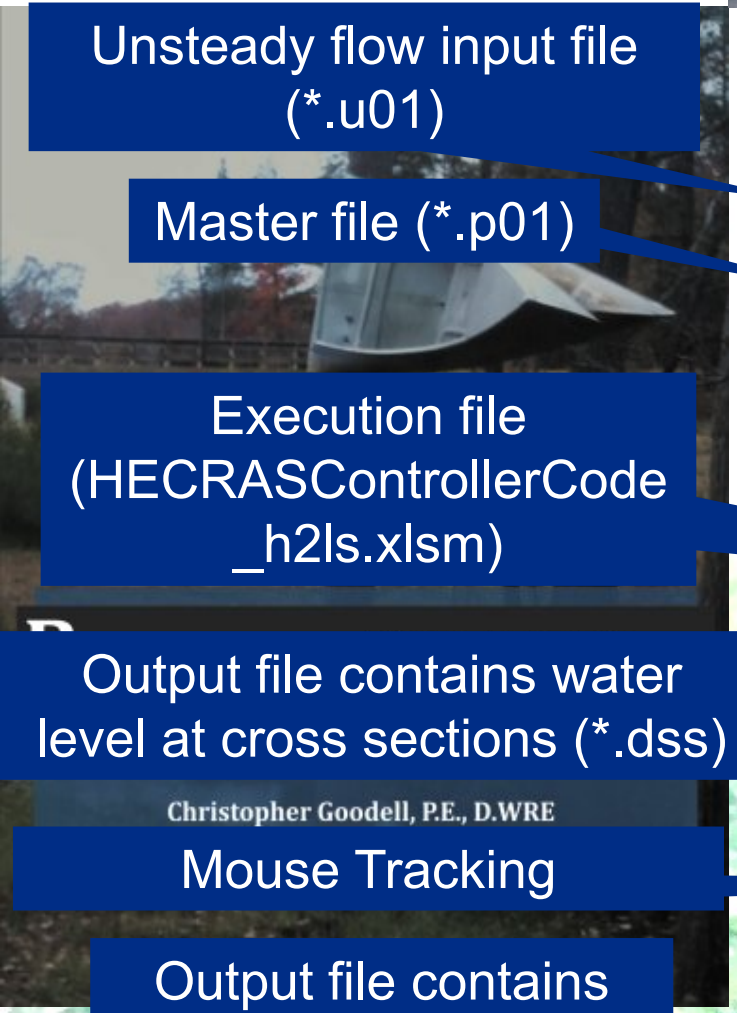
Master file (*.p01)

Execution file (HECRASControllerCode_h2ls.xlsm)

Output file contains water level at cross sections (*.dss)

Mouse Tracking

Output file contains flood depth (*.tif)



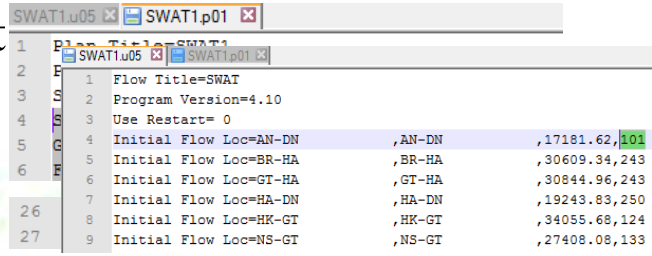
Automated procedure for HEC-RAS model

Create HEC-RAS project ← *Manual*

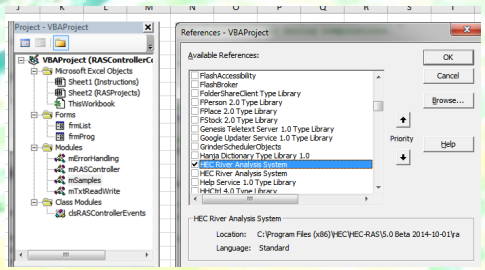
Contains all input, output files on one folder (30 mins, daily)

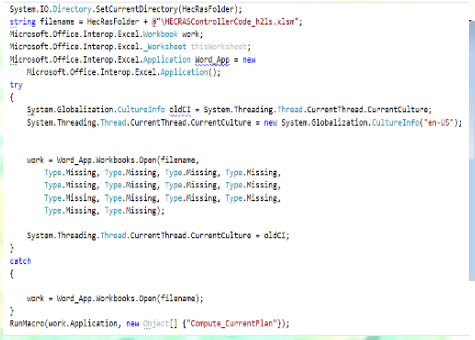
Aggregate all input files ← *Using read, write file commands*

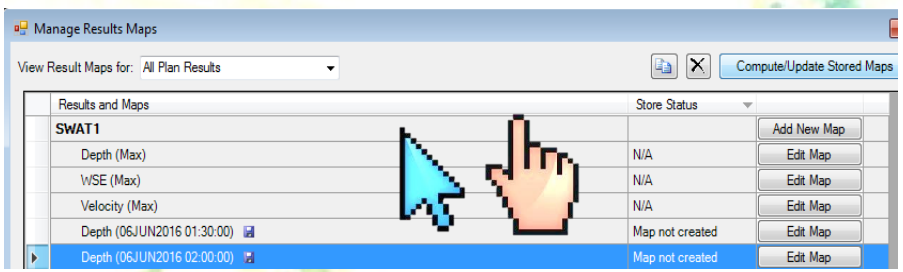
- Master file (*.p01): simulation duration, print output files (30 mins, daily).
- Unsteady flow input file (*.u01): update upper boundary condition and initial condition.



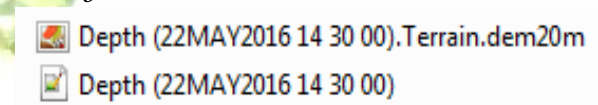
Automatically run execution file ← *Using module HEC-RAS Controller Code, Mouse Tracking*



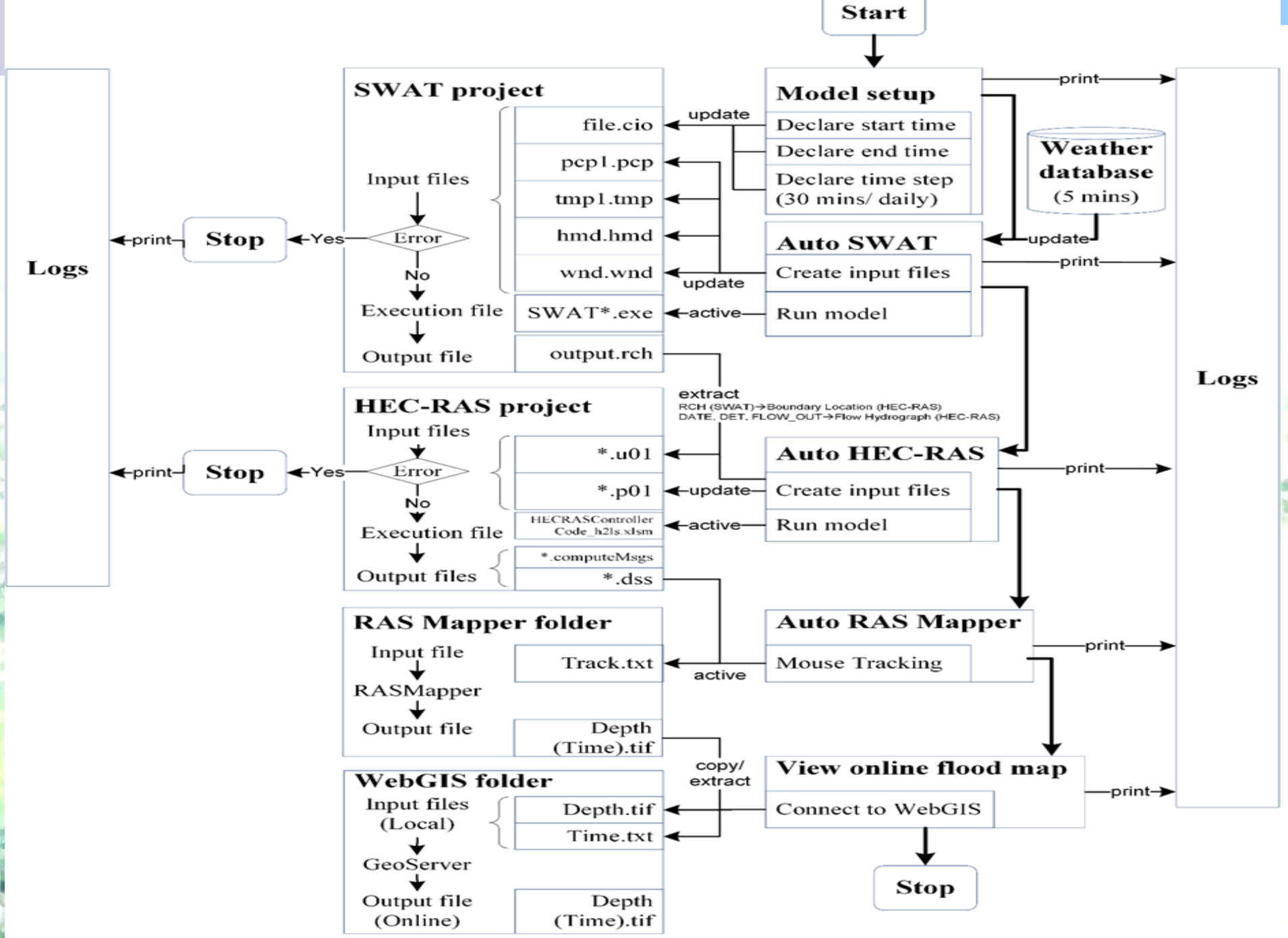




Automatically process output file ← *Using module GeoTIFF of GeoServer, module flood warning*



