The Soil and Water Assessment Tool (SWAT) Ecohydrological Model Circa 2015: Global Literature/Application Trends, Insights & Issues

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Presentation Outline

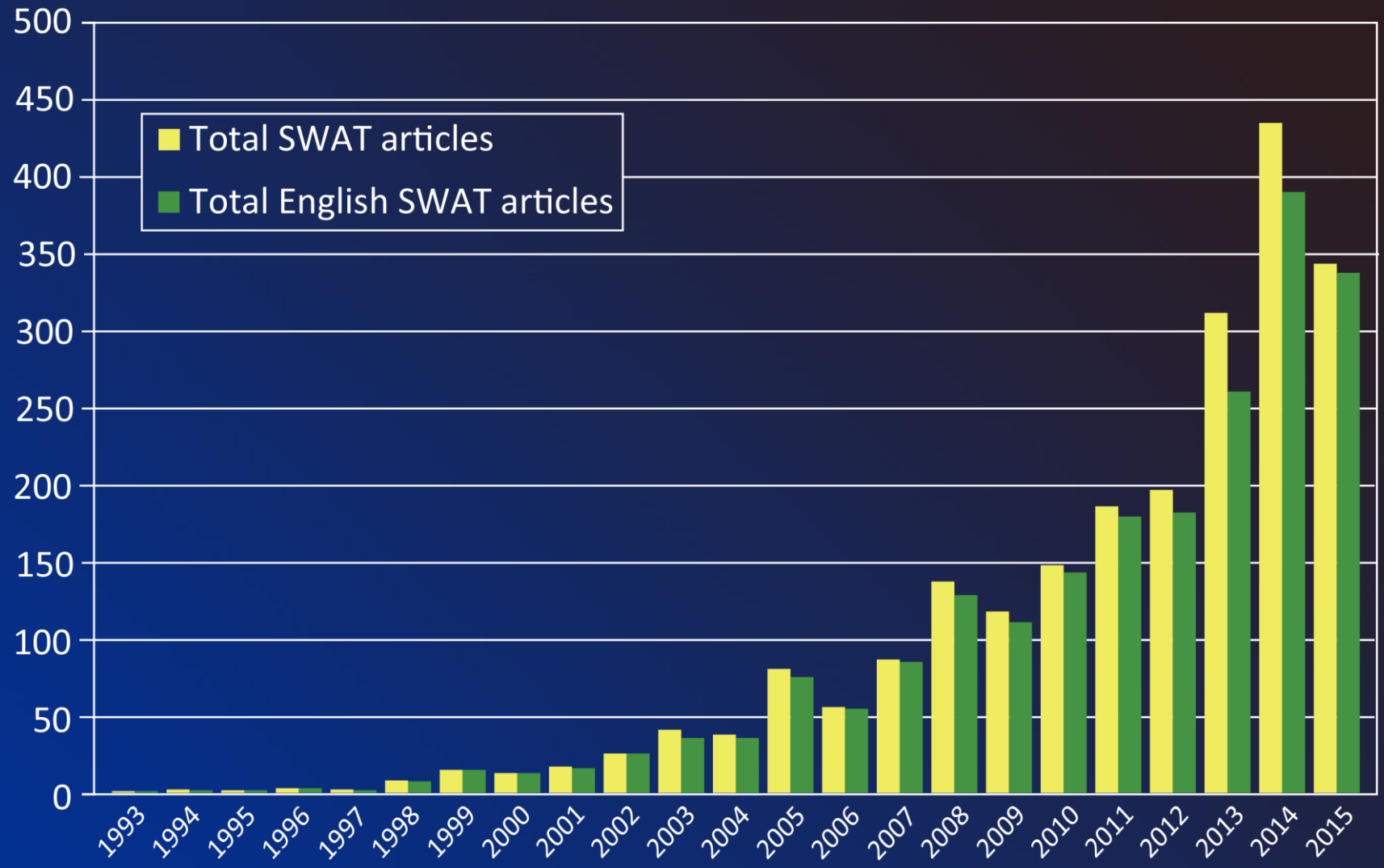
- Overview of current trends in SWAT literature
- One slide each: global interactions and developmental history
- Revisit Moriasi et al. (2007) NSE criteria
- Look at some application trends in Asia and Brazil - including rice paddy issues in Asia

