SWAT 2018: Global Impacts and Future Horizons

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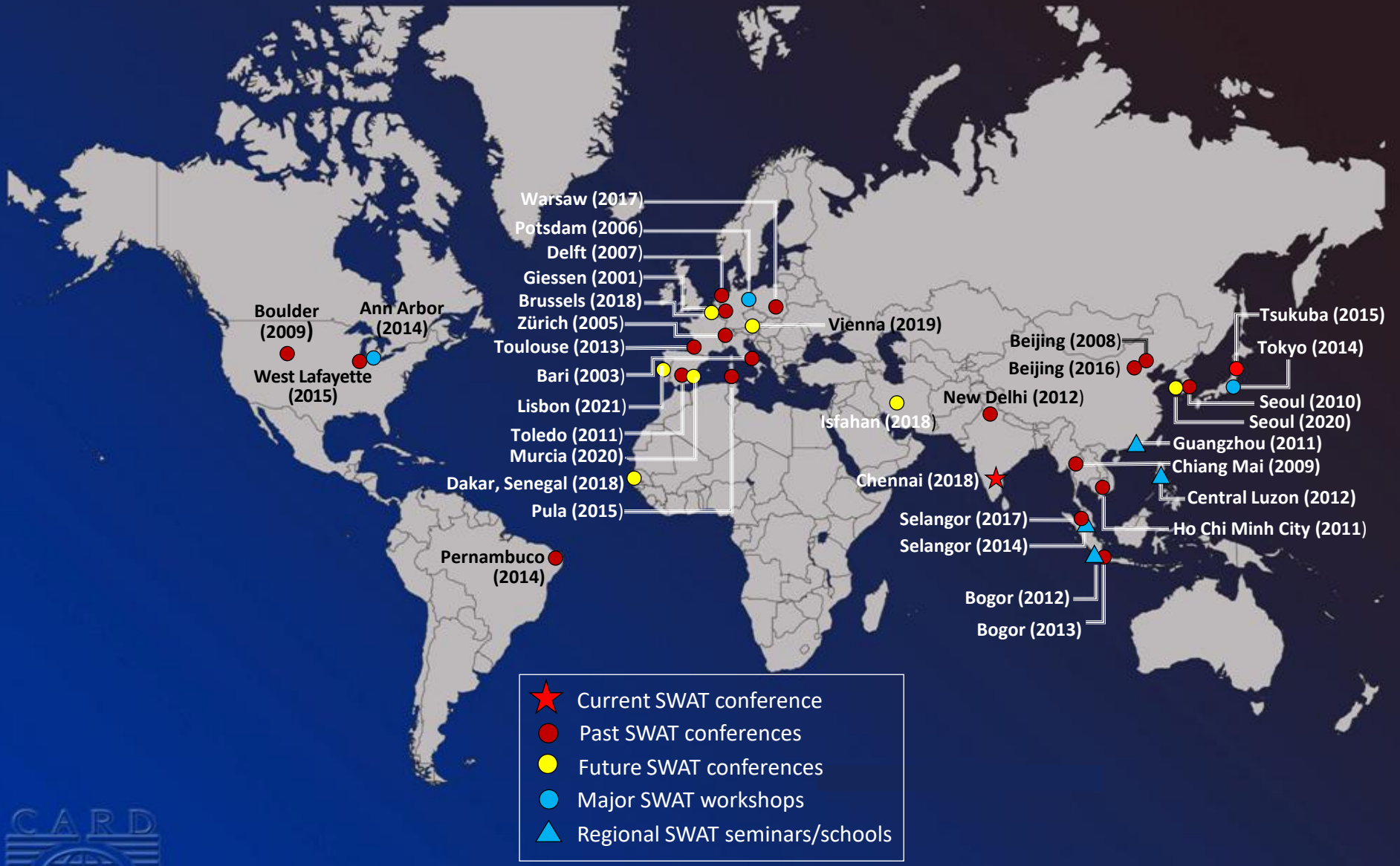
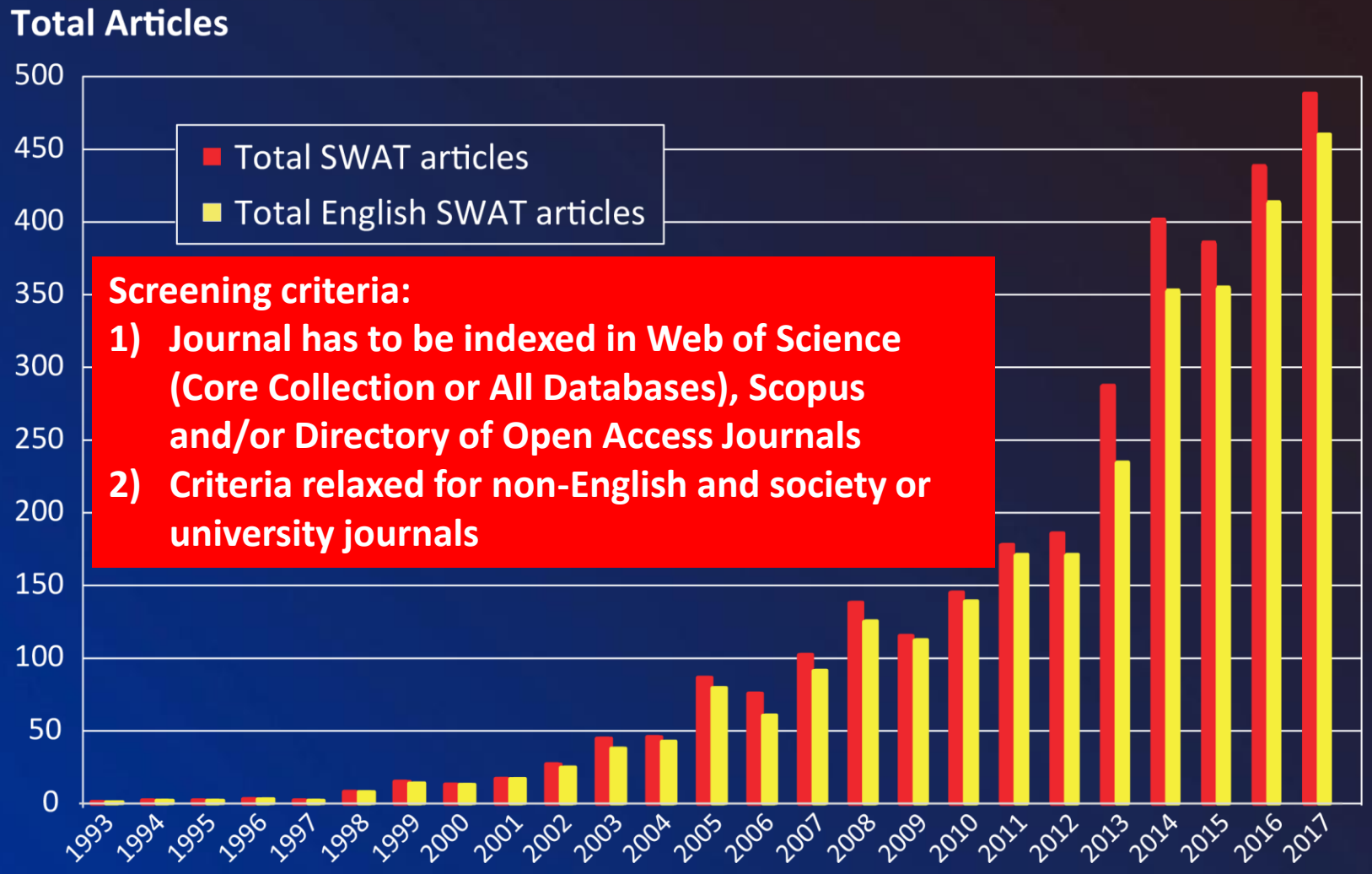
Presentation Overview

- SWAT conferences & publication trends
- Influence of Moriasi et al. studies
  - example summaries of SWAT statistical results
  - use of “soft data” / example applications
- Asia application trends and example applications
- Concluding thoughts on Future Horizons

Locations/Years of Past, Present & Future SWAT Events



Trends in SWAT-related articles in SWAT Literature Database (September_2017)



Source: https://www.card.iastate.edu/swat_articles/; data shown here includes both SWAT and modified SWAT applications as well as review articles (including literature citation analysis studies).

Heistermann et al. 2014 Bibliometric Analysis

Analyzed ~1.9 million references cited in over 170,000 articles categorized in 80 Journals in the Thomson Reuters Journal Citation Reports Water Resources Category for 1965 to 2012

"… the dominance of one topic is particularly remarkable: the use of watershed models and the related aspects of model calibration, evaluation, and uncertainty (ranks 7, 9, 10, 11, 16, 17, 19, 21, 25)."

11	Moriasi et al. 2007. Trans. ASABE
16	Gassman et al. 2007. Trans. ASABE
21	Arnold et al. 1998. J. Amer. Water Resources Assoc.

Source: Heistermann et al. 2014. Increasing life expectancy of water resources literature. Water Resources Research. 50: 5019–5028. Doi:10.1002/2014WR015674.

Web of Science All-Time Top-Cited SWAT-Related Studies (January 8, 2018)

Authors	Year	Title	Journal (rank)	Citations	
				All Databases	Core Collection
Arnold et al.	1998	Large area hydrologic modeling and assessment - part 1: Model development	JAWRA (1)	2,650	**2,447**
Moriasi et al.	2007	Model evaluation guidelines for systematic quantification of accuracy in watershed simulations	Trans. ASABE (1)	2,528	**2,423**
Gassman et al.	2007	The Soil and Water Assessment Tool: Historical development, applications, and future research directions	Trans. ASABE (2)	1,064	1,004
Arnold & Fohrer	2005	SWAT2000: Current capabilities and research opportunities in applied watershed modelling	Hydrol. Proc. (6)	607	566

Nexus Tools Platform: Popularity index P_r for 352 Models

SWAT P_r = 39.2

(no other hydrologic model P_r was close)

Source: Mannschatz et al. 2016. Nexus Tools Platform: Web-based comparison of modelling tools for analysis of water-soil-waste nexus. Environ. Model. & Software. 76: 137–153.