Flood depth file (*.tif): day, hour, flood depth (30 mins, daily)

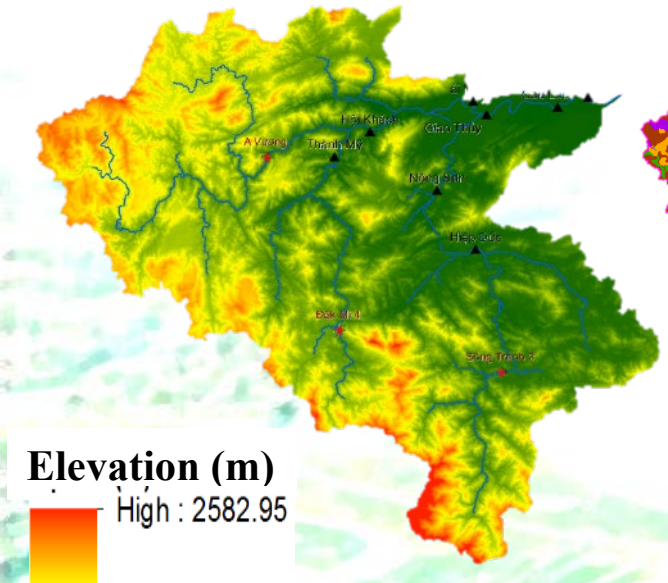


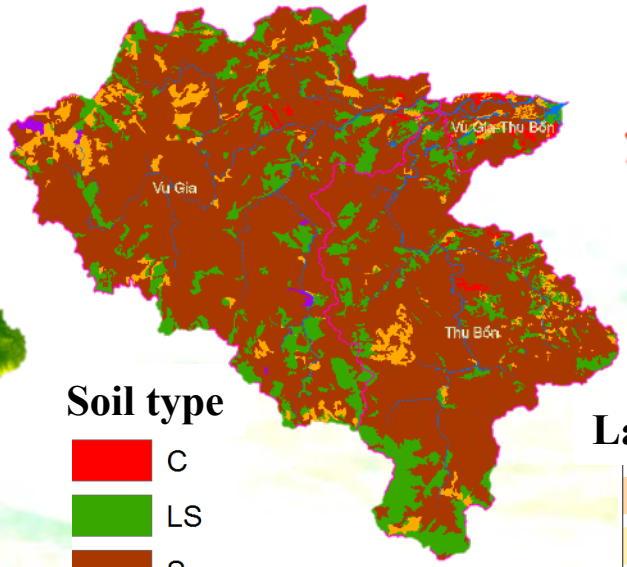
The flowchart of automated SWAT, HEC–RAS program for real-time flood forecasting

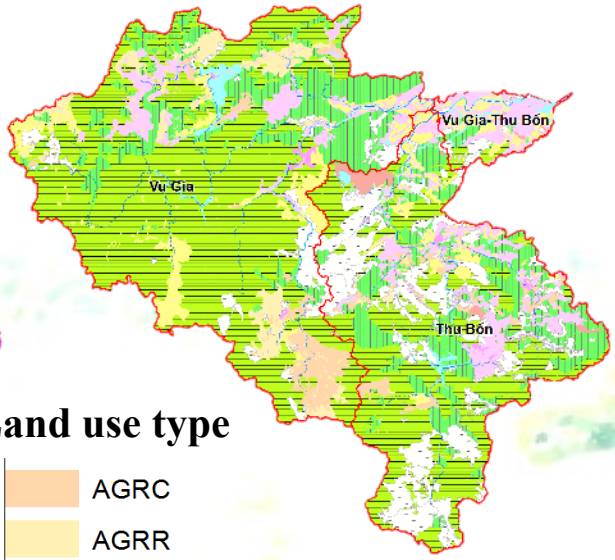
Results

Database

- DEM, soil, land use map







Elevation (m)

High : 2582.95

Low : -31.2808

Soil type

- C
- LS
- S
- SCL
- SIL
- WA

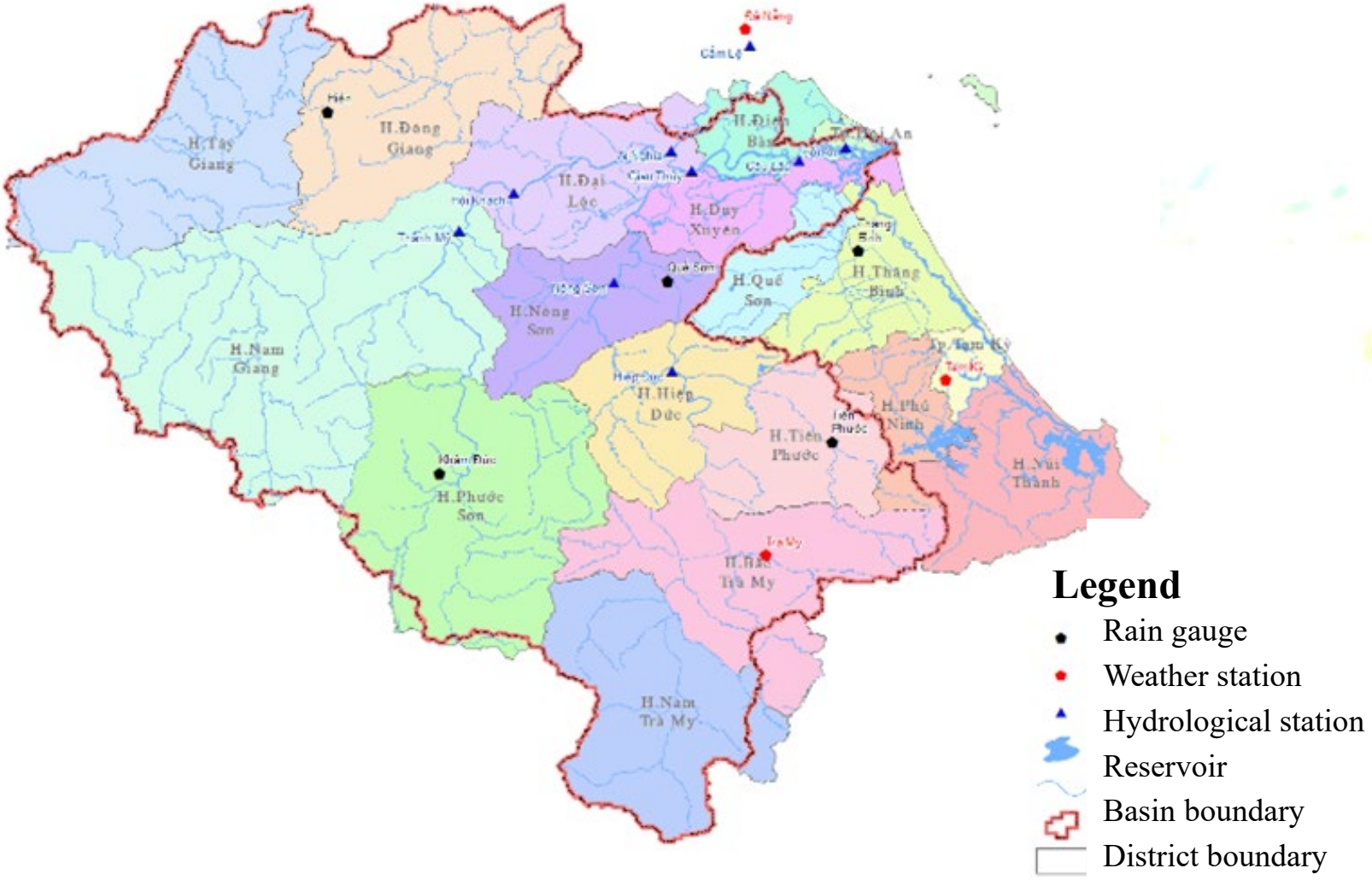
Land use type

- AGRC
- AGRR
- BARR
- FRSE
- FRST
- PAST
- RICE
- UIDU
- UINS
- URHD
- URML
- WATR

Database

- Historical meteo-hydrological data (1980- 2013)

17 rain gauges/ meteo-hydrological stations



Database

- Historical meteo-hydrological data (1980- 2013)