SWAT Literature Database

- SWAT literature database:
  - https://www.card.iastate.edu/swat_articles/
  - also accessible via link at SWAT website
  - Citation info for peer-reviewed journal articles including DOI and/or URL weblinks
  - Most abstracts not visible but included in searches

- Range of articles included in database
- - Currently >2,200 “peer-reviewed” articles
  - Majority are SWAT articles; a few other relevant papers included (e.g., EPIC & APEX description or review articles)
  - Over 500 different journals currently represented
  - Some suspected to be “predatory” (Jeff Beall, Univ. of Denver); http://scholarlyoa.com/publishers/

SWAT Peer-Reviewed Literature Trends (SWAT Literature Database; October 9, 2015)



Source: https://www.card.iastate.edu/swat_articles/; includes both SWAT and modified SWAT applications as well as review articles (some 2015 articles are not yet in database)

Web of Science All-Time Top-Cited JAWRA Papers (Oct. 8, 2015)

Authors (paper rank)	Year	Title	Model	Citations	
				All Databases	Core Collection
Arnold et al. (1)*	1998	Large Area Hydrologic Modeling and assessment - Part 1: Model Development	SWAT	1,820	1,654
Santhi et al. (2)	2001	Validation of the SWAT Model on a Large River Basin with Point and Nonpoint Sources	SWAT	416	374
Arnold et al. (4)	1999	Automated Methods for Estimating Baseflow and Ground Water Recharge from Streamflow Records	-	327	295
Srinivasan et al. (11)	1998	Large Area Hydrologic Modeling and assessment - Part II: Model Application	SWAT	166	155

*Total Google Scholar citations = 3,472; total Scopus citations = 2,160

Web of Science All-Time Top Cited Trans. ASAE/ASABE Papers (Oct. 8, 2015)

Authors (paper rank)	Year	Title	Model	Citations	
				All Databases	Core Collection
Moriasi et al. (1)*	2007	Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations	**SWAT**	1,214	1,162
Gassman et al. (3)	2007	The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions	**SWAT**	686	640
Williams et al. (6)	1984	A Modeling Approach to Determining the Relationship Between Soil Erosion and Soil Productivity	**EPIC**	537	496
Williams et al. (10)	1989	The EPIC Crop Growth-Model	**EPIC**	395	362

***Total Google Scholar citations = 2,046; total Scopus citations = 1,351**

Influential "SWAT Authors" Among 30 Top Water Quality Modeling Authors in JSWC Article

Rank	Author	Institution	Total Articles	Total Citations
1	J.G. Arnold	USDA-ARS	30	2415
2	R. Srinivasan	Texas A&M Univ.	27	2097
3	T.S. Steenhuis	Cornell Univ.	22	486
5	M.T. Walter	Cornell Univ.	20	399
14	F. Bouraoui	Comm. of European Communities	15	379
19	F.H. Hao	Beijing Normal Univ.	13	194
20	I. Chaubey	Purdue Univ.	12	238
21	Z.M. Easton	Virginia Tech Univ. (Cornell Univ.)	12	169
22	W. Ouyang	Beijing Normal Univ.	11	90

Source: Li et al. 2014. Worldwide performance and trends in nonpoint source pollution modeling research from 1994 to 2013: A review based on bibliometrics. Journal of Soil and Water Conservation 69(4): 121A-126A.

