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

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Texas A&M University
Content

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

**GIS – RS Team**
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- Ms. Trần Lê Như Quỳnh¹
- Ms. Trần Duy Long⁴
- Mr. Đặng Xuân Tiến¹

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- 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

(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?

\[ W_{\text{mean}} = 20.1 \text{ billion cbm}, \quad Q_{\text{mean}} = 400 \text{ cms} \]

\[ Q (\text{cms}): \]

\[ Q_{\text{flood}} = 309 - 778 > Q_{\text{dry}} = 60 - 130 \]

\[ Q_{\text{Nong Son (TB)}} > Q_{\text{Thanh My (VG)}} \]

\[ S = 10,350 \text{ sq.km} \]

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)
- Economic Growth Needs (hydropower construction, road building, deforestation)
- High Growth Population, Social Complex
- 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.
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 meteorological-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

<table>
<thead>
<tr>
<th>ID</th>
<th>Data types</th>
<th>Data sources</th>
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<tbody>
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<td></td>
<td><strong>Primary data</strong></td>
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<td>1</td>
<td>Socio-economic data</td>
<td>Participatory Rural Appraisal- PRA</td>
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<td>2</td>
<td>Real-time meteo-hydrological data</td>
<td>20 weather stations, 5 hydrological stations</td>
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<tr>
<td></td>
<td><strong>Secondary data</strong></td>
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<tr>
<td>1</td>
<td>Topographic map</td>
<td>Department of Natural Resources and Environment of Quang Nam province</td>
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<tr>
<td>2</td>
<td>2010 land use map</td>
<td>Environment of Quang Nam province</td>
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<tr>
<td>3</td>
<td>Soil map</td>
<td>Central Sub-Institute of Agricultural Planning and Design</td>
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<tr>
<td>4</td>
<td>Reservoir data (hydropower, irrigation)</td>
<td>Department of Natural Resources and Environment of Quang Nam province</td>
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<td>Meteo-hydrological data (1980- 2013)</td>
<td>Middle-Middle Region Hydro-Meteorological Centre</td>
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<td>Socio-economic data (2012- 2014)</td>
<td>Quang Nam Statistical Yearbook</td>
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<tr>
<td>7</td>
<td>Floods data (1998- 2015)</td>
<td>Irrigation Department of Quang Nam province</td>
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</tbody>
</table>
Structure of the real-time flood warning system

End users
- Households
- Managers

Telecommunications infrastructure

Internet

Data processing center

Flood warning module
Identify flooded households, estimate flood depths. Send flood warning messages to households, flood information to managers

WebGIS Server
Provide, manage HM, flood data

Database system
- Physical
- Socio-economic
- HM
- Flood

Flood simulating, forecasting module
Automatic flood simulating and forecasting based on SWAT-HEC-RAS model was calibrated, validated

Database Server
Receive, store data from stations

GSM/GPRS
Transmit data every 30 mins

1 U

Real-time hydro-meteorological (HM) data monitoring network

Rain gauge, Sensor:
- air temperature
- air humidity
- wind speed

Datalogger
Recorded data every 30 mins

Water level sensor

GSM/GPRS
Transmit data every 5 mins

GSM/GPRS
End users
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)*
HEC-RAS: Hydrologic Engineering Center's River Analysis System.
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

Watershed scale

Simulate water discharge at the outlets of the basin.

In-stream scale

Simulate flow velocity, water level at the cross sections.
How to integrate SWAT and HEC-RAS?