17 rain gauges/ meteo-hydrological stations

ID	Name	Type	Long. (⁰)	Lat. (⁰)	Elevation (m)	Data
1	Hiên	DM	107,64	15,92	497	P
2	Khâm Đức	DM	107,79	15,44	385	P
3	Tiên Phước	DM	108,32	15,48	64	P
4	Quế Sơn	DM	108,10	15,70	44	P
5	Thăng Bình	DM	108,35	15,74	16	P
6	Trà My	KT	108,23	15,33	102	P, T, S, W, H, E
7	Đà Nẵng	KT	108,20	16,03	10	P, T, S, W, H, E
8	Tam Kỳ	KT	108,47	15,57	7	P, T, S, W, H, E
9	Thành Mỹ	TV	107,82	15,77	70	P, L, D
10	Hội Khách	TV	107,89	15,81	12	P, L, D
11	Nông Sơn	TV	108,03	15,70	19	P, L, D
12	Ái Nghĩa	TV	108,10	15,87	6	P, L, D
13	Giao Thủy	TV	108,13	15,84	7	P, L
14	Câu Lâu	TV	108,27	15,86	2	P, L
15	Hội An	TV	108,33	15,88	3	P, L
16	Hiệp Đức	TV	108,10	15,58	35	P, L, D
17	Cẩm Lệ	TV	108,21	16,01	7	P, L

Note:

DM (Rain gauge),

KT (Weather station),

TV (Hydrological station),

P (Rainfall),

T (Temperature),

S (Sunshine),

W (Wind),

H (Humidity),

E (Evaporature),

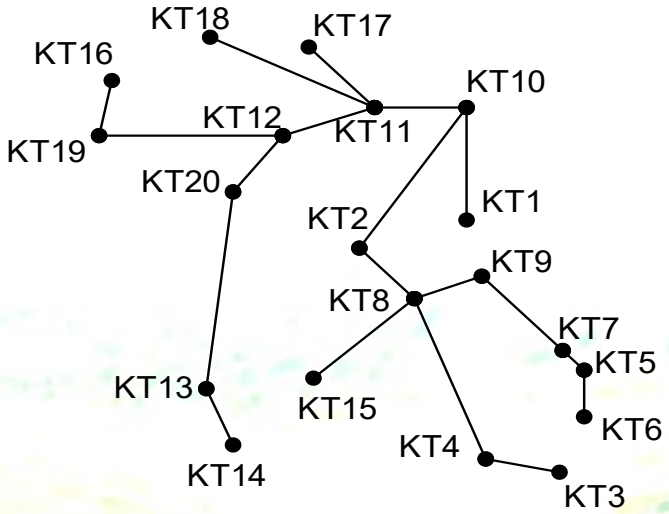
L (Water level),

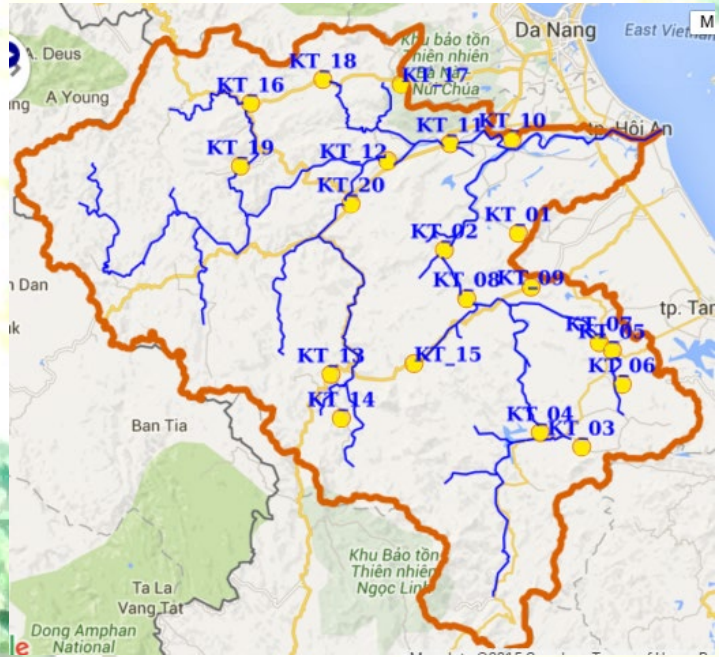
D (Water discharge)

Database

20 weather stations

ID	Code	Long. (˚)	Lat. (˚)
1	KT_01	108,13	15,70
2	KT_02	108,01	15,67
3	KT_03	108,27	15,30
4	KT_04	108,16	15,34
5	KT_05	108,31	15,48
6	KT_06	108,31	15,43
7	KT_07	108,31	15,51
8	KT_08	108,05	15,58
9	KT_09	108,18	15,59
10	KT_10	108,10	15,85
11	KT_11	108,03	15,86
12	KT_12	107,93	15,86
13	KT_13	107,82	15,45
14	KT_14	107,83	15,35
15	KT_15	107,94	15,48
16	KT_16	107,64	15,92
17	KT_17	107,91	15,97
18	KT_18	107,74	15,95





Database

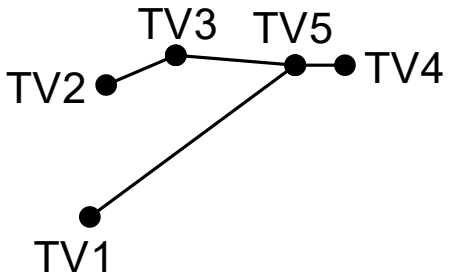
20 weather stations

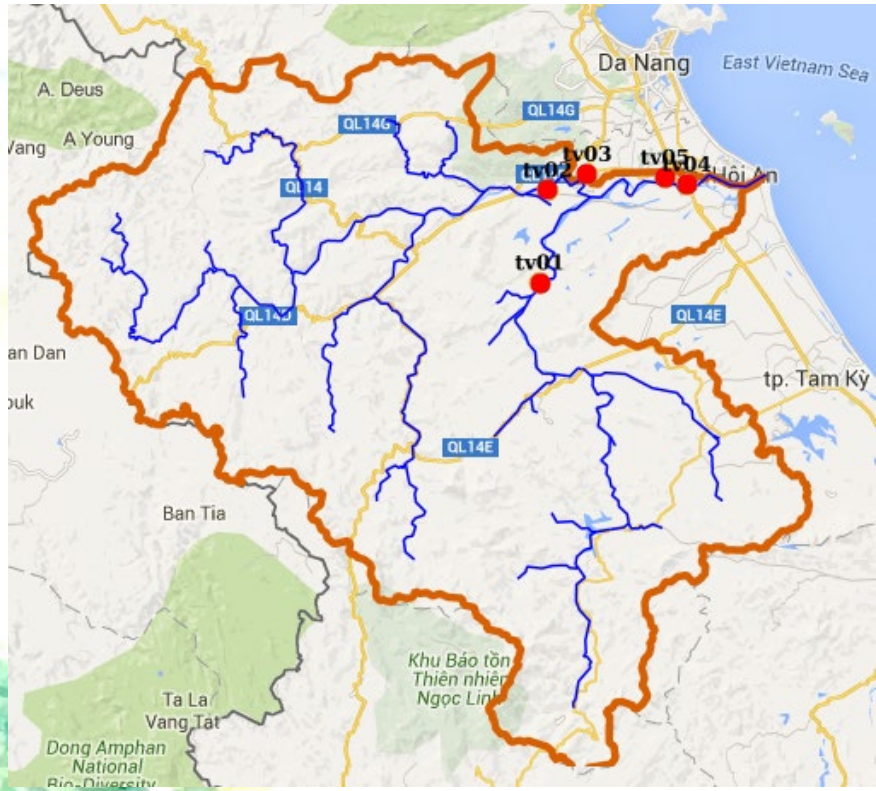
Field visit

Database

5 hydrological stations

ID	Code	Long. (˚)	Lat. (˚)	Elev. (m)
1	TV_04	108,03	15,71	6,40
2	TV_05	108,24	15,88	9,75
3	TV_03	108,11	15,88	9,45
4	TV_02	108,05	15,86	13,41
5	TV_01	108,31	15,48	36,29