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 through 2012

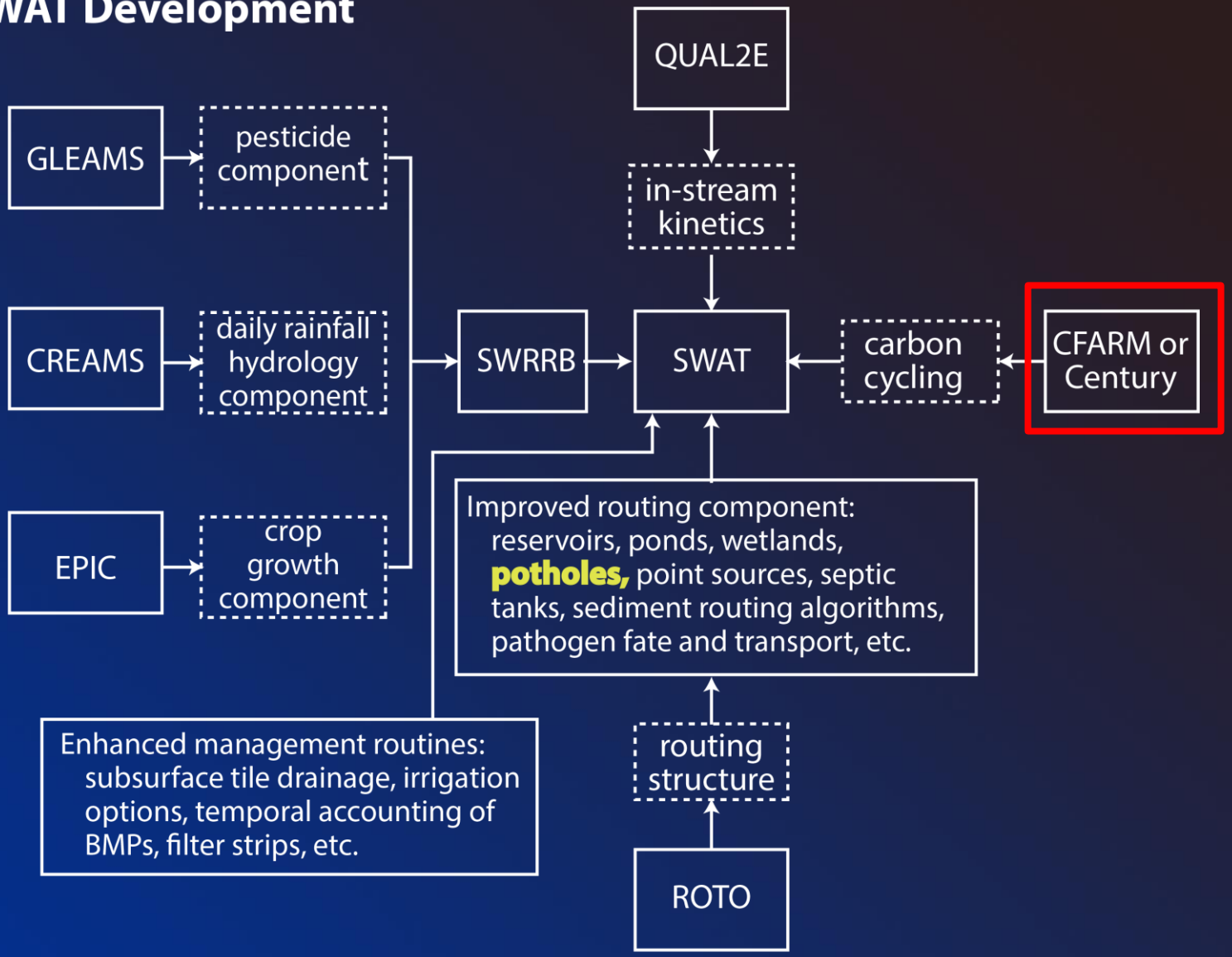
"… the dominance of one topic is particularly remarkable: the use of watershed models and the related aspects of model calibration, evaluation, and uncertainty (ranks 7, 9, 10, 11, 16, 17, 19, 21, 25)."

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.