Moriasi et al. (2007; 2015) Suggested Streamflow NSE & R^2 Criteria

(NSE: Nash-Sutcliffe modeling efficiency)

Performance Rating	NSE Criteria (2007 Annual or Monthly)	NSE Criteria (2015 Annual, Monthly or Daily)	R^2 Criteria (2015 Annual, Monthly or Daily)
Very good	0.75< NSE ≤1.00	0.80< NSE ≤1.00	0.85< R^2 ≤1.00
Good	0.65< NSE ≤0.75	0.70< NSE ≤0.80	0.75 < R^2 ≤ 0.85
Satisfactory	0.50< NSE ≤0.65	0.50< NSE ≤0.70	0.60 < R^2 ≤ 0.75
Unsatisfactory	NSE ≤ 0.50	NSE ≤ 0.50	R^2 ≤ 0.60

Sources: Moriasi et al. 2007. Transactions of the ASABE. 50(3): 885-900. Doi: 10.13031/2013.23153. & Moriasi et al. 2015. Transactions of the ASABE. 58(6): 1763-1785. Doi: 10.13031/trans.58.10715.

Frequency of SWAT Daily Streamflow Statistical Results (combined from six review studies*)

Frequency	Calibration		Validation	
	R^2	NSE	R^2	NSE
Total models	104	207	102	189
0.9 – 1.0	9	11	5	7
0.8 – 0.89	17	21	14	20
0.7 – 0.79	27	53	26	28
0.6 – 0.69	27	43	20	46
0.5 – 0.59	11	36	16	27
0.4 – 0.49	8	14	11	18
0.3 – 0.39	0	7	4	13
0.0 – 0.29	5	14	6	11
< 0.0	0	9	0	19

*(1) Gassman et al. 2007. Trans. ASABE 50(4): 1211-1250 (2) Douglas-Mankin et al. 2010. Trans. ASABE 53(5): 1423-1431 (3) Tuppad et al. 2011. Trans. ASABE (4) Gassman et al. 2014. JEQ 43(1): 1-8 (5) Akhaven & Mehrabi, personal communication (statistics compiled for Iranian SWAT studies) (6) Tan, personal communication (statistics compiled for southeast Asian studies)

Increasing Recognition for Checking Model Outputs with "Soft Data"

- Arnold et al. 2015. Hydrological processes and model representation: Impact of soft data on calibration. Transactions of the ASABE. 58(6): 1637-1660. Doi: 10.13031/trans.58.10710.

- Consider known water balance, vegetation biomass & other processes, literature data, expert opinion, etc. in evaluating model output

- SWAT CHECK: can identify possible input problems

  - http://swat.tamu.edu/software/swat-check/

SWAT-VSA Approach

- Easton et al. 2008. Re-conceptualizing the Soil and Water Assessment Tool (SWAT) model to predict runoff from variable source areas. *J. Hydrol.* 348(3-4): 279-291.

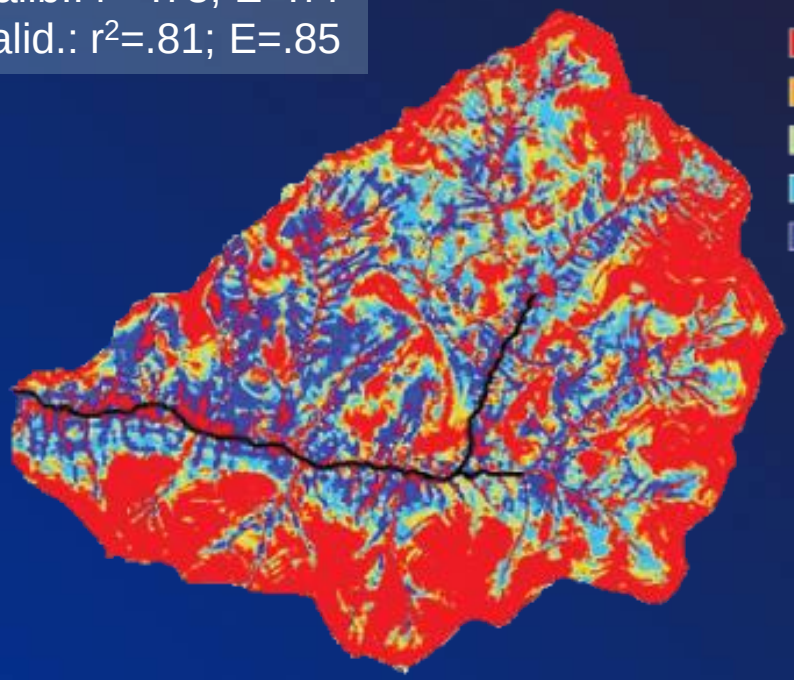
- Sub-watershed in the Cannonsville Reservoir watershed in south central New York, U.S.

  -Dominated by “Variable Source Area” (VSA) or saturation excess hydrology

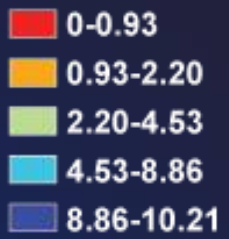
- Modified how the CN and available water content were defined (instead of model modification)

SWAT-VSA RCN Approach

Calib.: r^2=.78; E=.77
Valid.: r^2=.81; E=.85



SWAT-VSA Runoff (mm)



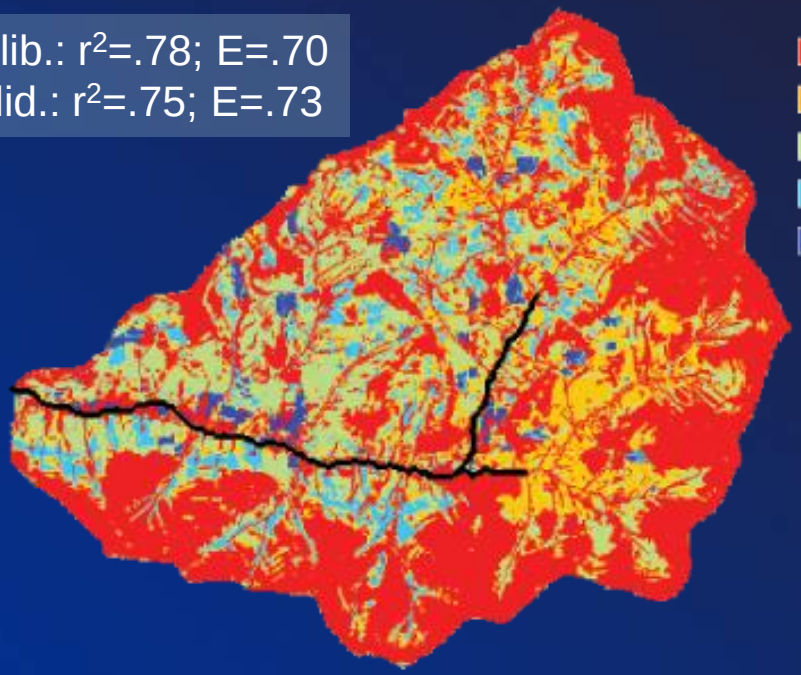
Calib.: r^2=.78; E=.79
Valid.: r^2=.80; E=.84

SWAT Runoff (mm)

Easton et al. 2008. Re-conceptualizing the soil and water assessment tool (SWAT) model to predict runoff from variable source areas. *Journal of Hydrology* 348(3-4): 279– 291.

SWAT-VSA RCN Approach

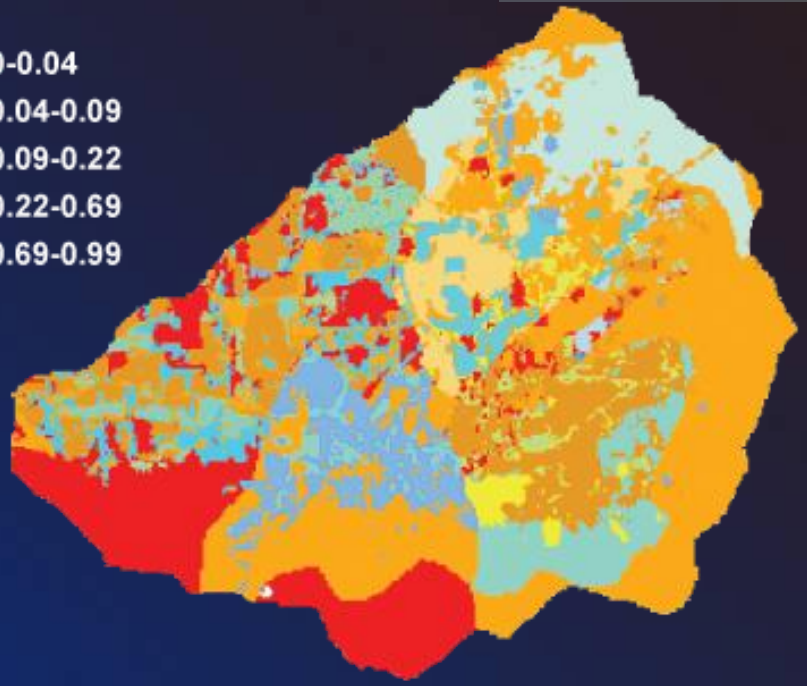
Calib.: r^2=.78; E=.70
Valid.: r^2=.75; E=.73



SWAT-VSA Dissolved P (kg ha^{-1})