Database

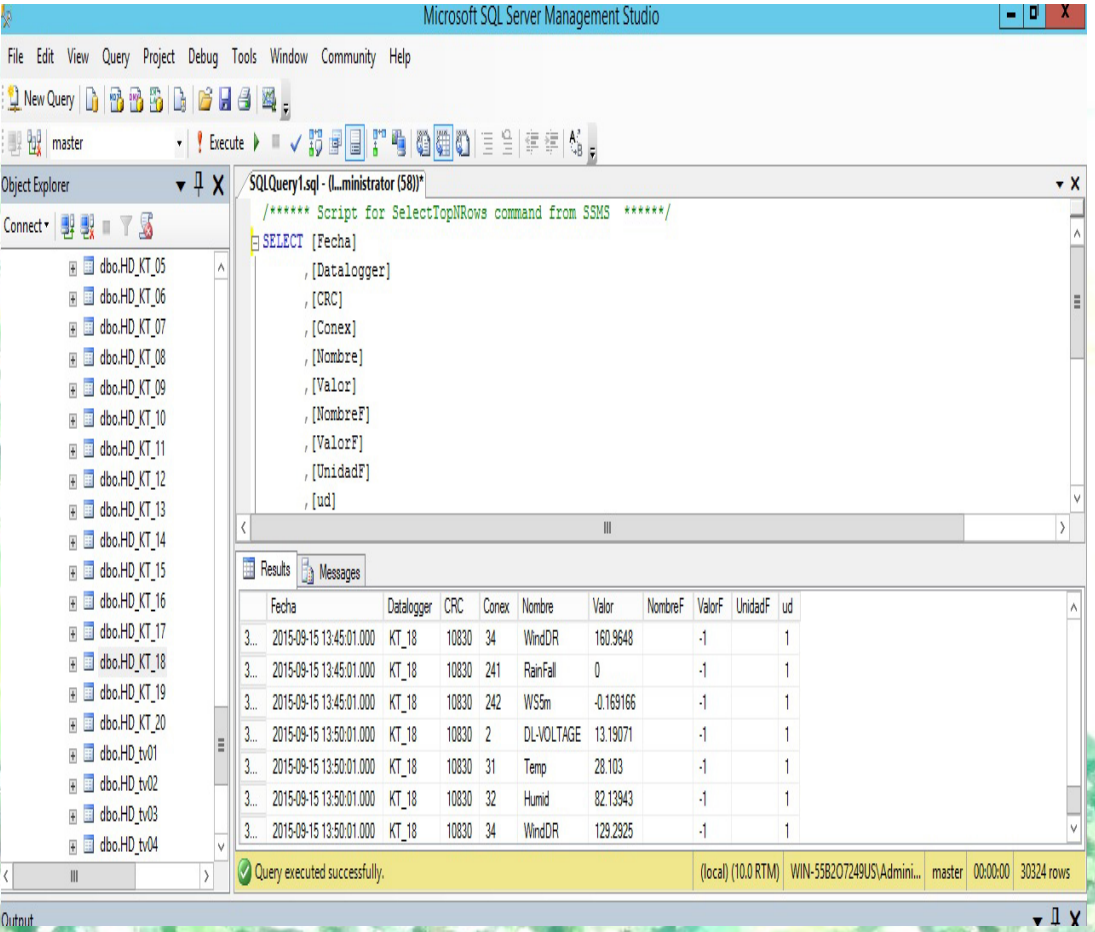
5 hydrological stations

Field visit

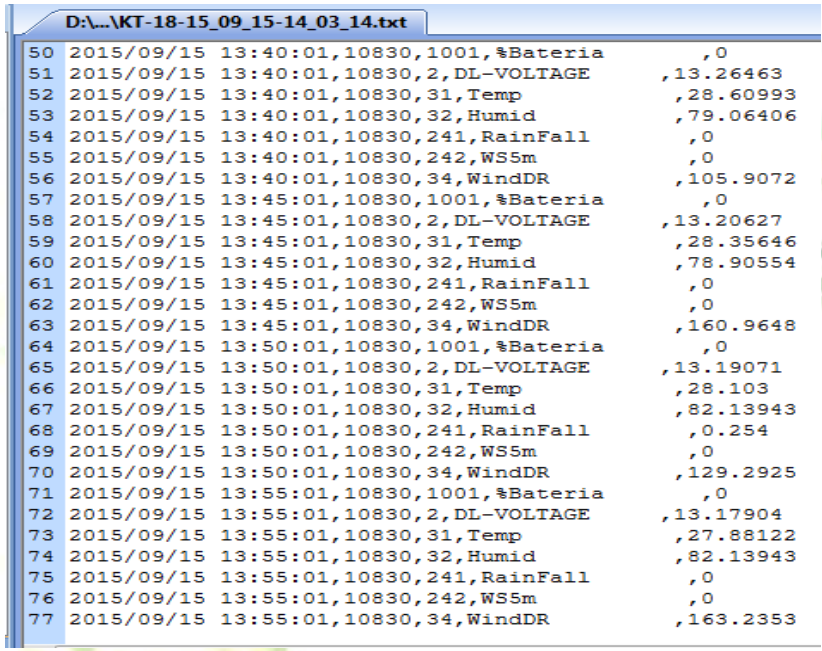
Database

- Real-time meteo-hydrological data (Aug 2015 to now)

Microsoft SQL Server



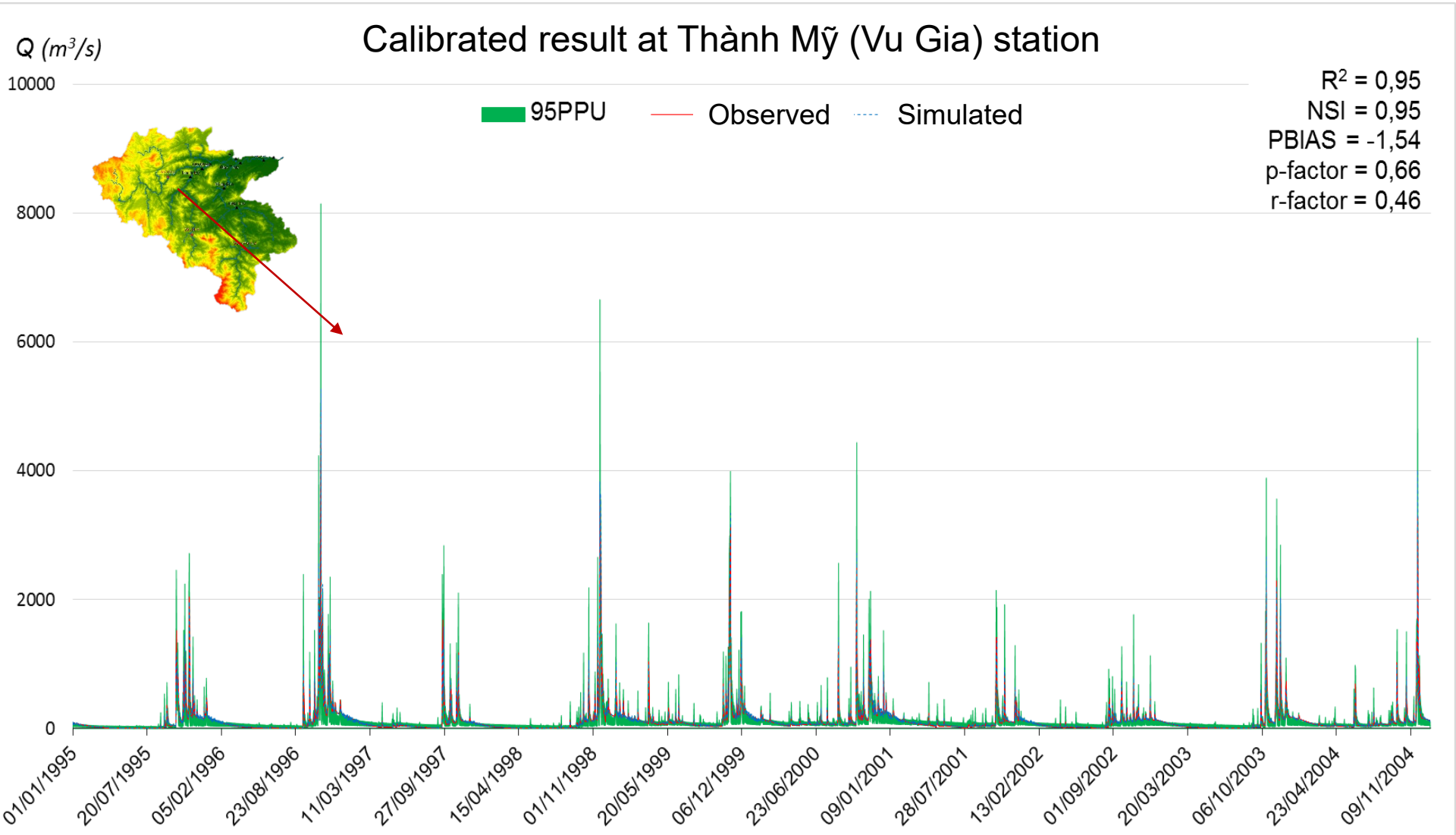
File *.txt



Calibration and validation of SWAT

- Calibration: 1995- 2004 (10 years).