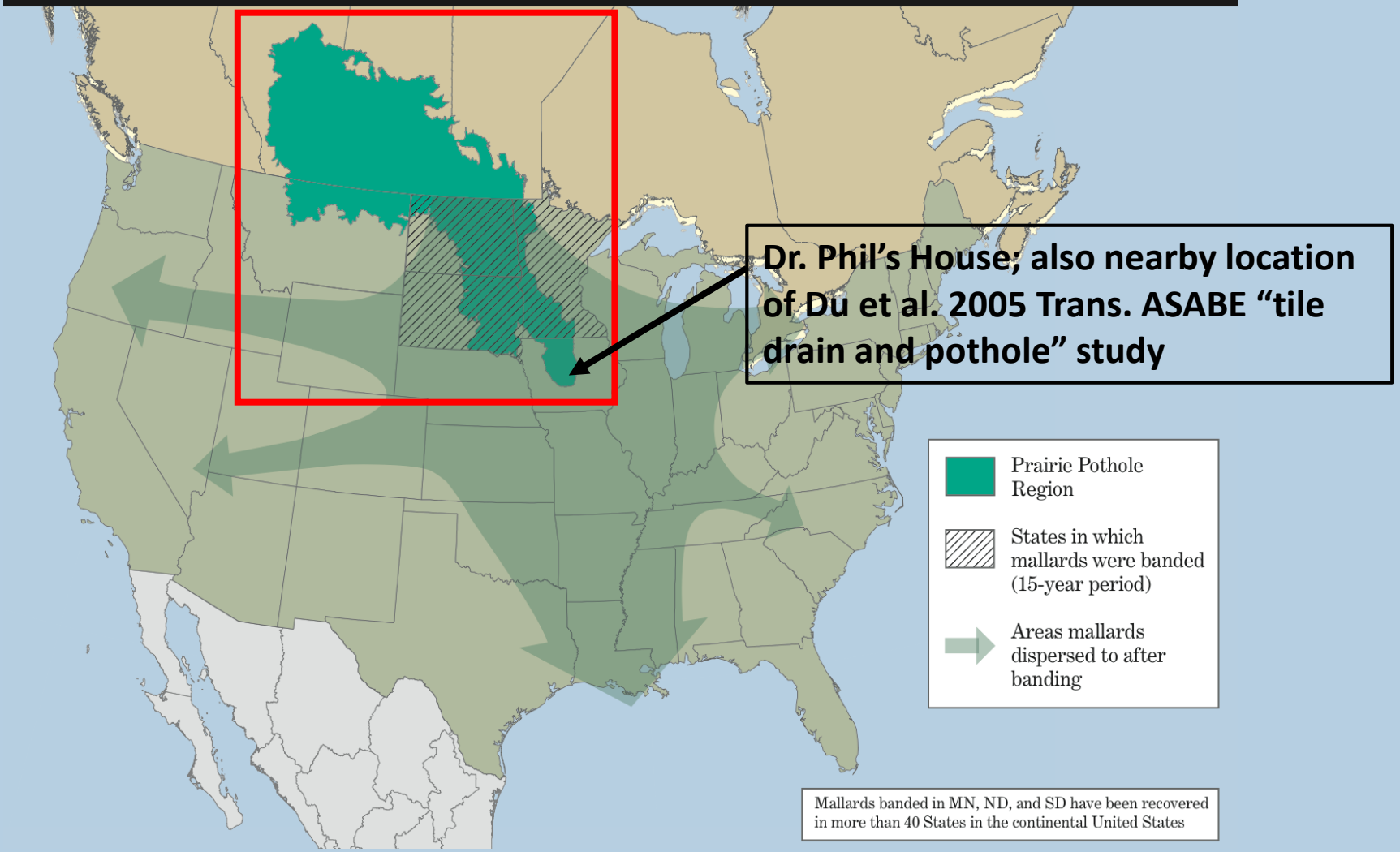
Major SWAT Conferences and Workshops: 2001 to 2017

Schematic of Historical SWAT Development



Williams et al. 2008. History of model development at Temple, Texas. Hydrological Sciences Journal 53(5): 948-960.

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/

Moriasi et al. (2007) Suggested Monthly NSE & RSR Criteria

(NSE: Nash-Sutcliffe modeling efficiency)
(RSR: RMSE-observations standard deviation ratio)

Performance Rating	NSE Criteria	RSR Criteria
Very good	0.75<NSE≤1.00	0.0<RSR≤0.50
Good	0.65<NSE≤0.75	0.50<RSR≤0.60
Satisfactory	0.50<NSE≤0.65	0.60<RSR≤0.70
Unsatisfactory	NSE≤0.50	RSR≤0.70

Source: Moriasi et al. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE. 50(3): 885-900. Doi: 10.13031/2013.23153.