0-0.04
0.04-0.09
0.09-0.22
0.22-0.69
0.69-0.99

Calib.: r^2=.59; E=.39
Valid.: r^2=.66; E=.54



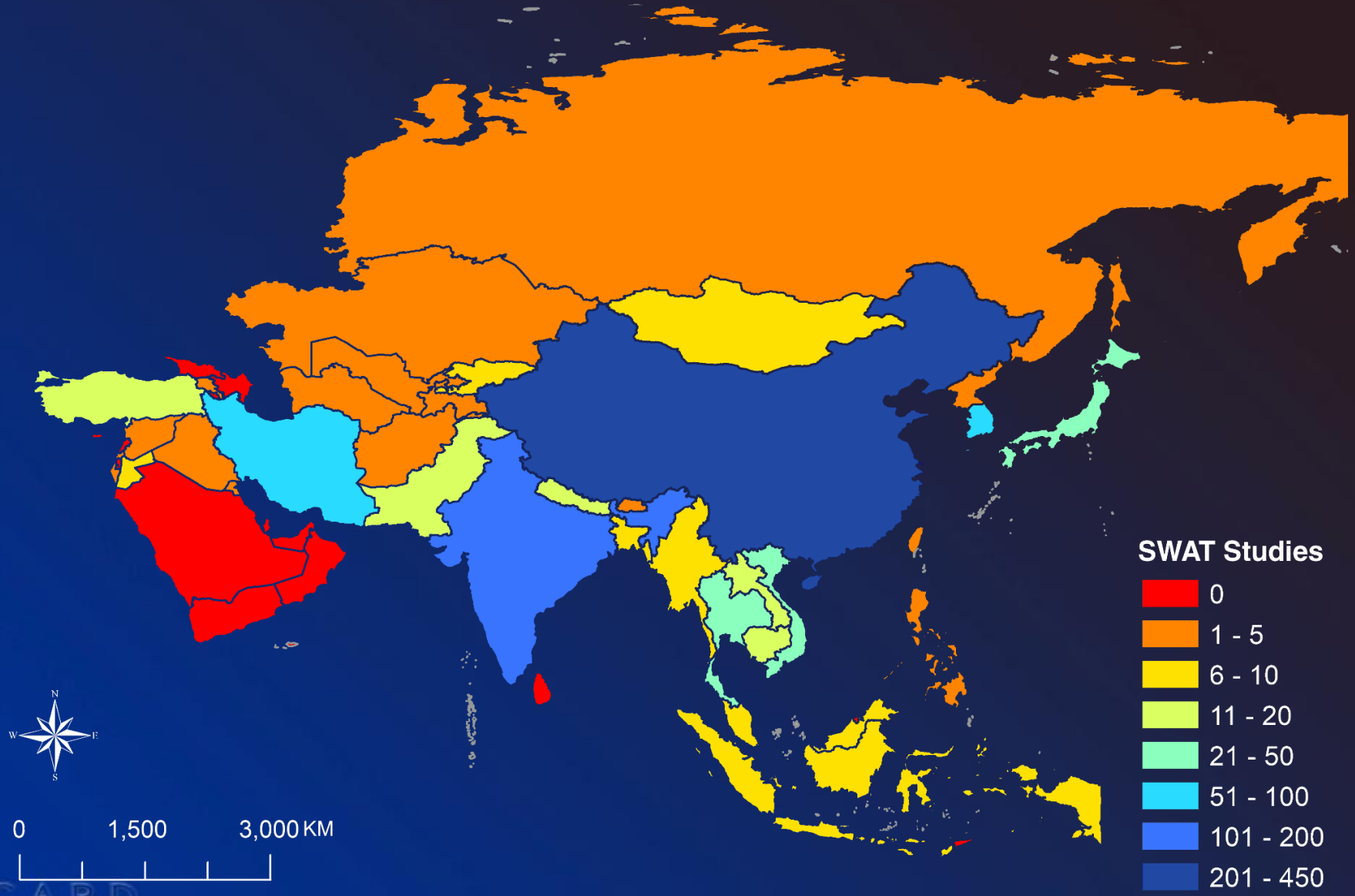
SWAT Dissolved P (kg ha^{-1})

Easton et al. 2008. Re-conceptualizing the soil and water assessment tool (SWAT) model to predict runoff from variable source areas. *Journal of Hydrology* 348(3-4): 279– 291.

North American Modified SWAT Models

Locations of SWAT-Related Events in Asia

Asia SWAT Studies Published in English



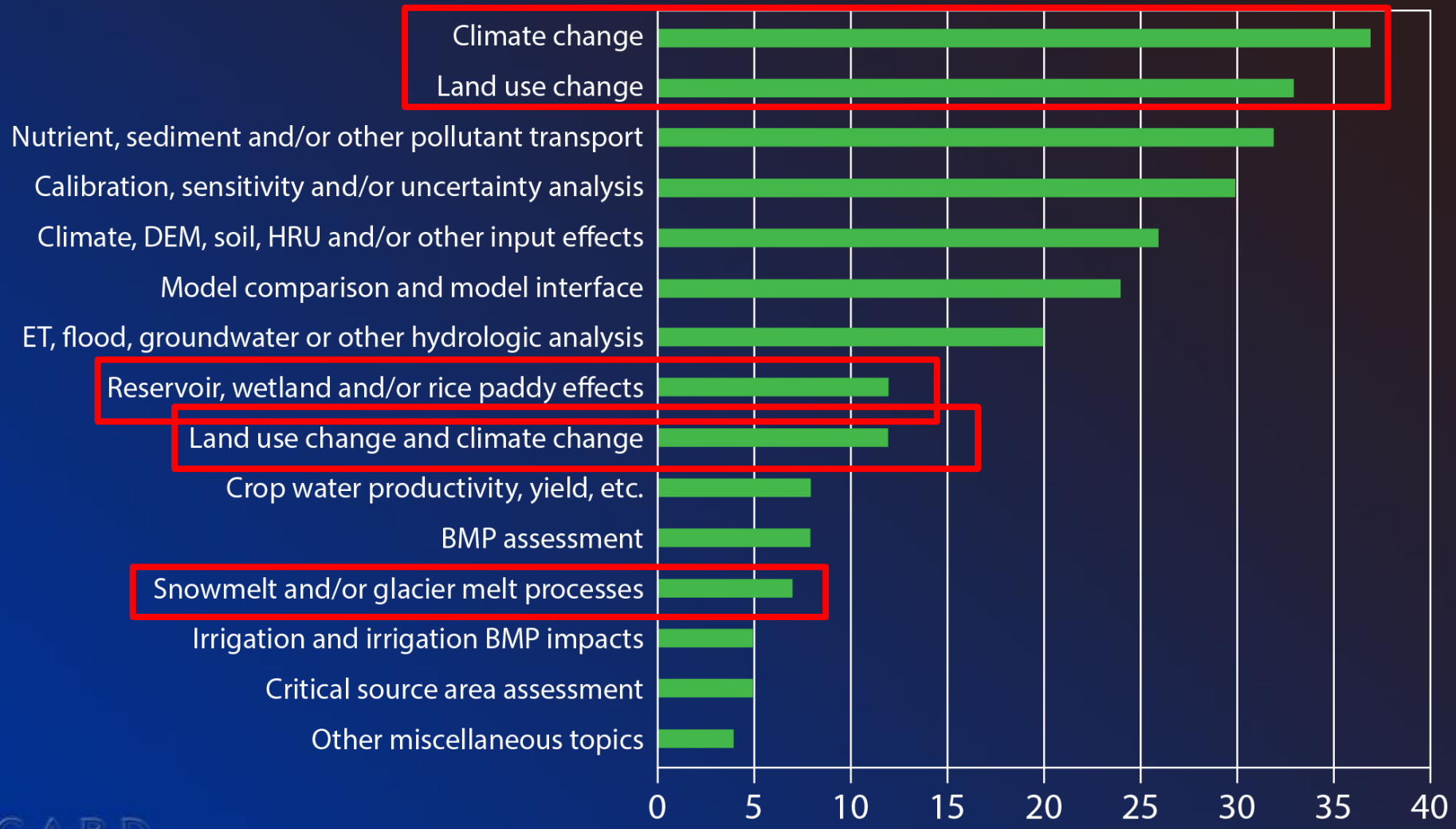
Source: SWAT Literature Database (https://www.card.iastate.edu/swat_articles/)

Influence of Major SWAT Events on Southeast Asia Publishing Trends

Country	Year	Event	English Studies	
			≤Year	>Year
Thailand	2009	Chiang Mai conference	1	27
Vietnam	2011	Ho Chi Minh City conference	4	31
Philippines	2012	Central Luzon Seminar/School	1	2
Indonesia	2012/ 2013	Bogor SWAT Seminar/School & Bogor SWAT Conference	0	10
Malaysia	2014	Selangor SWAT Seminar/School	3	7

Source: SWAT Literature Database (https://www.card.iastate.edu/swat_articles/)

China SWAT Application Trends (October, 2015)



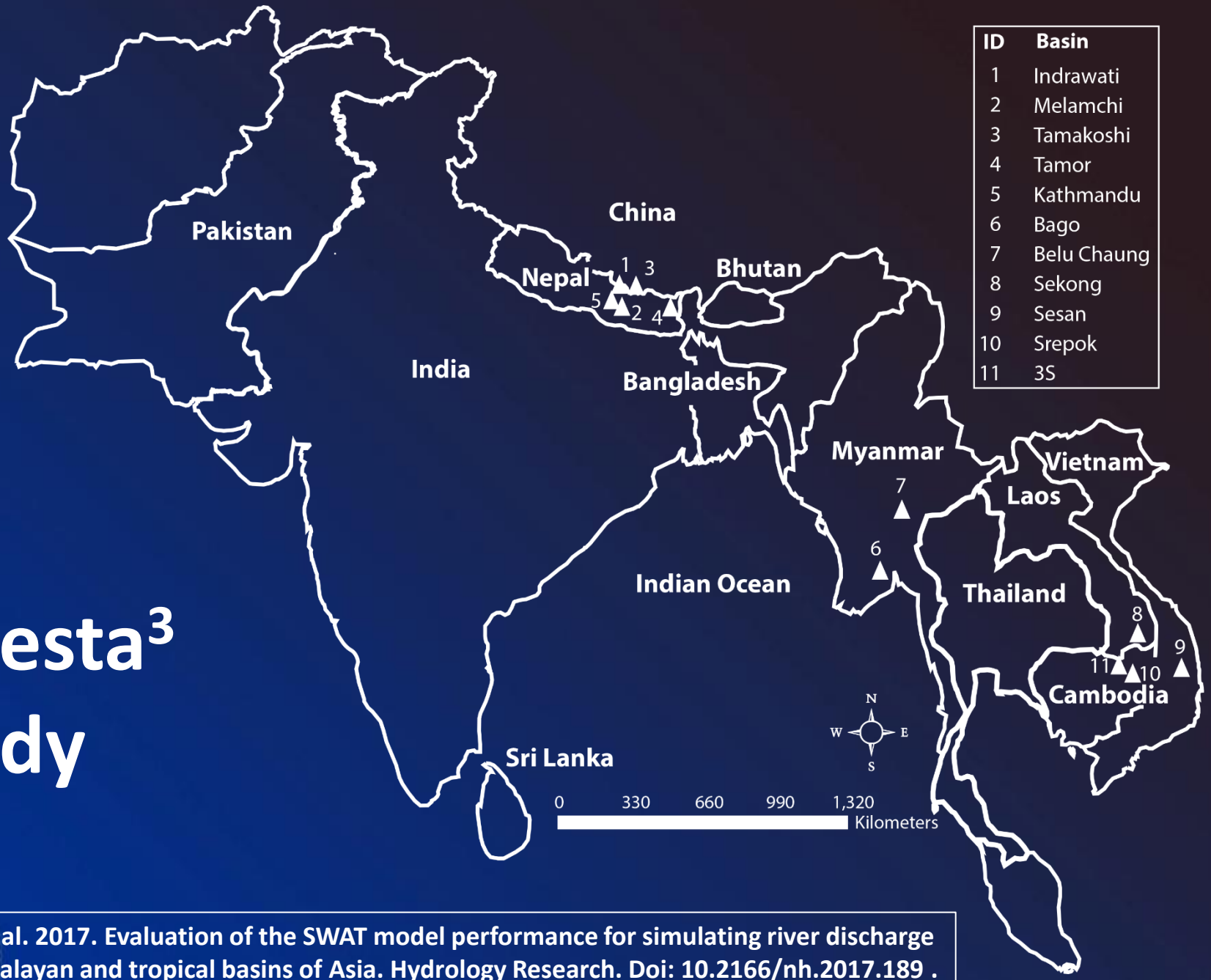
Source: SWAT Literature Database (https://www.card.iastate.edu/swat_articles/)