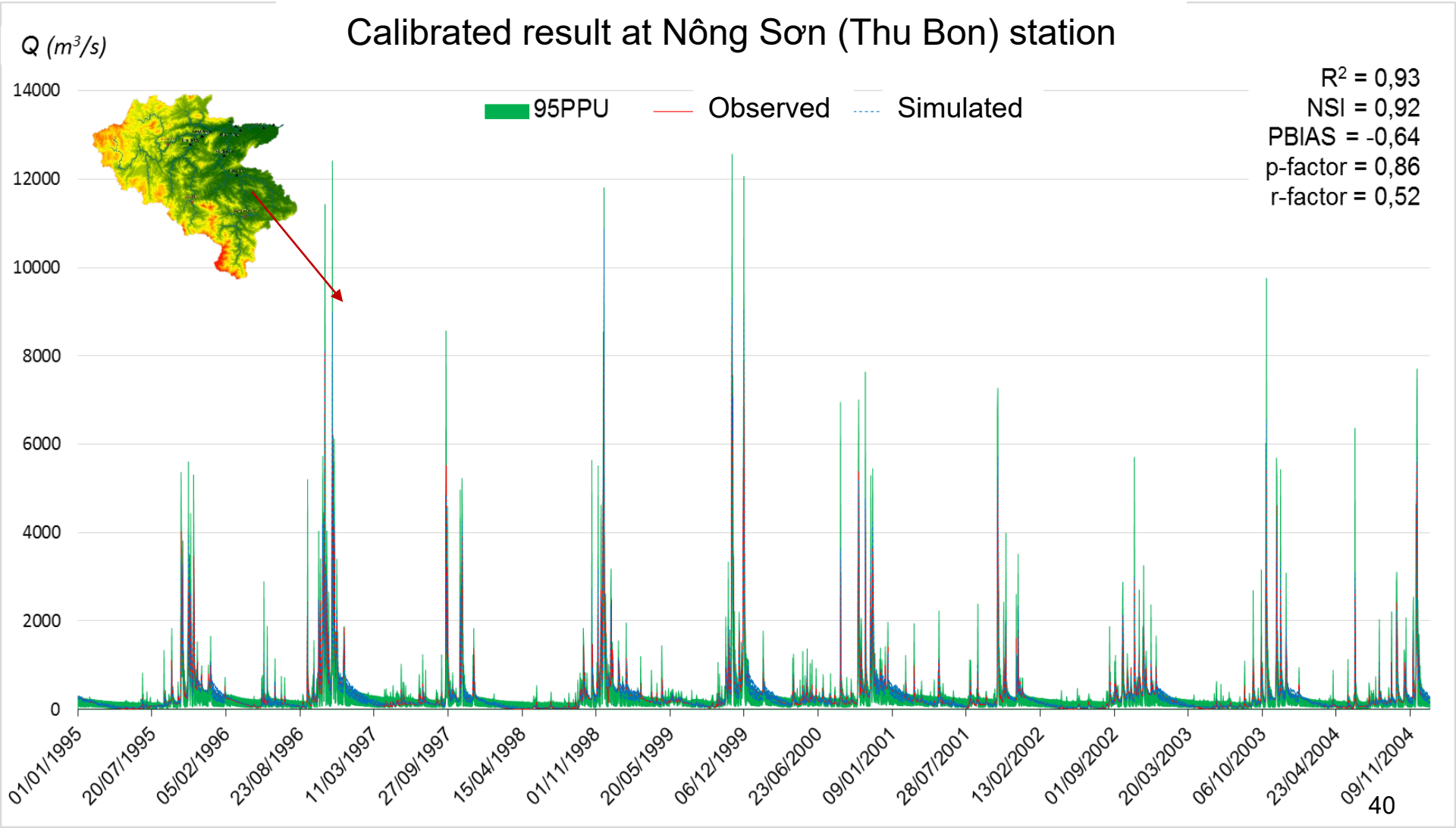
SUFI-2



Calibration and validation of SWAT

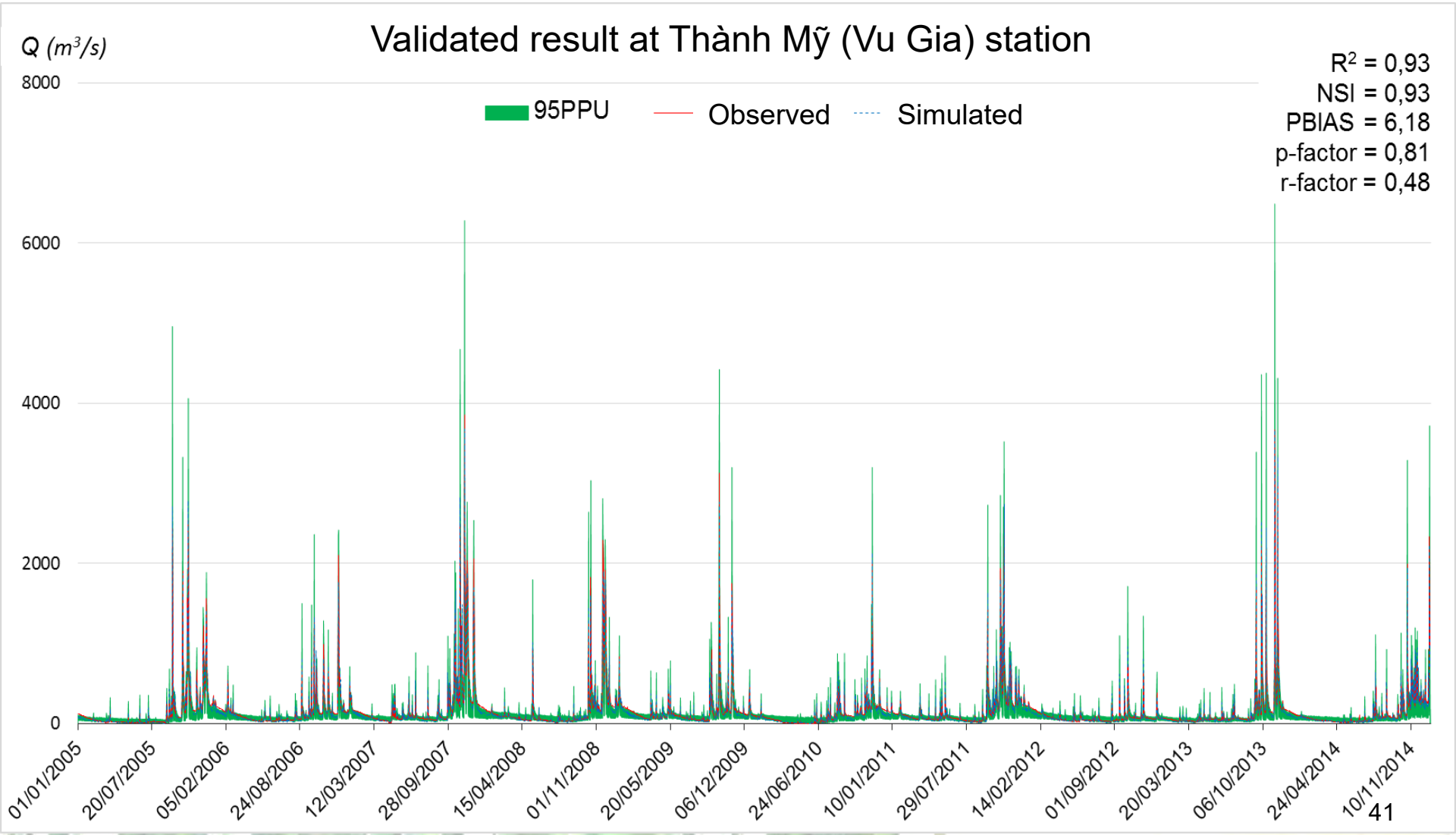
- Calibration: 1995- 2004 (10 years).