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

Frequency	Calibration		Validation	
	R^2	NSE	R^2	NSE
Total models	67	151	63	127
0.9 – 1.0	9	7	3	1
0.8 – 0.89	10	12	7	9
0.7 – 0.79	16	35	15	15
0.6 – 0.69	17	32	14	32
0.5 – 0.59	5	27	12	21
0.4 – 0.49	5	11	4	12

Moriai et al. … as evaluation time step increases, a stricter performance rating is warranted

*(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

A Few More thoughts on NSE, etc. Criteria

- Remember: Moriasi et al. present **SUGGESTED** criteria
- We can be too strict; e.g., monthly sediment NSE of 0.47 by Beeson et al. (2014)* "unsatisfactory"
- Stronger need to focus on water balance processes, etc. being accurate (more reliance on "soft data")
- Need for more review of "bad SWAT stuff"?!**

***Beeson et al. 2014. JEQ. 43(1): 26-36. Doi: 10.2134/jeq2012.0148.**
****van Griensven et al. Hydrol & Earth Syst Sci. 16: 3371-3381. Doi: 10.5194/hess-16-3371-2012.**

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 basin in upstate New York

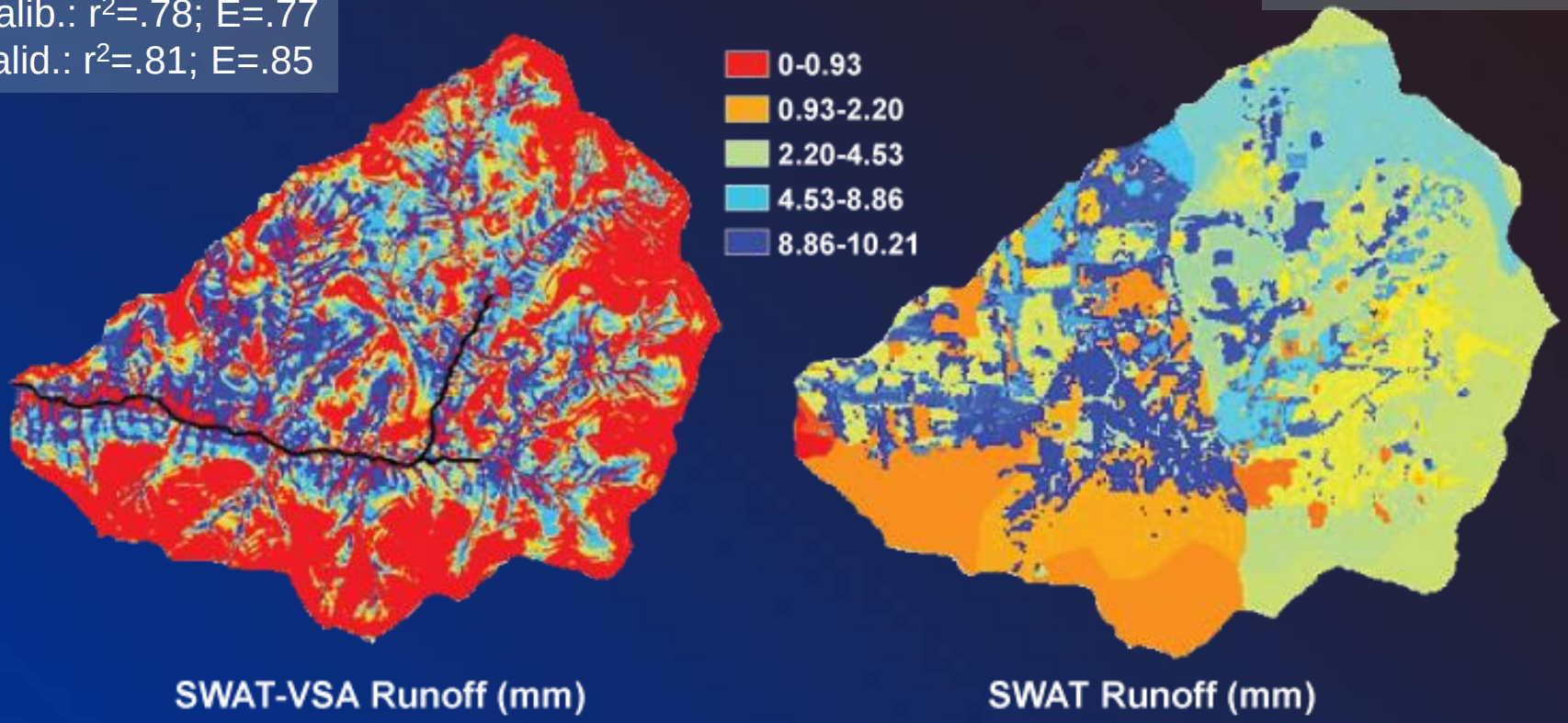
  -Dominated by Variable Source Area (VSA) hydrology