Summary of "Indian Subcontinent" Studies (SWAT Literature Database)

Country	Total Studies	Climate Change	Hydrologic Testing	Other
Bangladesh	9	5	6	land use change (2)
Bhutan	5	5	5	land use change (1)
India	130	30	30	Model comparison or interface (15)
Nepal	20	14	14	snowmelt or glacier melt processes (3)
Pakistan	13	3	8	snowmelt or glacier melt processes (2)

Source: SWAT Literature Database (https://www.card.iastate.edu/swat_articles/)

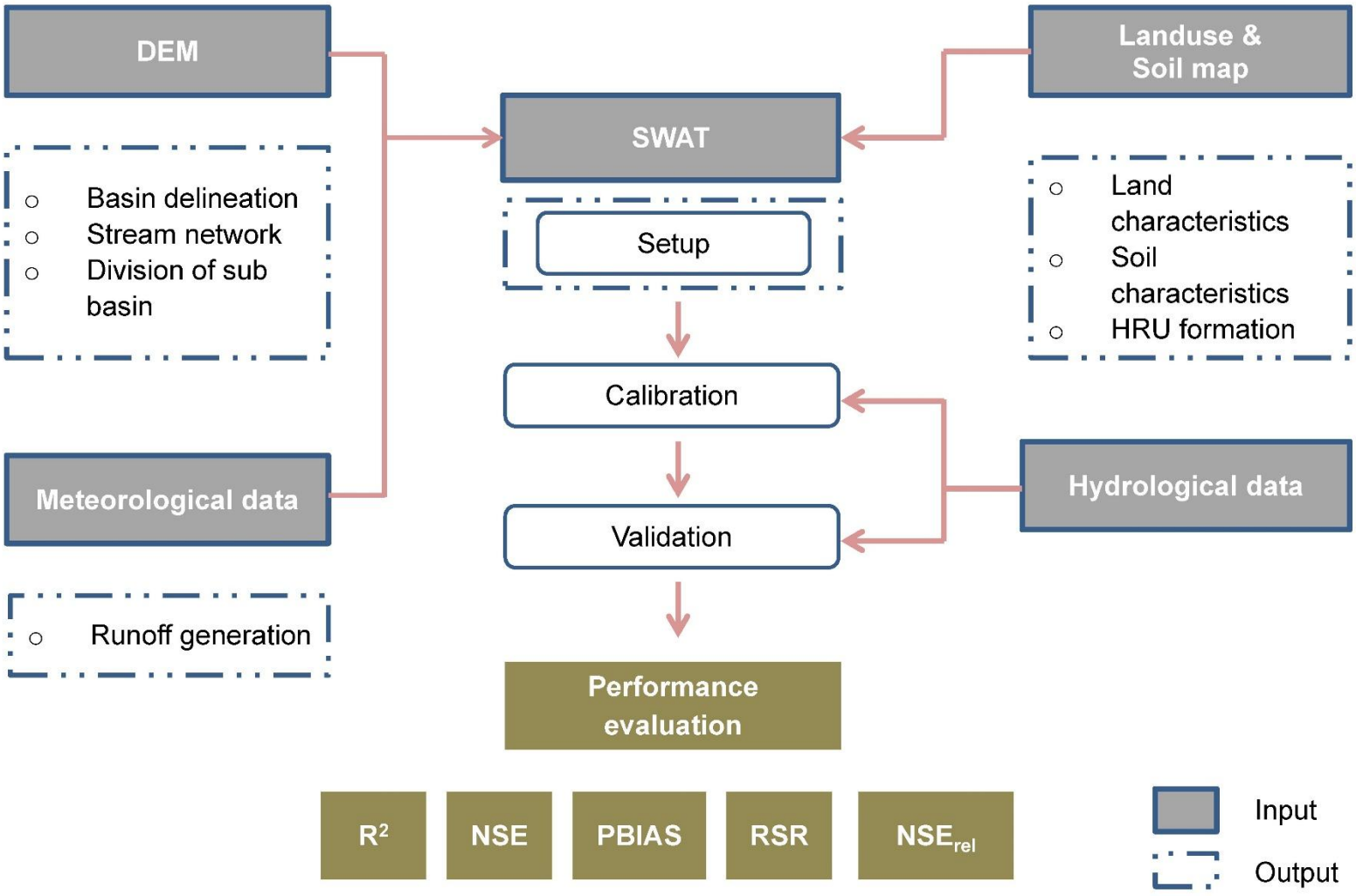
Shresta[3] Study



ID	Basin
1	Indrawati
2	Melamchi
3	Tamakoshi
4	Tamor
5	Kathmandu
6	Bago
7	Belu Chaung
8	Sekong
9	Sesan
10	Srepok
11	3S

Shresta et al. 2017. Evaluation of the SWAT model performance for simulating river discharge in the Himalayan and tropical basins of Asia. Hydrology Research. Doi: 10.2166/nh.2017.189 .

Simulation Framework used by Shresta[3]



Shresta et al. 2017. Evaluation of the SWAT model performance for simulating river discharge in the Himalayan and tropical basins of Asia. Hydrology Research. Doi: 10.2166/nh.2017.189 .

Shresta[3] Findings

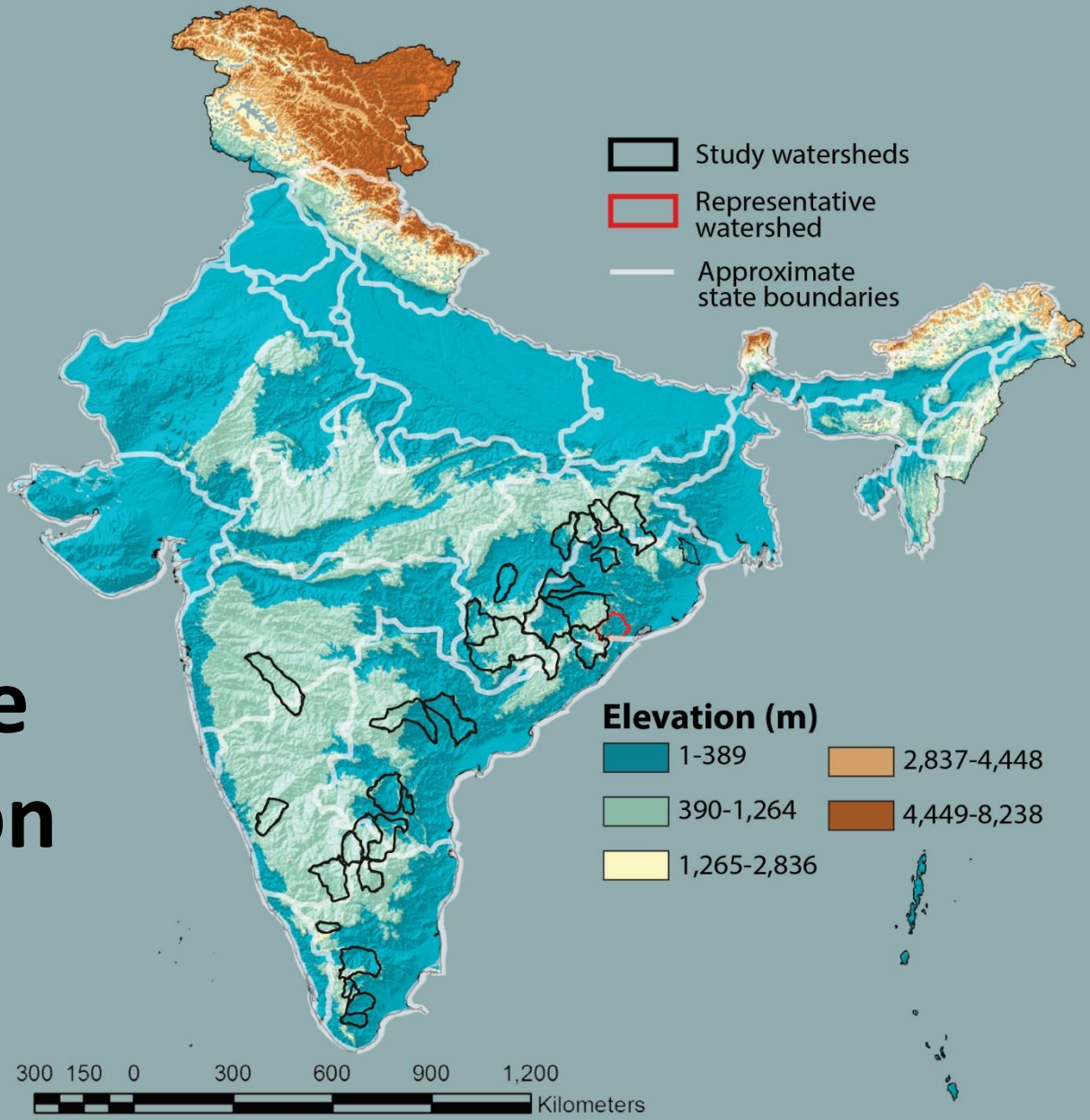
- SWAT was determined to be hydrologically applicable for both Himalayan and tropical systems

- Model streamflow performance was stronger for the Himilayan systems; e.g., daily calibration NSE range results:
  - -Himalayan: 0.72 to 0.81
  - - Tropical: 0.36 to 0.72

- The majority of SWAT simulations overpredicted low flow conditions or underpredicted peak discharge conditions