SUFI-2



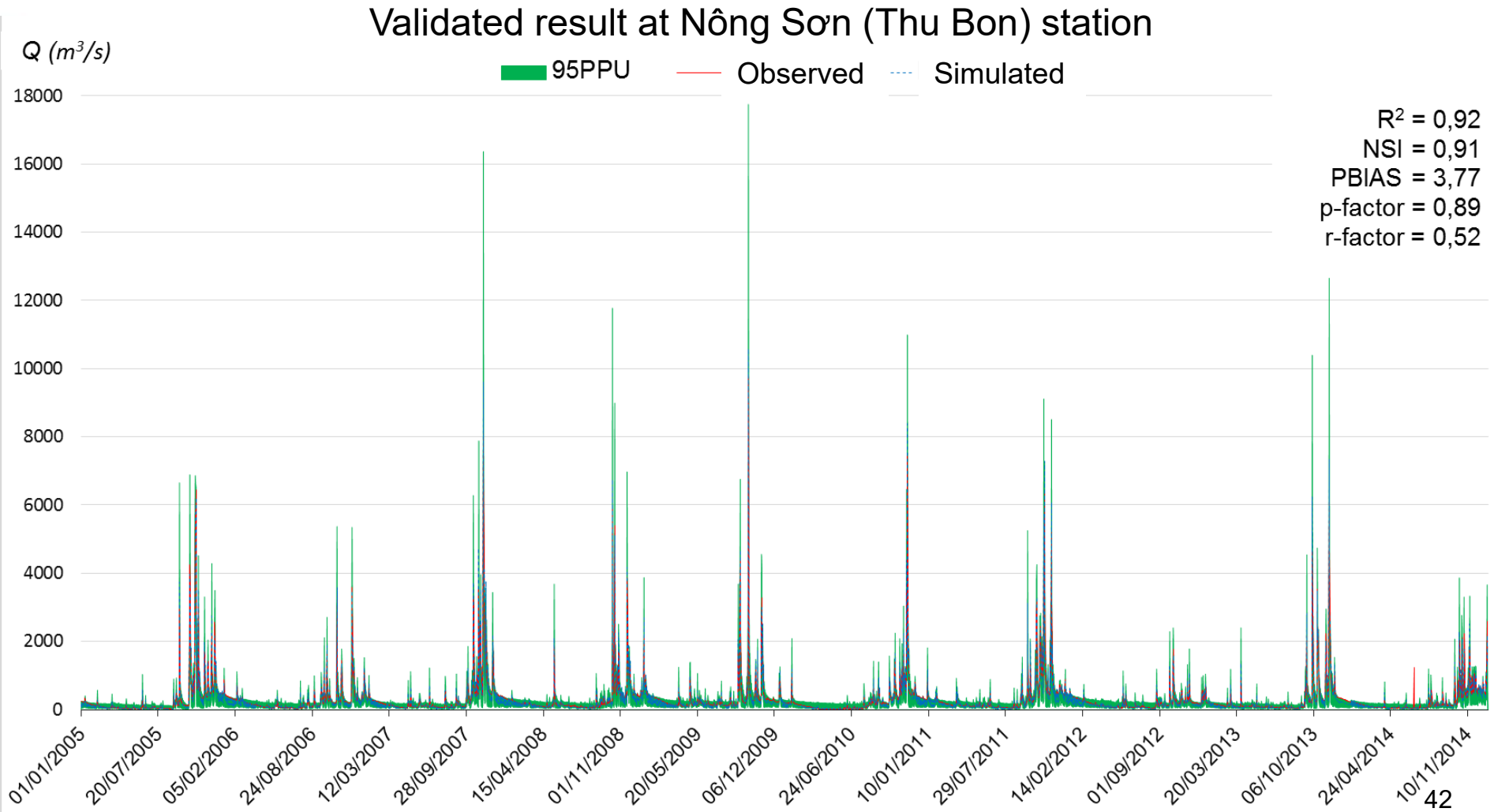
Calibration and validation of SWAT

- Validation: 2005- 2014 (10 years).



Calibration and validation of SWAT

- Validation: 2005- 2014 (10 years).

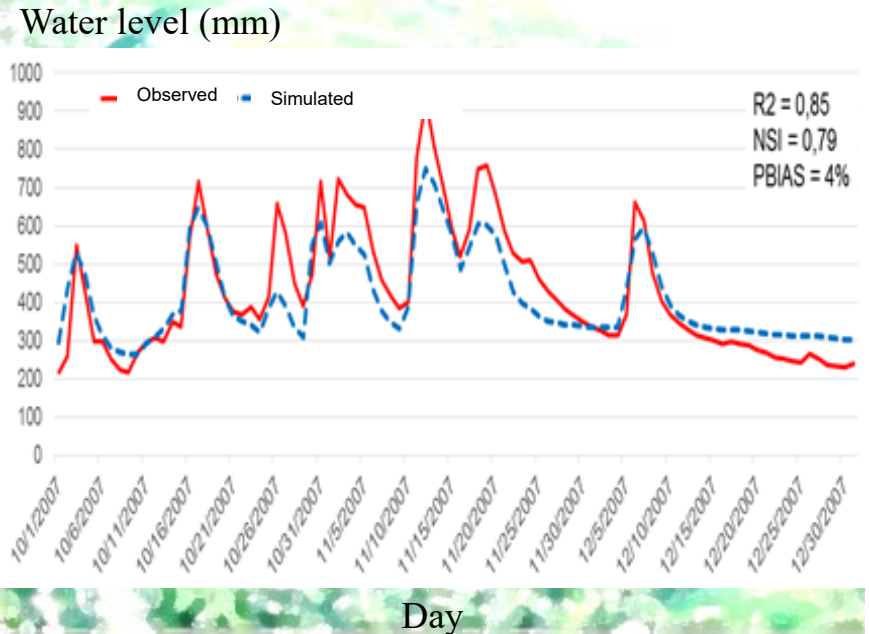


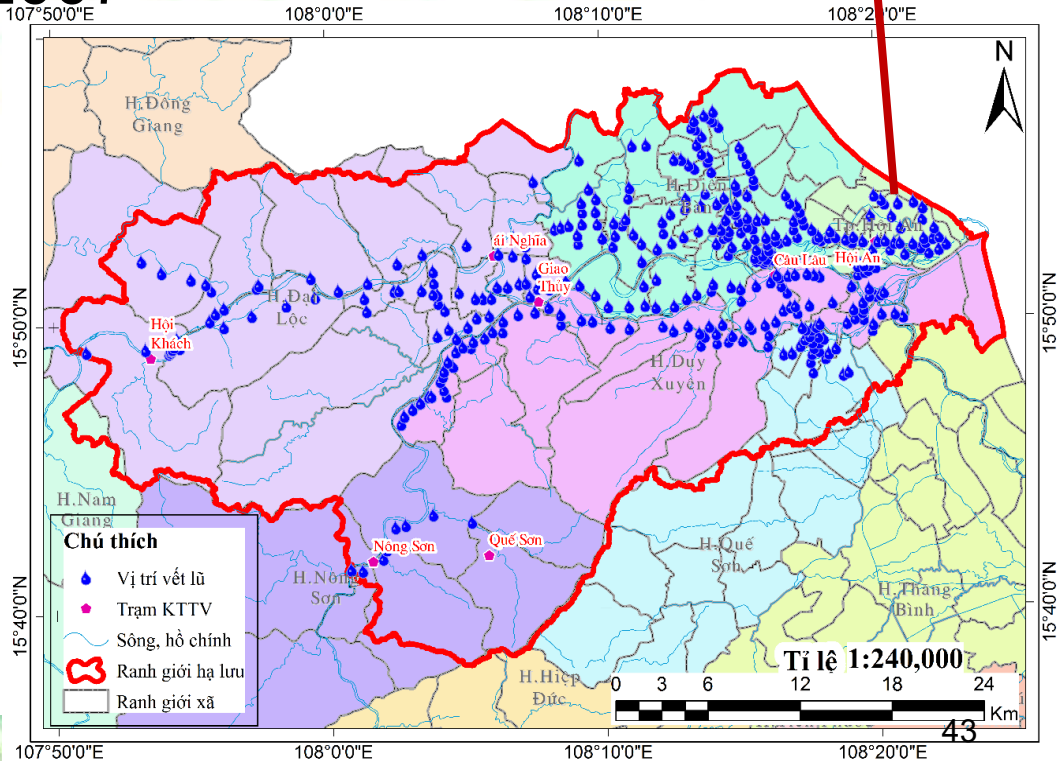
Calibration and validation of HEC-RAS

Trial and error method

- Calibration:
  - ✓ Flood event: 29 Sep 2009.
  - ✓ R^2 = 0,84, NSI = 0,56, PBIAS = -14,68%.
- Validation:
  - ✓ Flood event: Oct- Dec 2007
  - ✓ Giao Thuy station