- 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

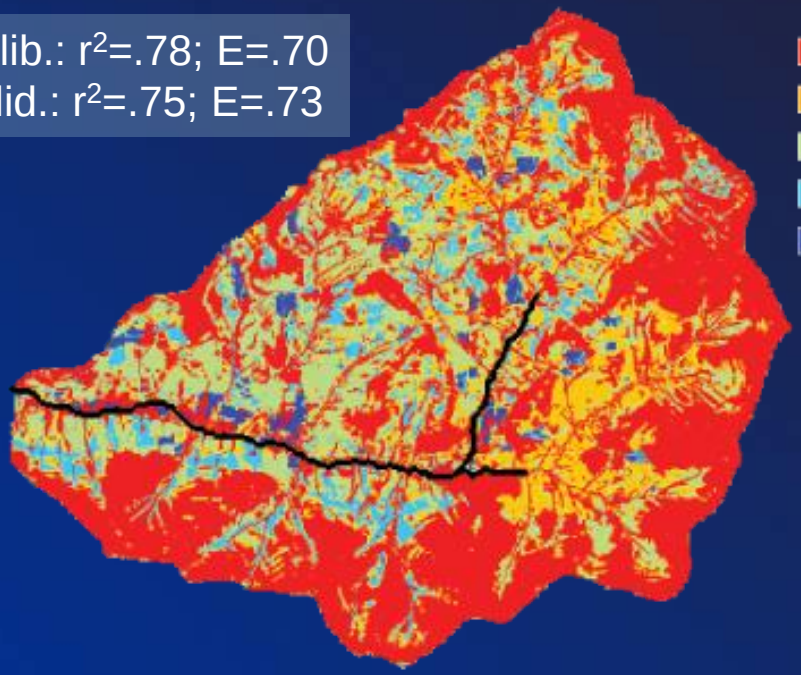
Calib.: r^2=.78; E=.79
Valid.: r^2=.80; E=.84



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

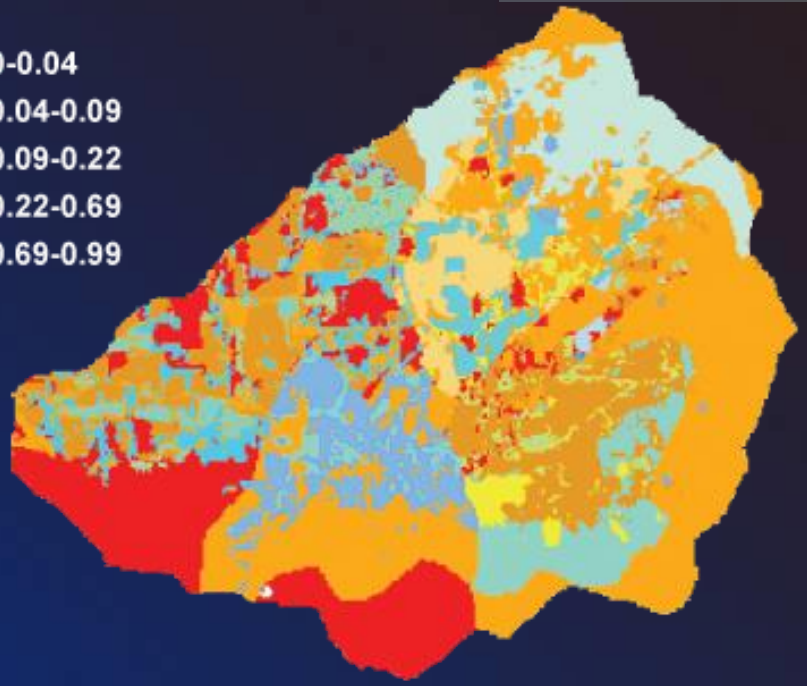
Calib.: r^2=.78; E=.70
Valid.: r^2=.75; E=.73