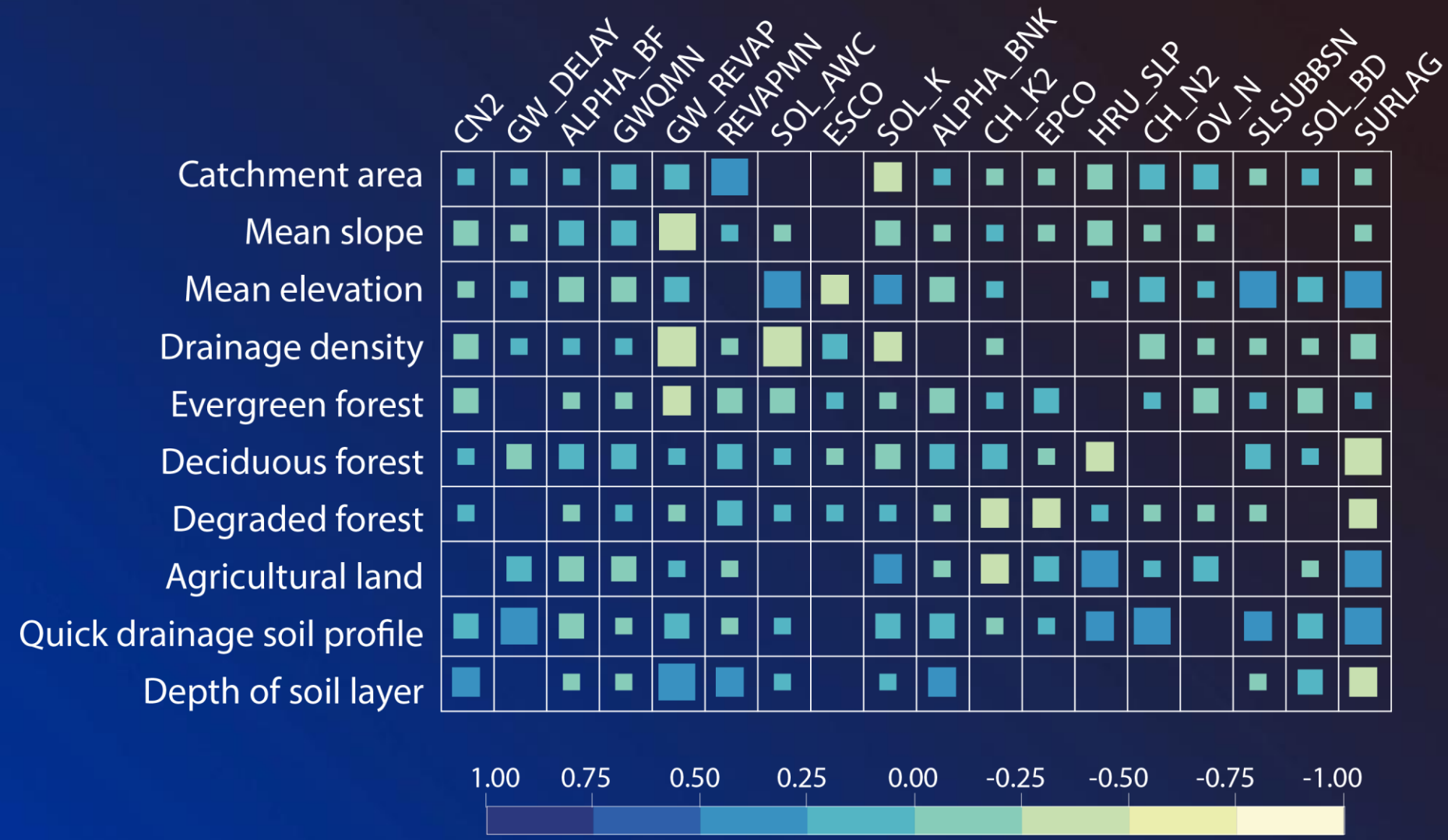
Shresta et al. 2017. Evaluation of the SWAT model performance for simulating river discharge in the Himalayan and tropical basins of Asia. Hydrology Research. Doi: 10.2166/nh.2017.189 .

India Study: Estimation of Streamflow in 32 Ungauged Watersheds Using Multiple Regionalization Techniques



Adapted from: Swain & Petra. 2017. Streamflow estimation in ungauged catchments using regionalization techniques. J Hydrol. 544: 420-433. Doi: 10.1016/j.jhydrol.2017.08.054

Correlation Between SWAT & Watershed Characteristics



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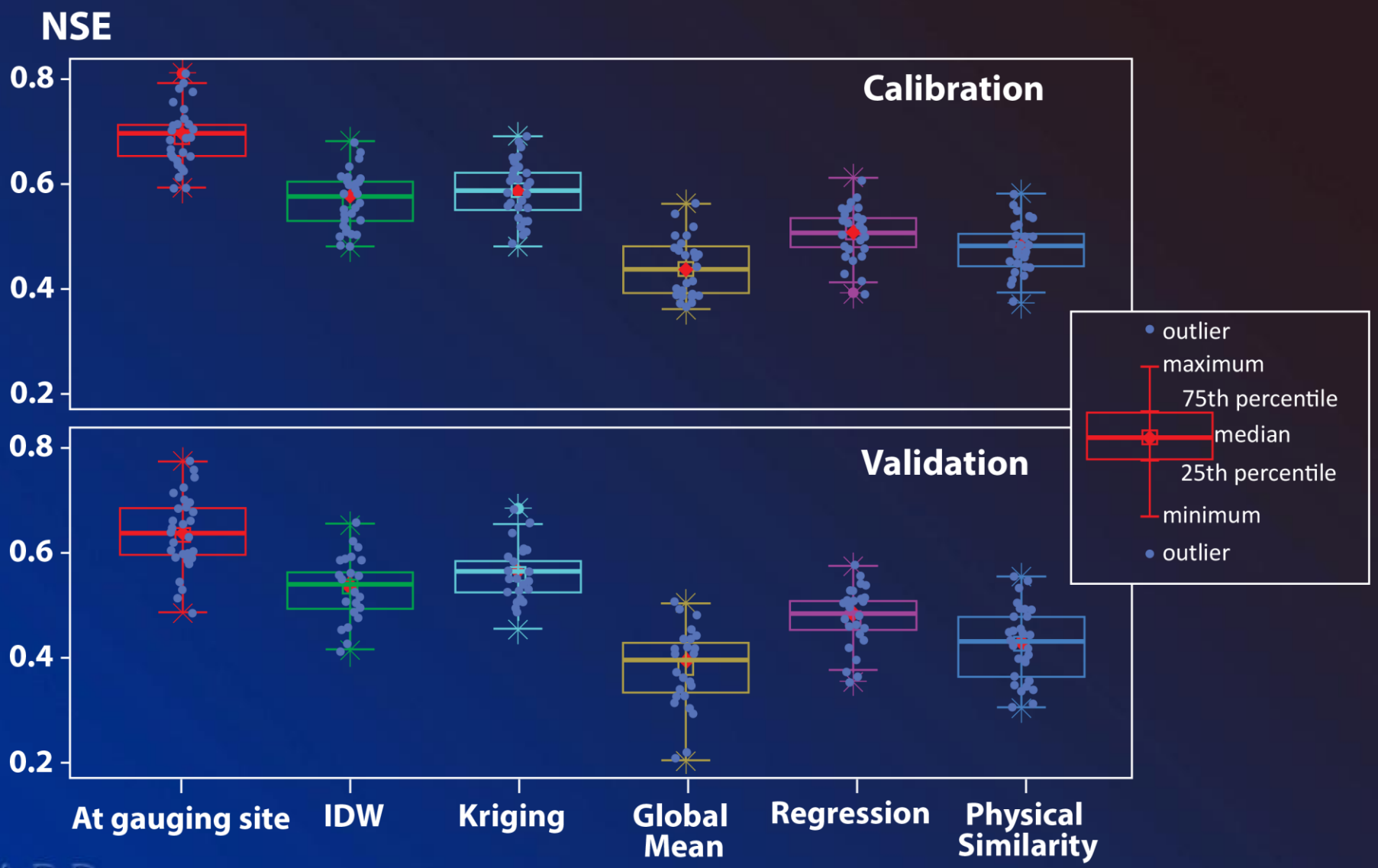
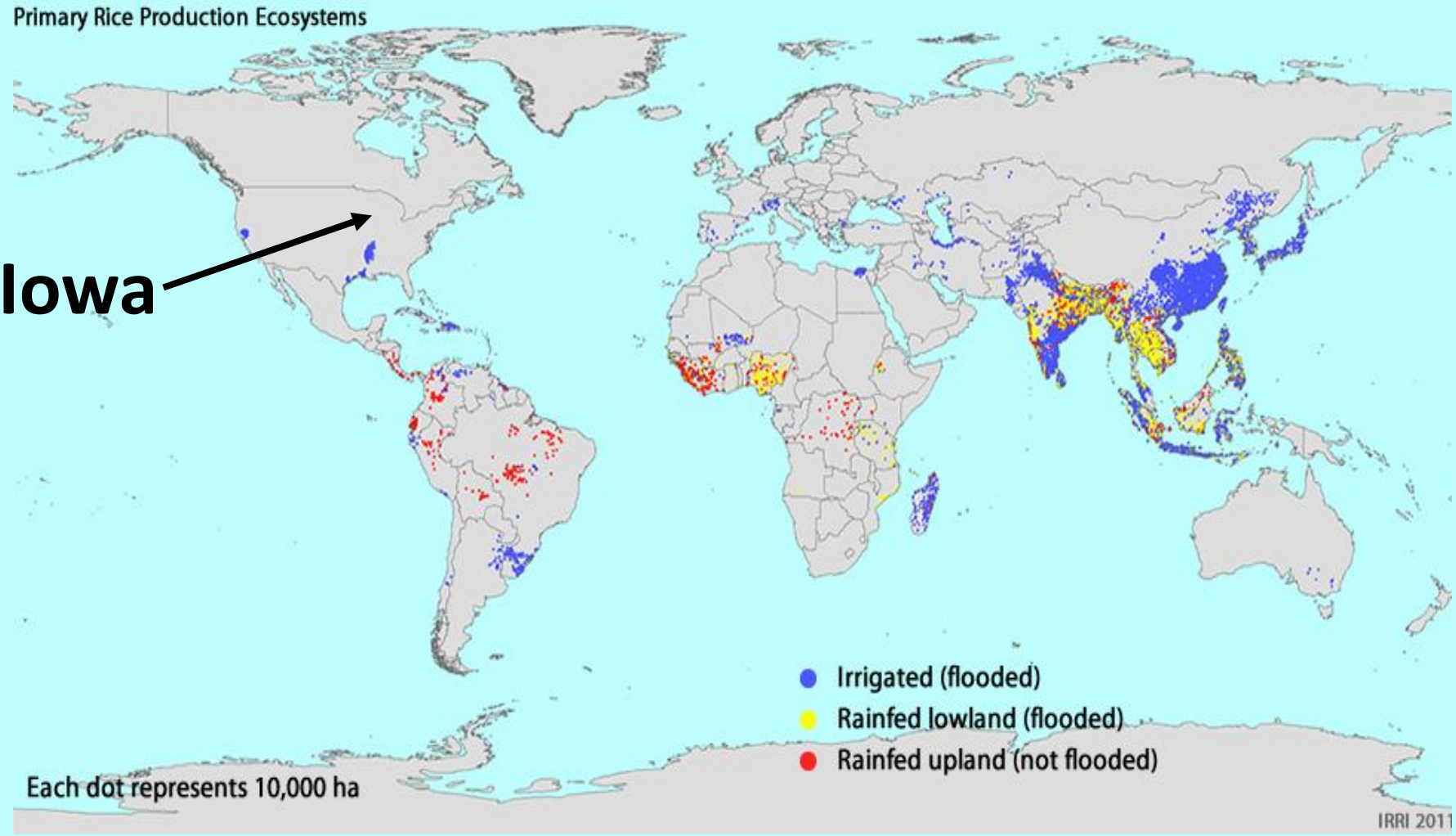
Correlation Between SWAT & Watershed Characteristics