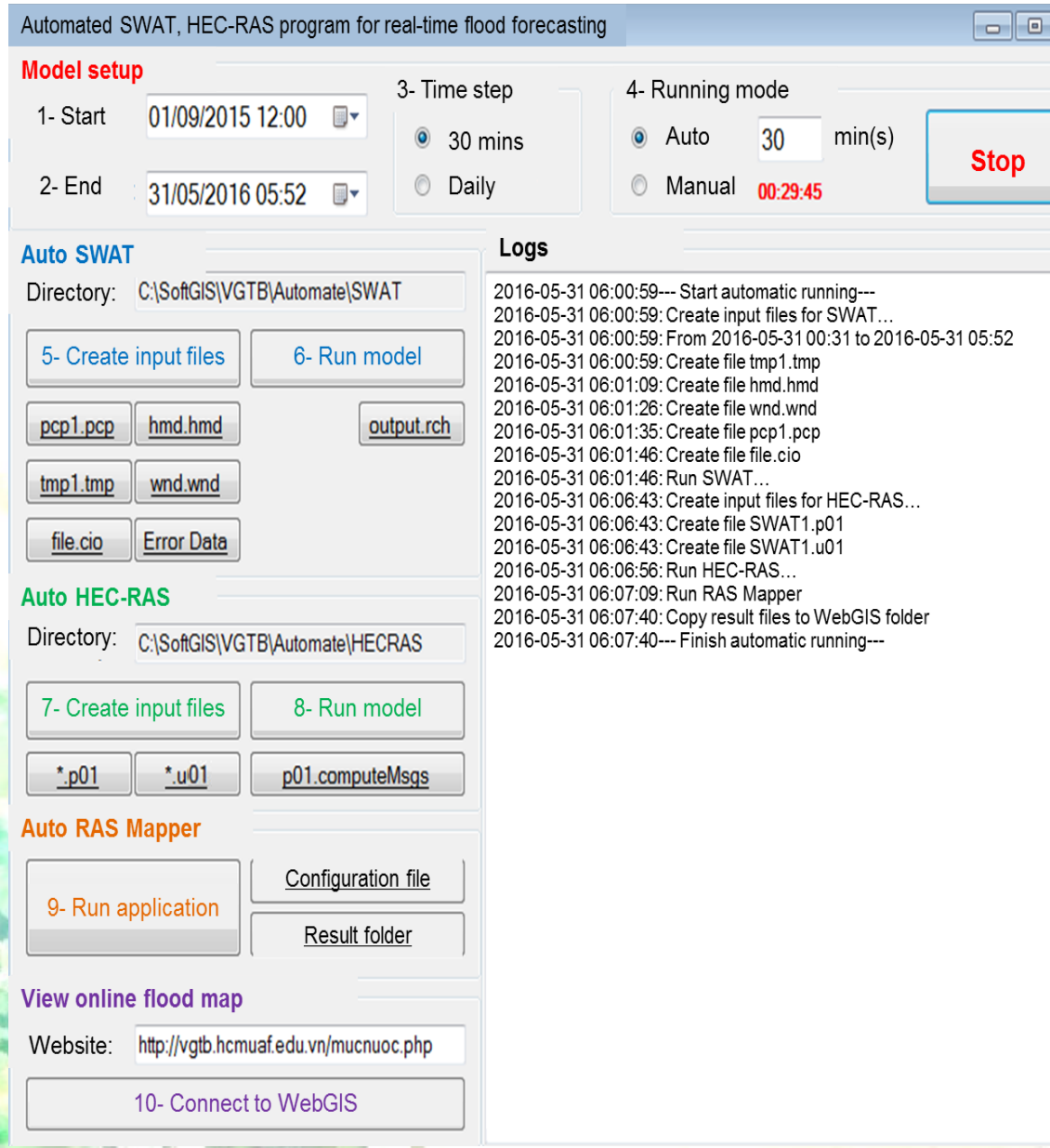
371 flood marker in 2009





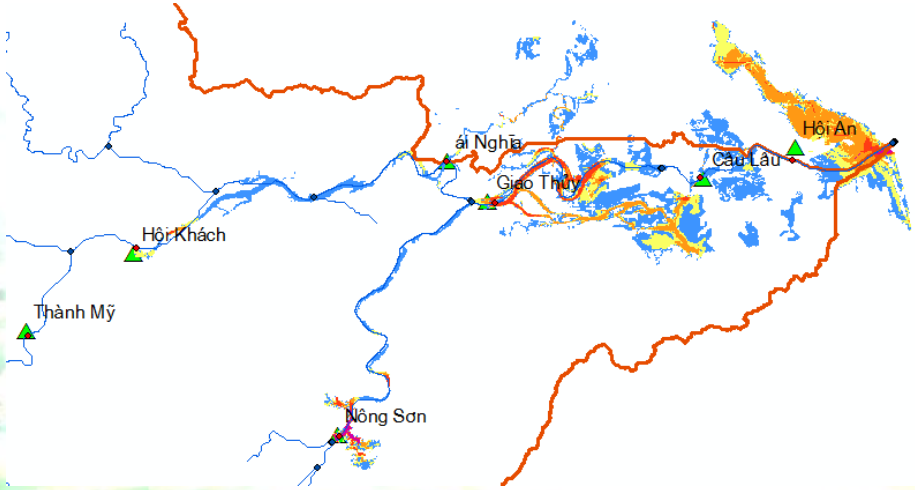
Automated SWAT, HEC-RAS module for real-time flood forecasting

- **Model setup**: Declare start time, end time, time step (30 mins, daily), running mode (automatic, manual).
- **Start/ Stope**: Turn on/ off automatic running mode.
- **Auto SWAT**: Create input files, run model, link to input files (pcp1.pcp, tmp1.tmp, hmd.hmd, wnd.wnd, file.cio), errors report of input data (Error Data), link to output file (output.rch).
- **Auto HEC-RAS**: Create input files, run model, link to input files (*.p01, *.u05), results report of running model (p01.computeMsgs).
- **Auto RAS Mapper**: Run application, link to configuration file "Mouse Tracking", result folder.
- **View online flood map**: Connect to WebGIS to view flood depth map.
- **Logs**: Display timeline for step-by-step implementation and start/ finish status of the whole process.

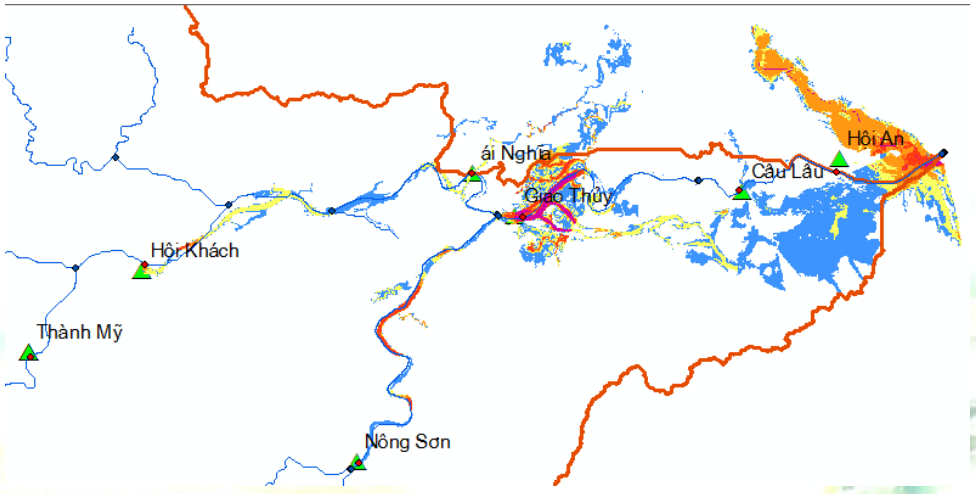


Result of flood simulation in 2015 (1 Sep- 20 Nov 2015)

14 Oct



1 Nov



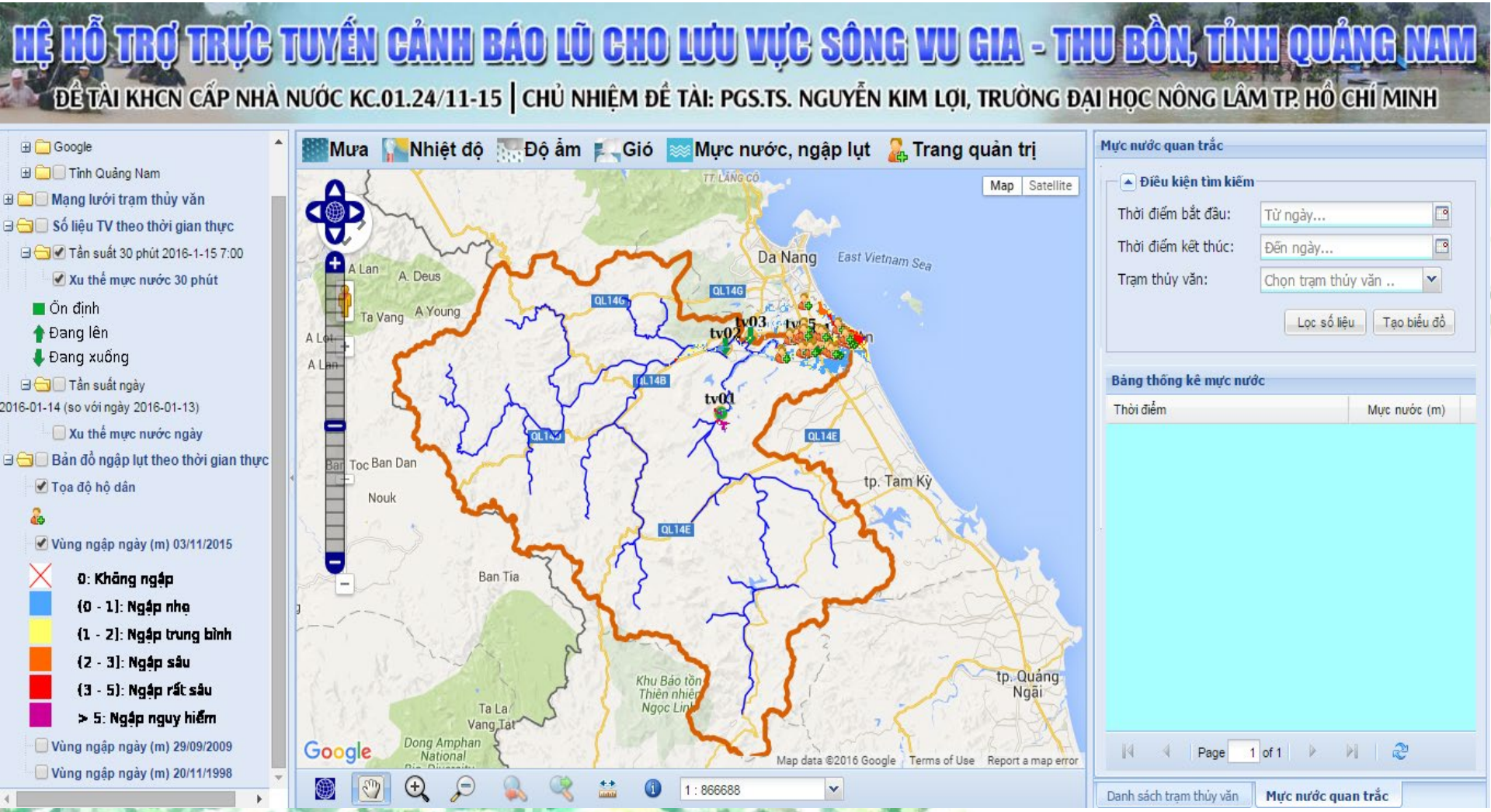
3 Nov

Flood depth (m)