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

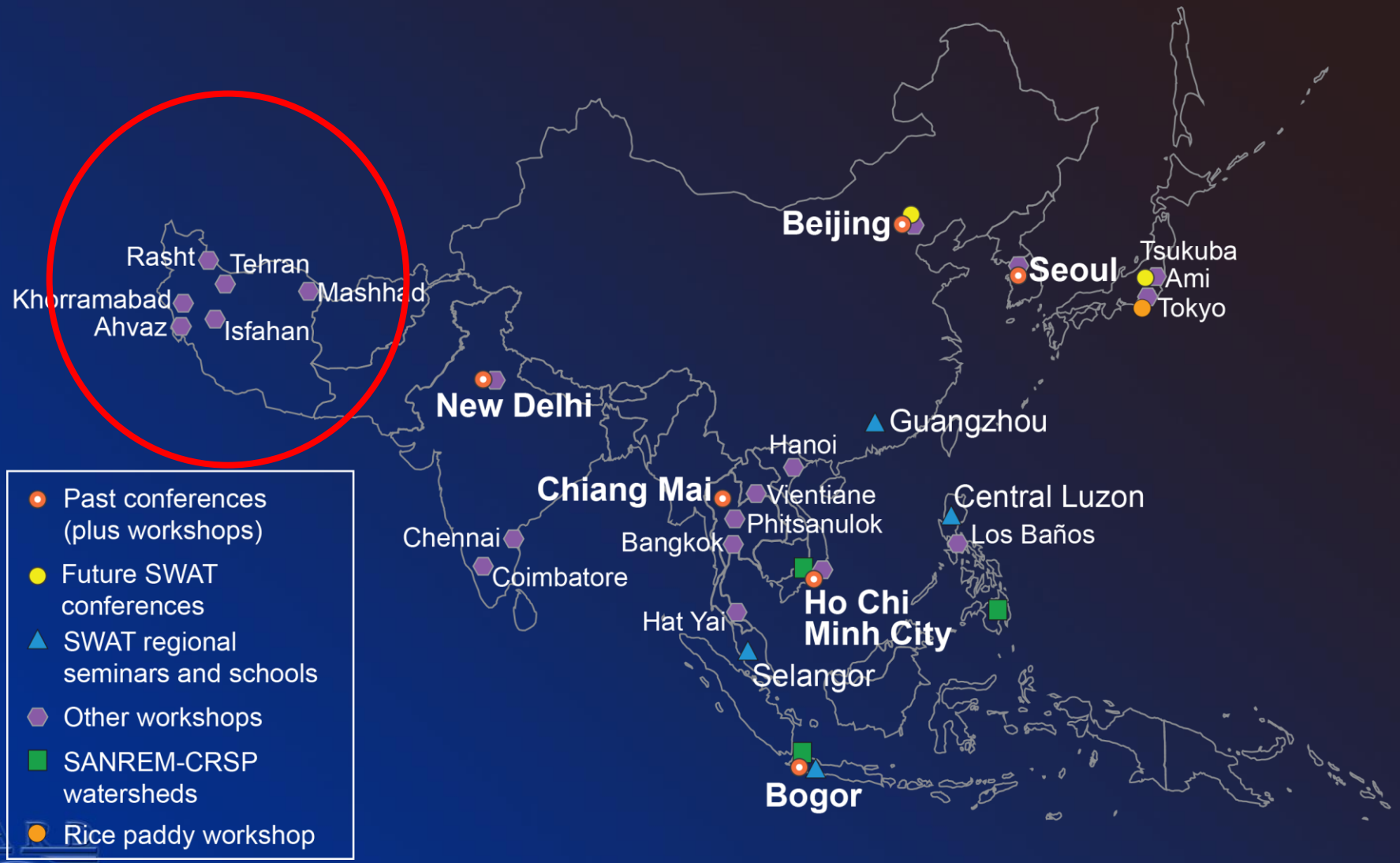
Calib.: r^2=.59; E=.39
Valid.: r^2=.66; E=.54