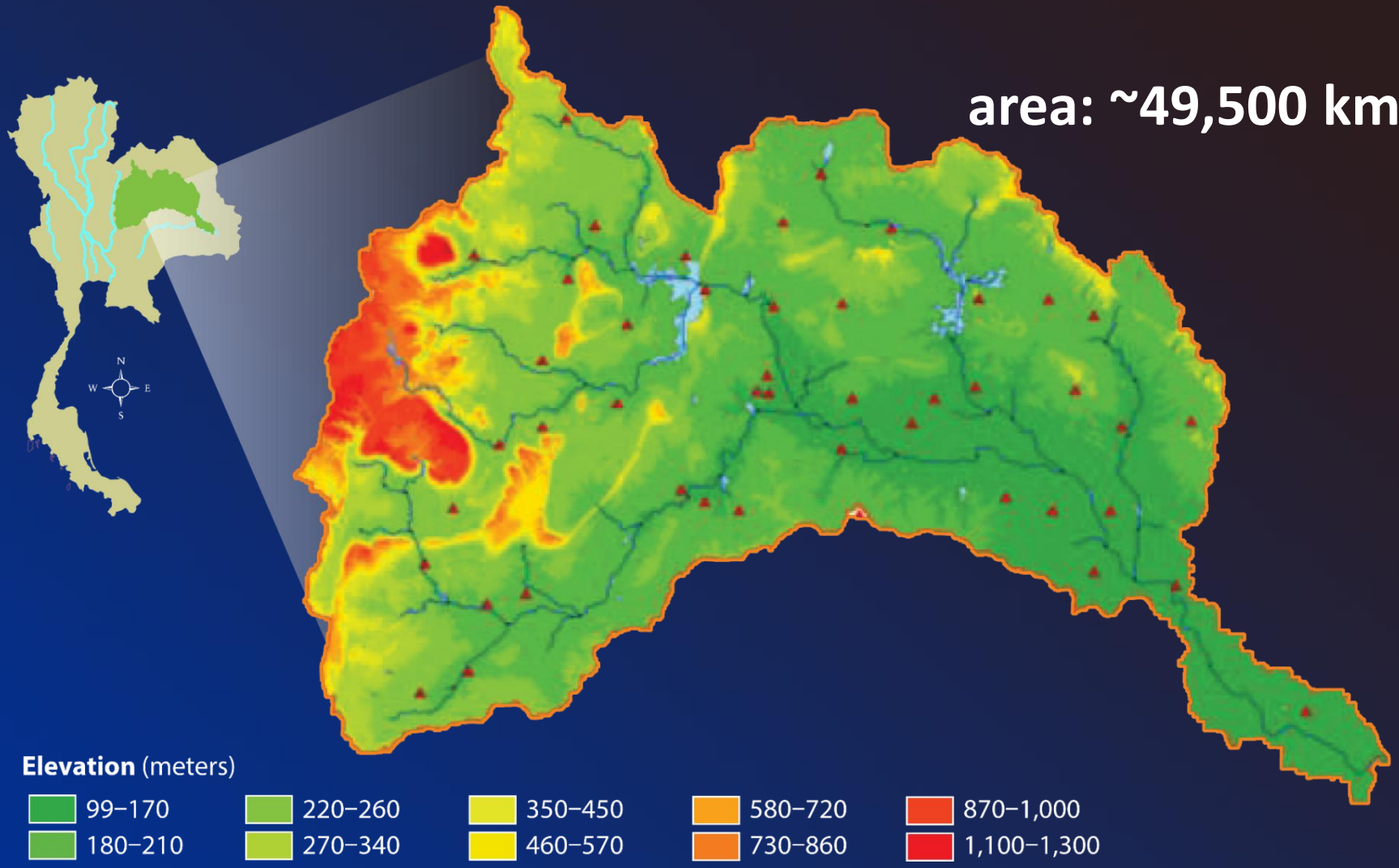
Adapted from: Swain & Petra. 2017. Streamflow estimation in ungauged catchments using regionalization techniques. J Hydrol. 544: 420-433. Doi: 10.1016/j.jhydrol.2017.08.054

Distribution of Global Rice Production



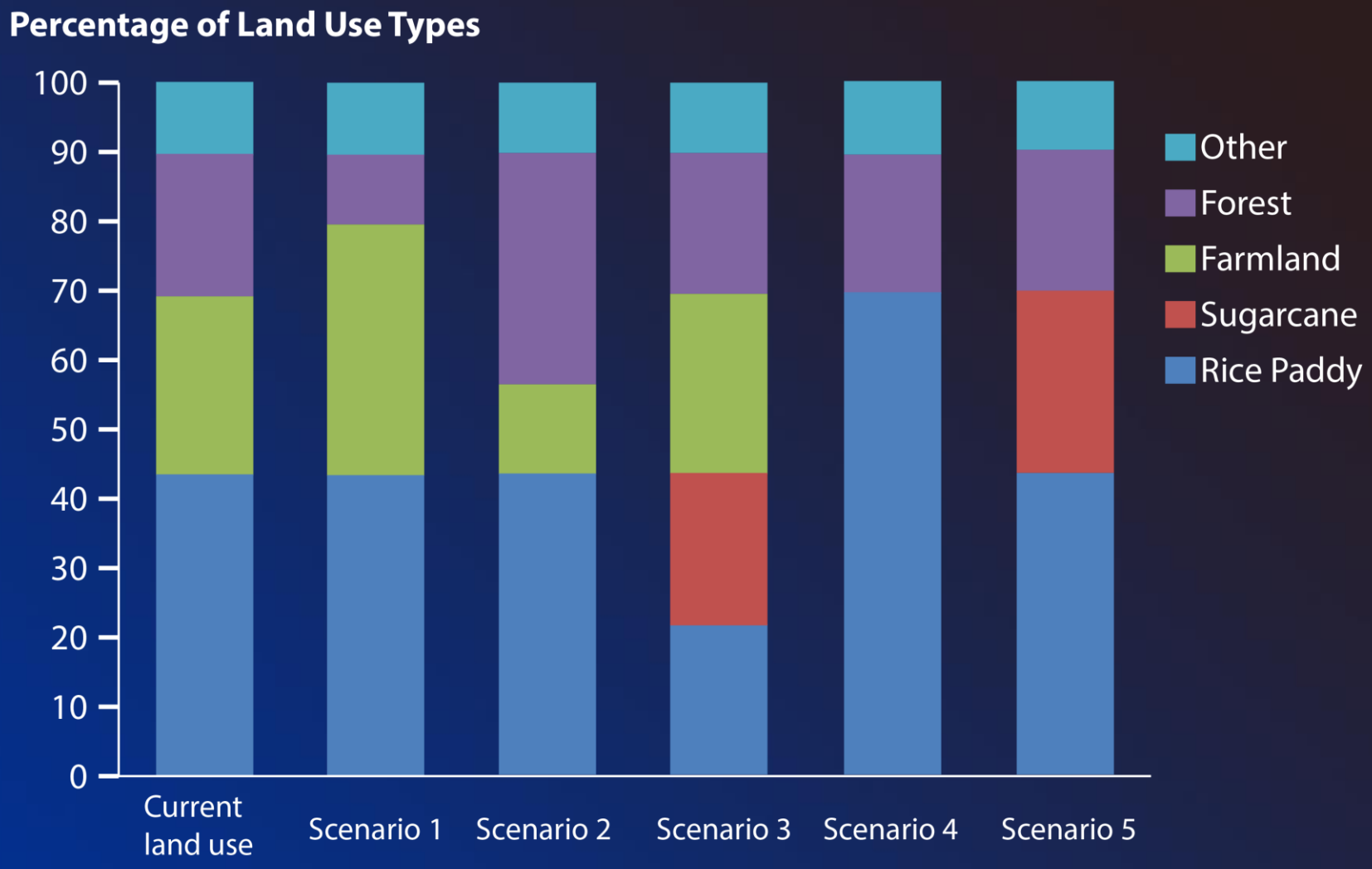
Source: Rice Knowledge Bank: Submerged Soils for Rice Production. International Rice Research Institute (IRRI). Available at: http://www.knowledgebank.irri.org/submergedsoils/index.php/rice-growing-environments/lesson-1