**SWAT**
- River network, flow direction
- Water discharge
- Time step (30 mins, 1 day)

**HEC-RAS**
- Geometric data
- Boundary condition, initial condition
- Time step (30 mins, 1 day)

Synchronize
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)

Weather database (5 mins)
(MS SQL Server)

Run SWAT

Aggregate data every 30 mins
(rainfall), daily (others data)

Update file.cio
(simulation duration, print output files on 30 mins)

SWAT project (30 mins)

Rainny season
(IX – XII)

Weather database (5 mins)
(MS SQL Server)

Run SWAT

Aggregate data every 30 mins
(rainfall), daily (others data)

Update file.cio
(simulation duration, print output files on daily)

SWAT project (30 mins)

Dry season
(I – VIII)

Aggregate data every day
(all data)

Update file.cio
(simulation duration, print output files on daily)

SWAT project (daily)

Water discharge output.rch (30 mins)

Water discharge output.rch (daily)
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 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)

Output file contains flood depth (*.tif)

Water discharge output.rch (30 mins)

Update *.u01 (upper boundary, 30 mins)

Update *.p01 (simulation duration, print output files on 30 mins)

HEC-RAS project (30 mins)

Run HEC-RAS

Water level *.dss (30 mins)

Run RAS Mapper

Water level *.dss (daily)

Flood depth *.tif (30 mins)

Flood depth *.tif (daily)

Update *.u01 (upper boundary, daily)

Update *.p01 (simulation duration, print output files on daily)

HEC-RAS project (daily)
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
- 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
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

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Type</th>
<th>Long. (°)</th>
<th>Lat. (°)</th>
<th>Elevation (m)</th>
<th>Data</th>
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</thead>
<tbody>
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<td>DM</td>
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<tr>
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<td>15.84</td>
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<tr>
<td>14</td>
<td>Cầu Lâu</td>
<td>TV</td>
<td>108.27</td>
<td>15.86</td>
<td>2</td>
<td>P, L</td>
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</tbody>
</table>

**Note:**
- DM (Rain gauge),
- KT (Weather station),
- TV (Hydrological station),
- P (Rainfall),
- T (Temperature),
- S (Sunshine),
- W (Wind),
- H (Humidity),
- E (Evaporation),
- L (Water level),
- D (Water discharge)
## Database

### 20 weather stations

<table>
<thead>
<tr>
<th>ID</th>
<th>Code</th>
<th>Long. (°)</th>
<th>Lat. (°)</th>
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<td>15,95</td>
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Database

20 weather stations

Field visit
Database

5 hydrological stations

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<th>ID</th>
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<th>Long. (°)</th>
<th>Lat. (°)</th>
<th>Elev. (m)</th>
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<td>TV_01</td>
<td>108,31</td>
<td>15,48</td>
<td>36,29</td>
</tr>
</tbody>
</table>
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).

Calibrated result at Thành Mỹ (Vu Gia) station

- $R^2 = 0.95$
- $NSI = 0.95$
- $PBIAS = -1.54$
- $p$-factor = 0.66
- $r$-factor = 0.46
Calibration and validation of SWAT

- **Calibration**: 1995-2004 (10 years).

Calibrated result at Nông Sơn (Thu Bon) station

- $R^2 = 0.93$
- $NSI = 0.92$
- $PBIAS = -0.64$
- $p$-factor = 0.86
- $r$-factor = 0.52
Calibration and validation of SWAT

- Validation: 2005-2014 (10 years).

Validated result at Thành Mỹ (Vu Gia) station

- $R^2 = 0.93$
- NSI = 0.93
- PBIAS = 6.18
- p-factor = 0.81
- r-factor = 0.48
Calibration and validation of SWAT

- Validation: 2005-2014 (10 years).

Validated result at Nông Sơn (Thu Bon) station

\[ Q \ (m^3/s) \]

- 95PPU
- Observed
- Simulated

\[ R^2 = 0.92 \]
\[ NSI = 0.91 \]
\[ PBIAS = 3.77 \]
\[ p-factor = 0.89 \]
\[ r-factor = 0.52 \]
Calibration and validation of HEC-RAS

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/ Stop**: 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/](http://vgtb.hcmuaf.edu.vn/)
Real-time flood and meteo-hydrological data on WebGIS

For managers: [http://vgtb.hcmuaf.edu.vn/admin/](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.
Optimal Selection of Number and Location of Meteo-Hydrological Monitoring Networks on Vu Gia – Thu Bon River Basin using GIS

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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 meteorological 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 meteorological 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 isohyets 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

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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.
Thank you for your attention!