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 15

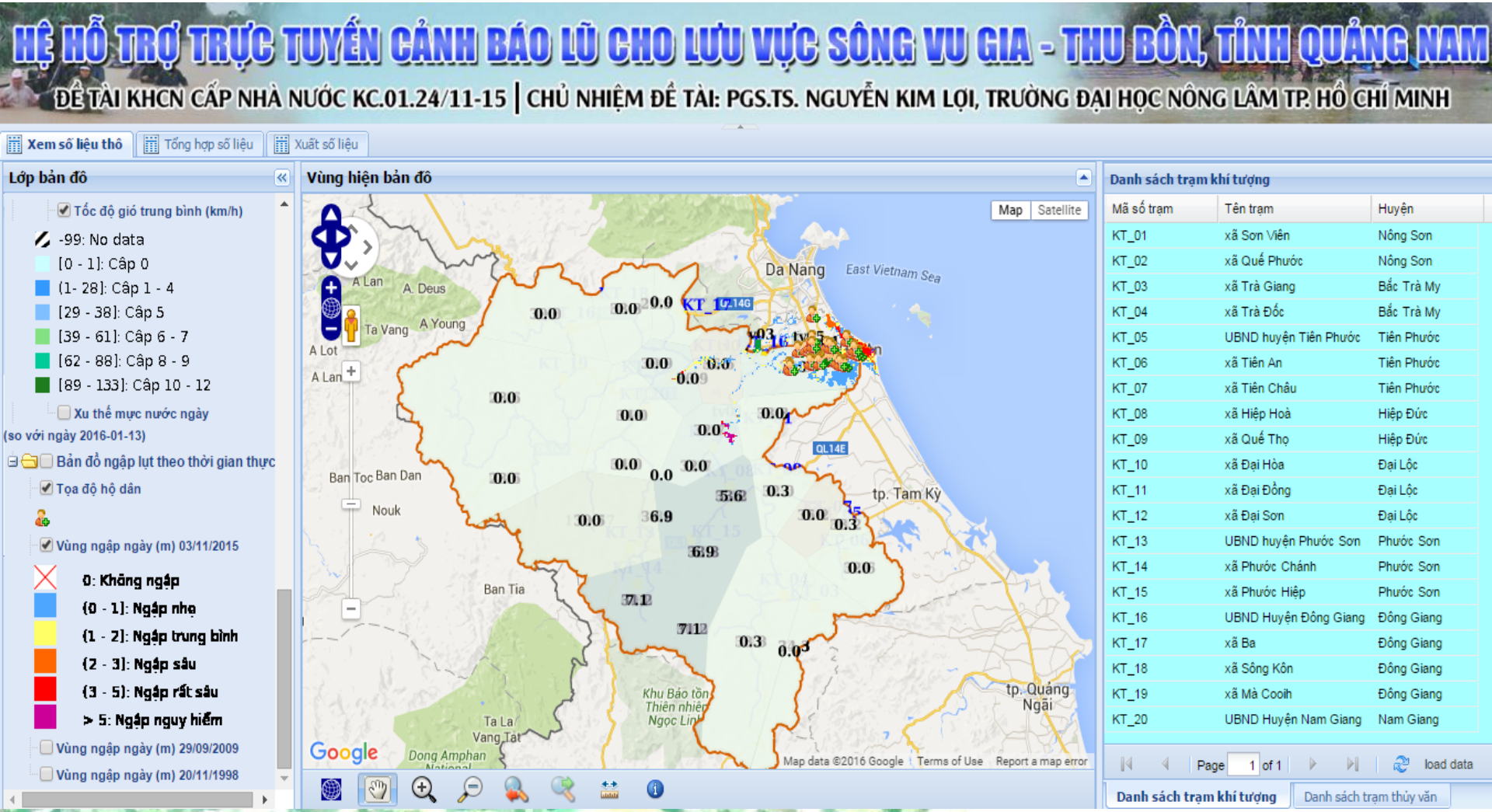
Real-time flood and meteo-hydrological data on WebGIS

- For households: http://vgtb.hcmuaf.edu.vn/



Real-time flood and meteo-hydrological data on WebGIS

- For managers: http://vgtb.hcmuaf.edu.vn/admin/



Conclusions

Conclusions

- The calibration and validation results of both SWAT and HEC-RAS models were satisfactory for flood simulation and forecasting on Vu Gia- Thu Bon river basin.
- The whole process of real-time flood forecasting on the basin was automated by integrating SWAT and HEC-RAS model.

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Optimal Selection of Number and Location of Meteo-Hydrological Monitoring Networks on Vu Gia – Thu Bon River Basin using GIS

Nguyen Thi Hong[#], Phan Thi Thanh Truc[*], Nguyen Duy Liem[*], Nguyen Kim Loi[*]

[#] *Faculty of Geology, VNU University of Science, Thanh Xuan District, Ha Noi City, Vietnam*
E-mail: nthong@vnu.edu.vn

[*] *Department of Applied Geomatics, Nong Lam University- Ho Chi Minh City, Vietnam*
E-mail: nguyenduyliem@hcmuaf.edu.vn

Abstract*— Meteorological data play a particularly important role in hydrologic research because the climate and weather of an area exert a profound influence on most hydrologic processes. Meanwhile, hydrological data are critical for performing a range of purposes, including water resources assessment, impacts of climate change and flood forecasting and warning. It can be said that the prevention of disasters caused by floods and droughts would be impossible without rational forecasting technology based on an understanding of the rainfall-runoff phenomenon and statistical analysis of past hydrological data, which cannot be achieved without meteo-hydrological observations. The lack of adequate meteo-hydrological data affects the ability to model, predict and plan for catastrophic events such as floods and droughts which have obvious negative impacts on public health and socio-economic aspects. The accurate estimation of the spatial distribution of meteorological and hydrological parameters requires a dense network of instruments, which entails large installation and operational costs. It is thus necessary to optimize the number and location of meteo-hydrological stations. This paper presents a GIS-based approach to establishing an optimal meteo-hydrological station network on Vu Gia- Thu Bon river basin for developing an up-to-date real time flood warning system. Based on statistical analysis of the annual rainfall total data at 9 existing gauges in the study area from 1980 to 2013, it showed that the error of the existing network was about 7.47%. Considering 9 rain gauges as a standard representative of rainfall over the region, if the error decreases from 7.47% to 5%, the number of additional rain gauges should be 20. For adequate and economical network design, these additional rain gauges were spatially distributed between the different isohyetals after considering the relative distances between rain gauges, their accessibility, personnel required for making observations using multi-layers analysis and spatial interpolation. For hydrological stations, based on consideration existing network with the requirements set out by the flood warning system, the number of stations should be five. In terms of spatial distribution, three stations were distributed across two main tributaries of Vu Gia- Thu Bon river basin, behind the dams for water discharge calibration and the others were located on downstream for water stage calibration. The results of the study provided a scientific approach can be applied to optimizing the meteo-hydrological station network over the river basin.

***Keywords*— meteorological; meteo-hydrological; river basin; GIS**

Automated procedure of real-time flood forecasting in Vu Gia – Thu Bon river basin, Vietnam by integrating SWAT and HEC–RAS models

Nguyen Kim Loi, Nguyen Duy Liem, Le Hoang Tu, Nguyen Thi Hong, Cao Duy Truong, Vo Ngoc Quynh Tram, Tran Thong Nhat, Tran Ngoc Anh and Jaehak Jeong

ABSTRACT

The precise and reliable simulation of hydrologic and hydraulic processes is important for efficient flood forecasting and warning. The study proposes a real-time flood forecasting system which integrates a coupled hydrological-hydraulic modeling system, weather station network, and stream gauges in a web-based visualization environment. An automated procedure was developed for linking dynamically terrestrial rainfall-runoff processes and river hydraulics by coupling the SWAT hydrological model and the HEC–RAS hydraulic model. The flood forecasting system was trialed in the Vu Gia – Thu Bon river basin, Quang Nam province, Vietnam. The results showed good statistical correlation between predicted and measured stream flow for a 10-year calibration period ($R^2 = 0.95$, $NSI = 0.95$, $PBIAS = -1.54$) and during the following 10-year validation period as well ($R^2 = 0.93$, $NSI = 0.93$, $PBIAS = 6.18$). A close-up analysis of individual storm events indicated that the magnitude and timing of peak floods were accurately predicted in 2015 ($R^2 = 0.88$, $NSI = 0.69$, $PBIAS = 4.50$) and 2016 ($R^2 = 0.80$, $NSI = 0.93$, $PBIAS = 6.18$). In addition, the automated procedure was demonstrated to be reliable with dependable computational efficiency of less than 5 minutes processing time.

Key words | flood forecasting, flood warning system, HEC–RAS, SWAT, Vu Gia – Thu Bon river basin

Nguyen Kim Loi (corresponding author)
Nguyen Duy Liem
Le Hoang Tu
Vo Ngoc Quynh Tram
Nong Lam University,
Ho Chi Minh City,
Vietnam
E-mail: *ngkloi@hcmuaf.edu.vn*

Nguyen Thi Hong
Tran Ngoc Anh
Hanoi University of Science,
Vietnam National University,
Hanoi,
Vietnam

Cao Duy Truong
Tran Thong Nhat
Ho Chi Minh University of Natural Resources and Environment,
Ho Chi Minh City,
Vietnam

Jaehak Jeong
Texas A&M University,
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