Chi River Basin, Thailand SWAT application



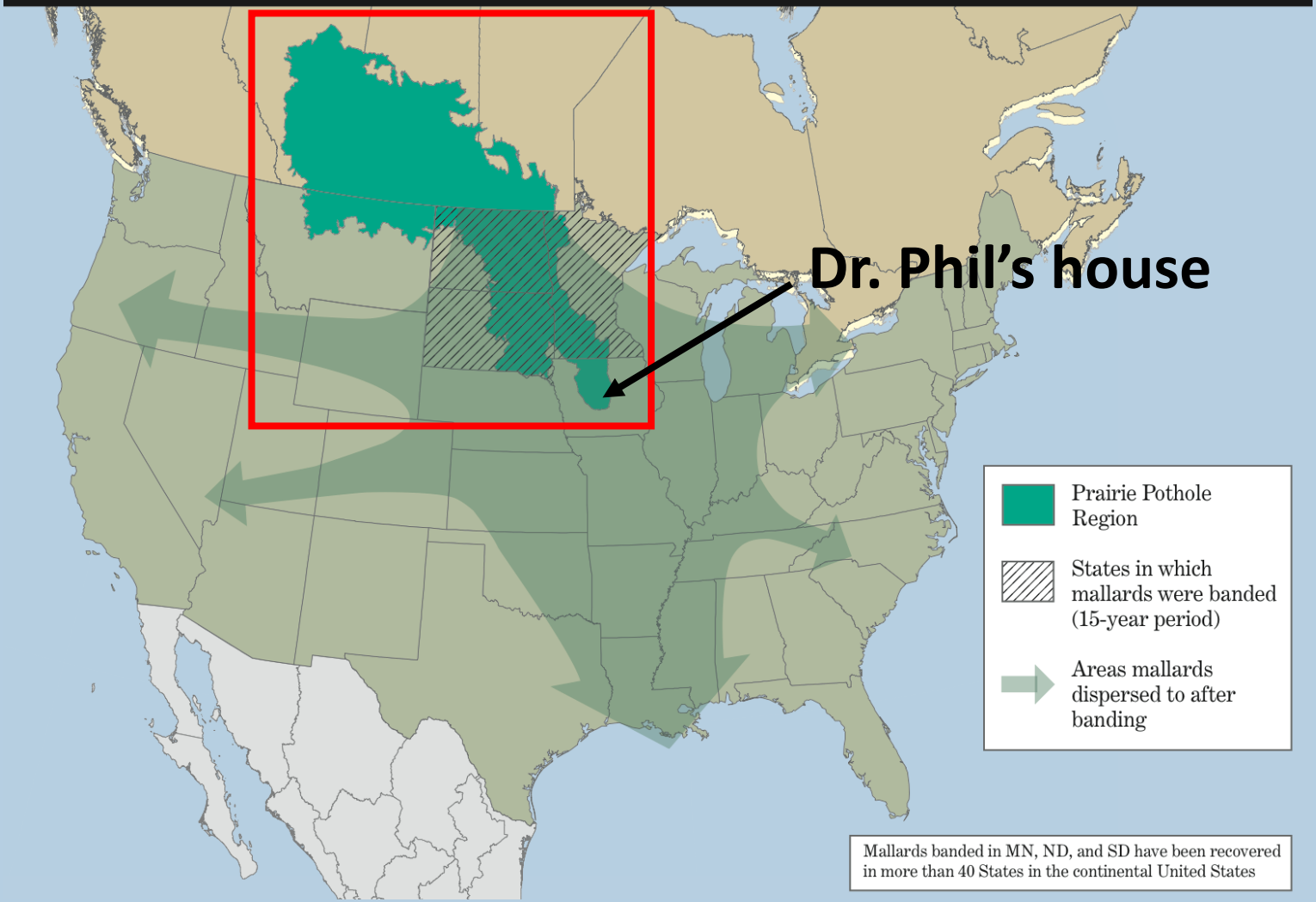
Source: Homdee et al. Impacts of land cover changes on hydrologic responses: A case study of Chi River Basin, Thailand. Annual J. of Hydraulic Engr., JSCE. 55: S31-S36.

Chi River Basin, Thailand SWAT application



Source: Homdee et al. Impacts of land cover changes on hydrologic responses: A case study of Chi River Basin, Thailand. Annual J. of Hydraulic Engr., JSCE. 55: S31-S36.

The Importance of the Prairie Pothole Region to National Waterfowl Populations



Source: Prairie Pothole Joint Venture. 2014. Available at: http://ppjv.org/resources/maps

Examples of Potholes in North American Prairie Pothole Region

Sources: http://www.plainsandprairiepotholeslcc.org/research-project/iowa-wetland-assessment-and-restorable-wetland-inventory/; http://academic.emporia.edu/aberjame/student/drake2/ppr.html#Introduction ; & http://outdoorsmidwest.wordpress.com/

Rice Related Parameters Mentioned in SWAT Documentation (2002 manual)

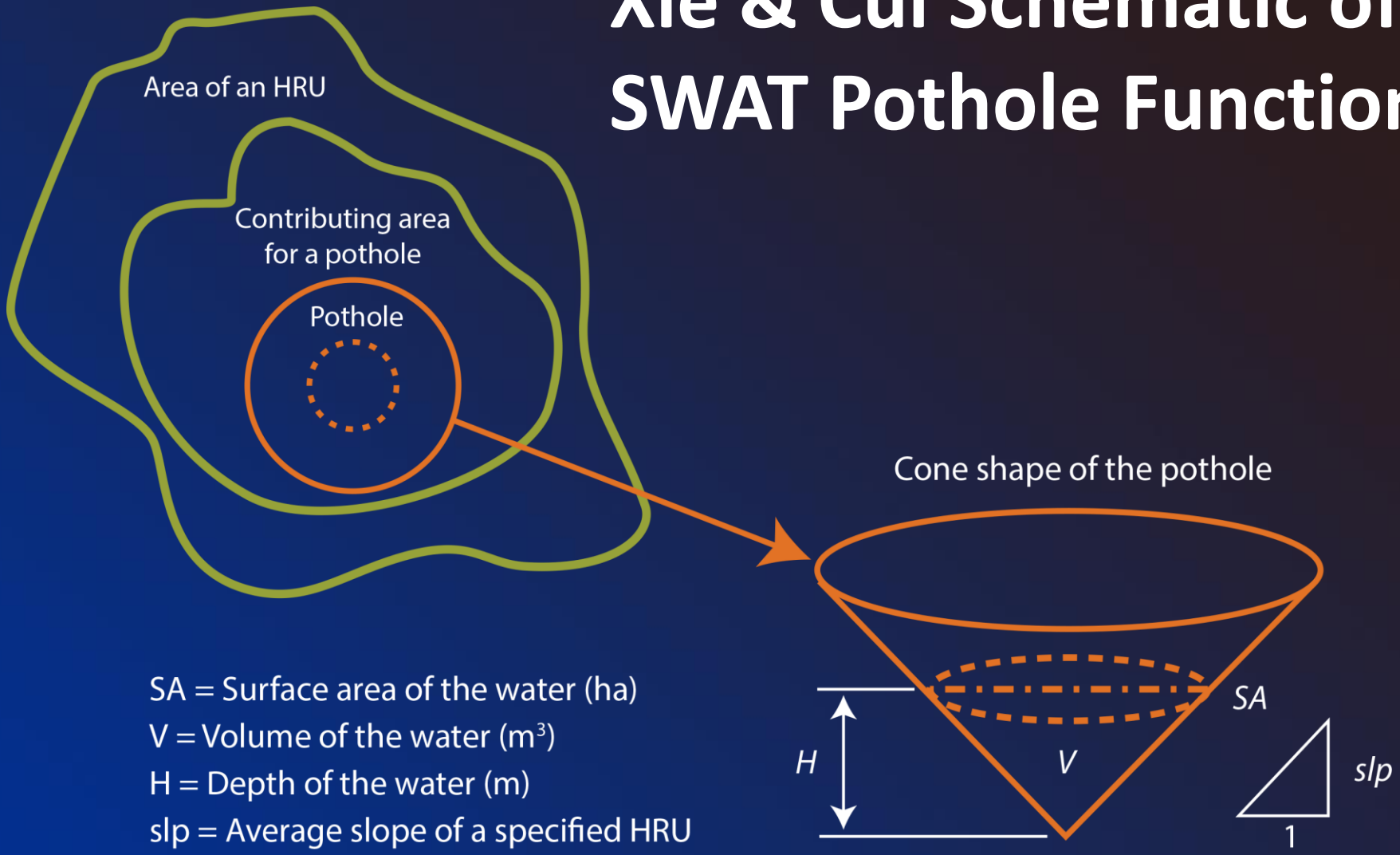
- EVLAI: LAI level that stops further evaporation from water surface for plants (e.g., rice) growing in ponded environment
- MGT_OPT = 13: releases/impounds water in HRUs growing rice or other plants
- Description of the use of the pothole algorithms states that rice paddies are a similar type of hydrologic system and that the pothole algorithms should be used to simulate rice paddies

Xie & Cui Modified SWAT Study in China

~1,129 km² Zhanghe Irrigation District (ZID); 41% rice, 18% upland crops, 16% forest, 25% bare/water/urban

Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Xie & Cui Schematic of SWAT Pothole Function



SA = Surface area of the water (ha)
V = Volume of the water (m^3)
H = Depth of the water (m)
slp = Average slope of a specified HRU

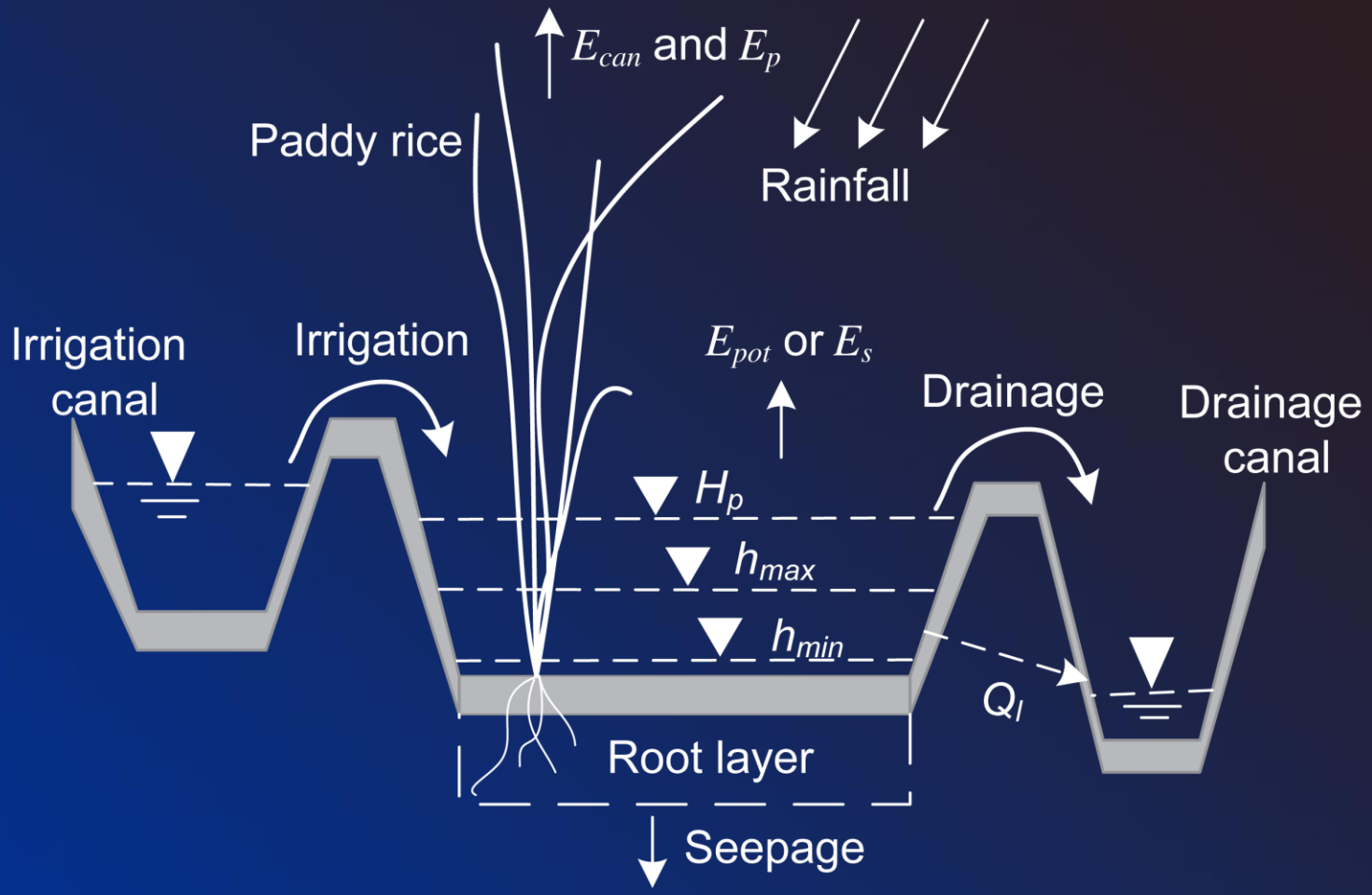
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Xie & Cui Modifications to SWAT

- Changed pothole shape from cone to cuboid, that also featured a constant surface area
- Introduced ET calculations that differentiated between dry and wet periods for a rice paddy
- Incorporated scheme to regulate paddy water depths via irrigation and drainage at different growth stages
  - as a function of three critical depths
- Added real-time irrigation from ponds

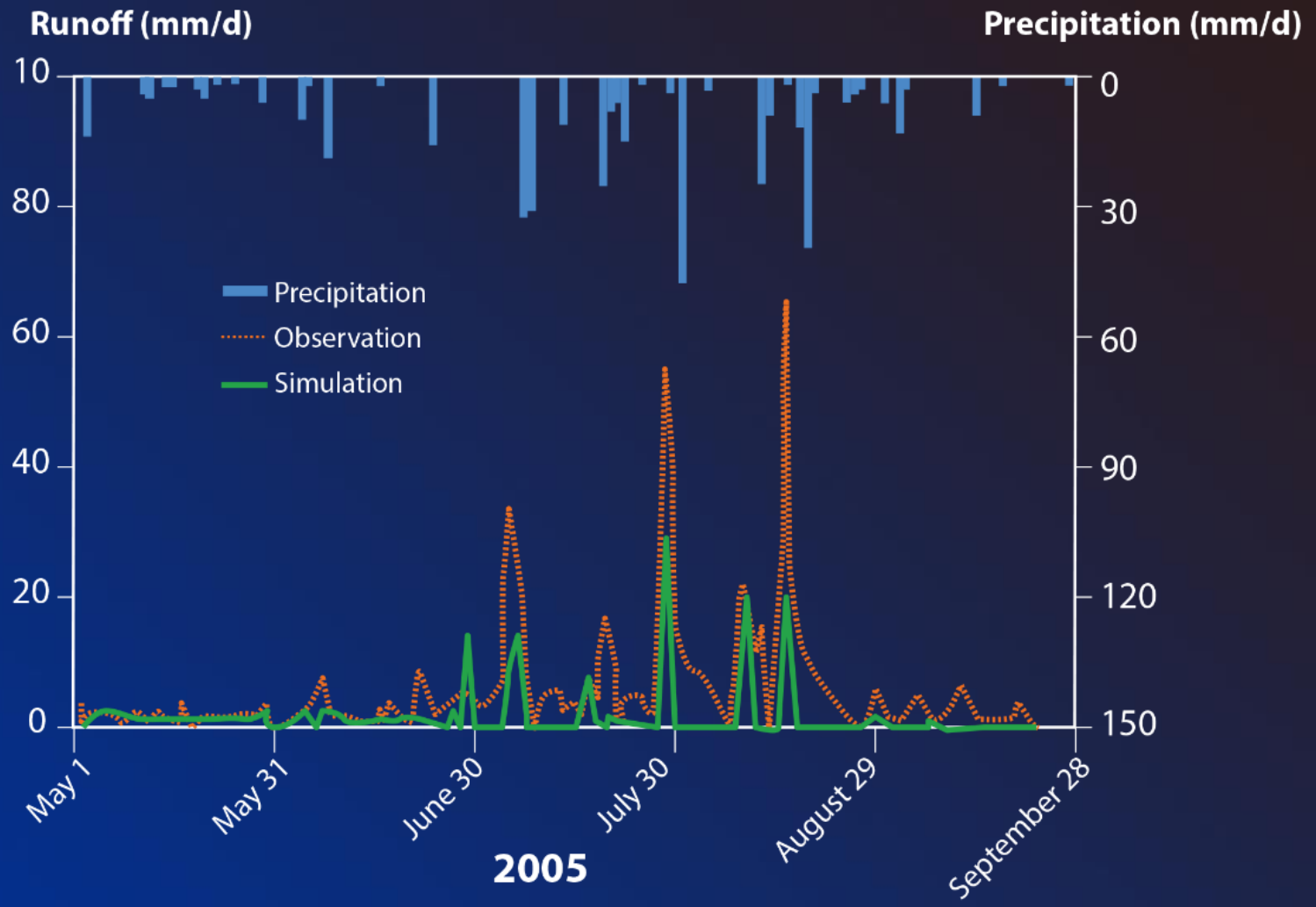
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Schematic of Rice Paddy Water Balance Dynamics



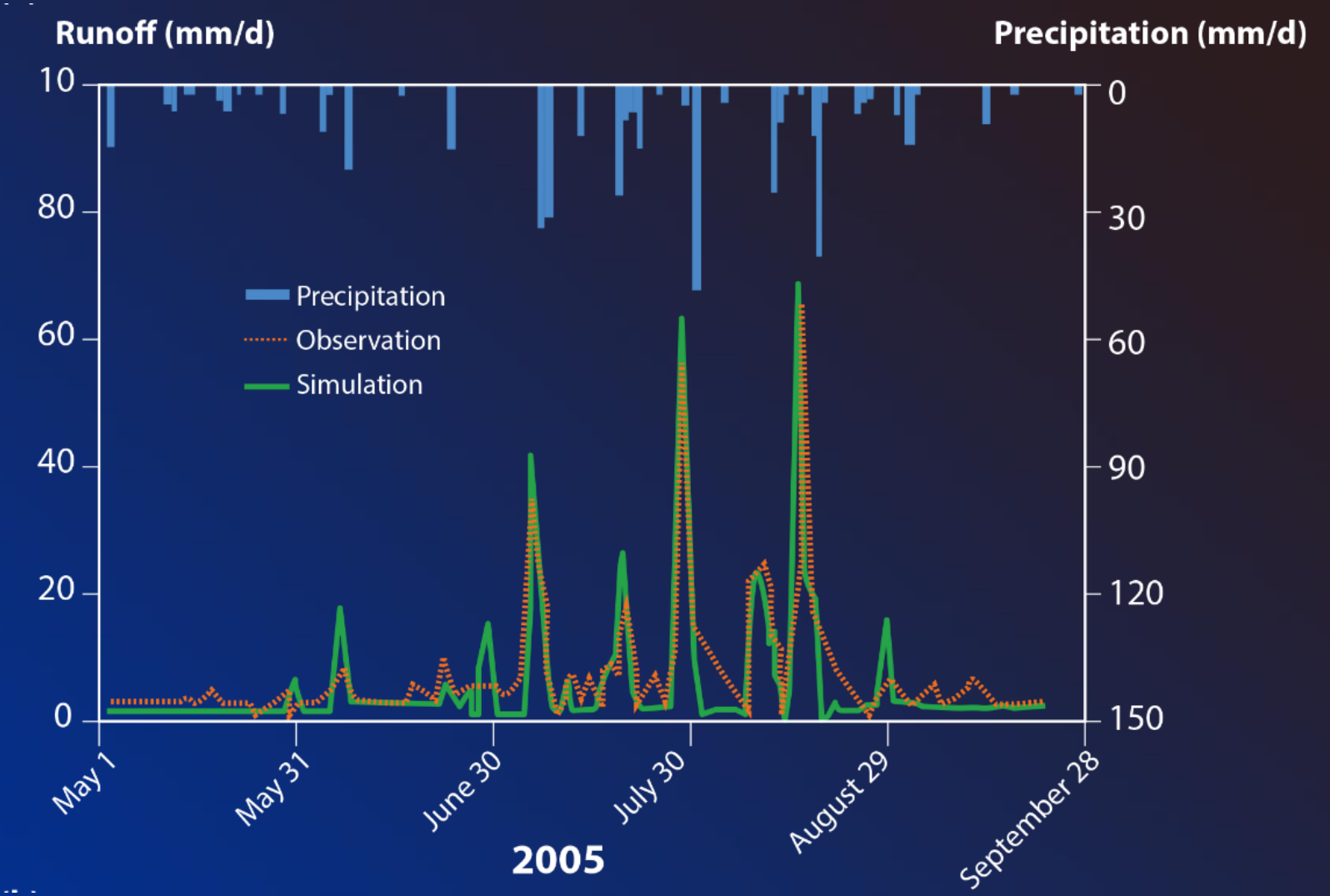
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Streamflow Results for Original SWAT Model



Source: Xie & Cui. 2011. *Journal of Hydrology* 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Streamflow Results for Modified SWAT Model



Source: Xie & Cui. 2011. *Journal of Hydrology* 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Some Concluding Thoughts

- SWAT has proven to be a useful model worldwide and in Asia

- Testing results indicate that SWAT can accurately replicate streamflow, etc. for many different kinds of conditions.
  - but good statistics can mask problems
  - code and/or input modifications can be needed to achieve desired results

- Continued development of a variety of algorithms needed, e.g., rice paddy module