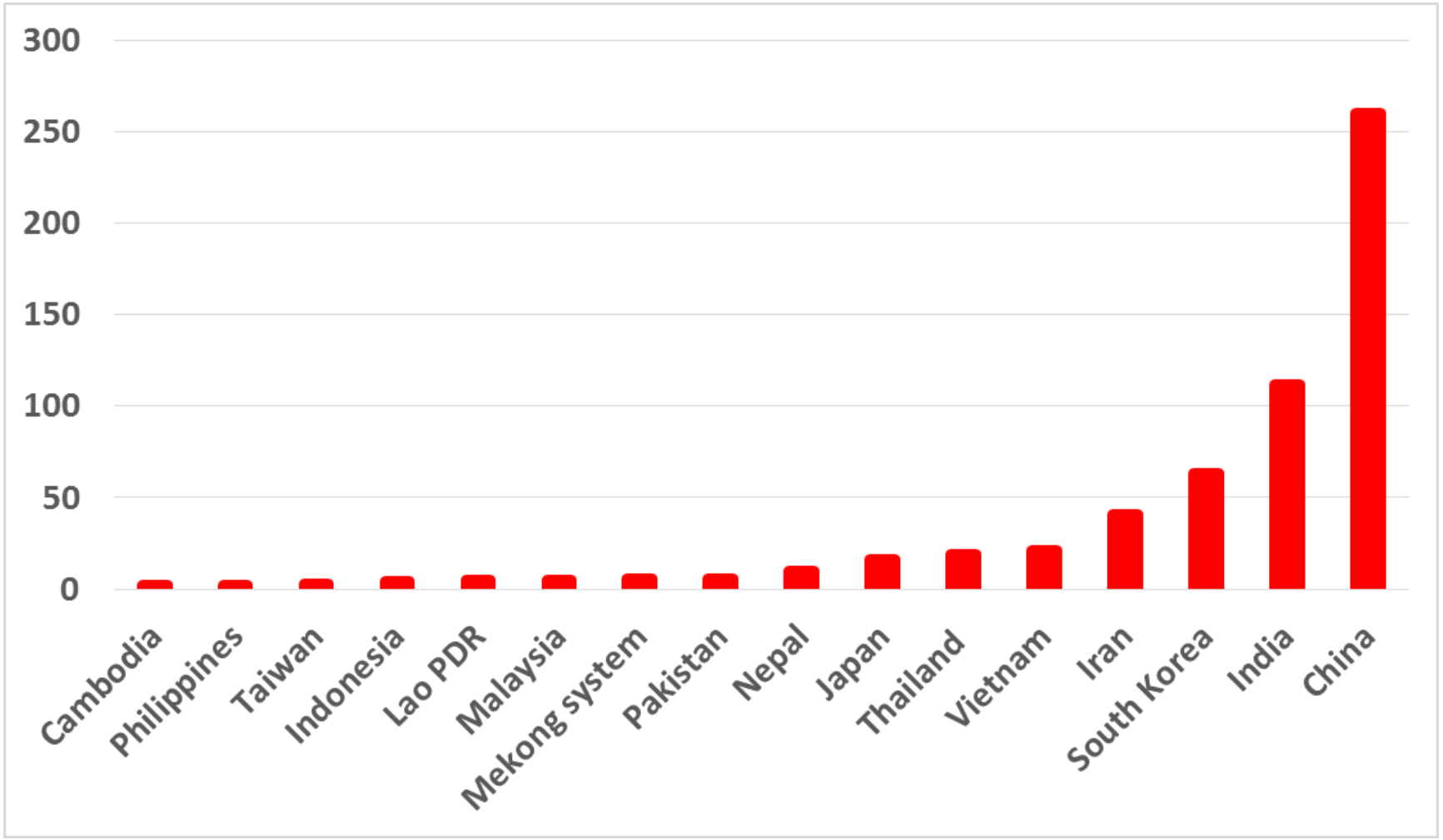
SWAT Dissolved P (kg ha^{-1})

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.

A Closer Look at Asia SWAT-Related Activities

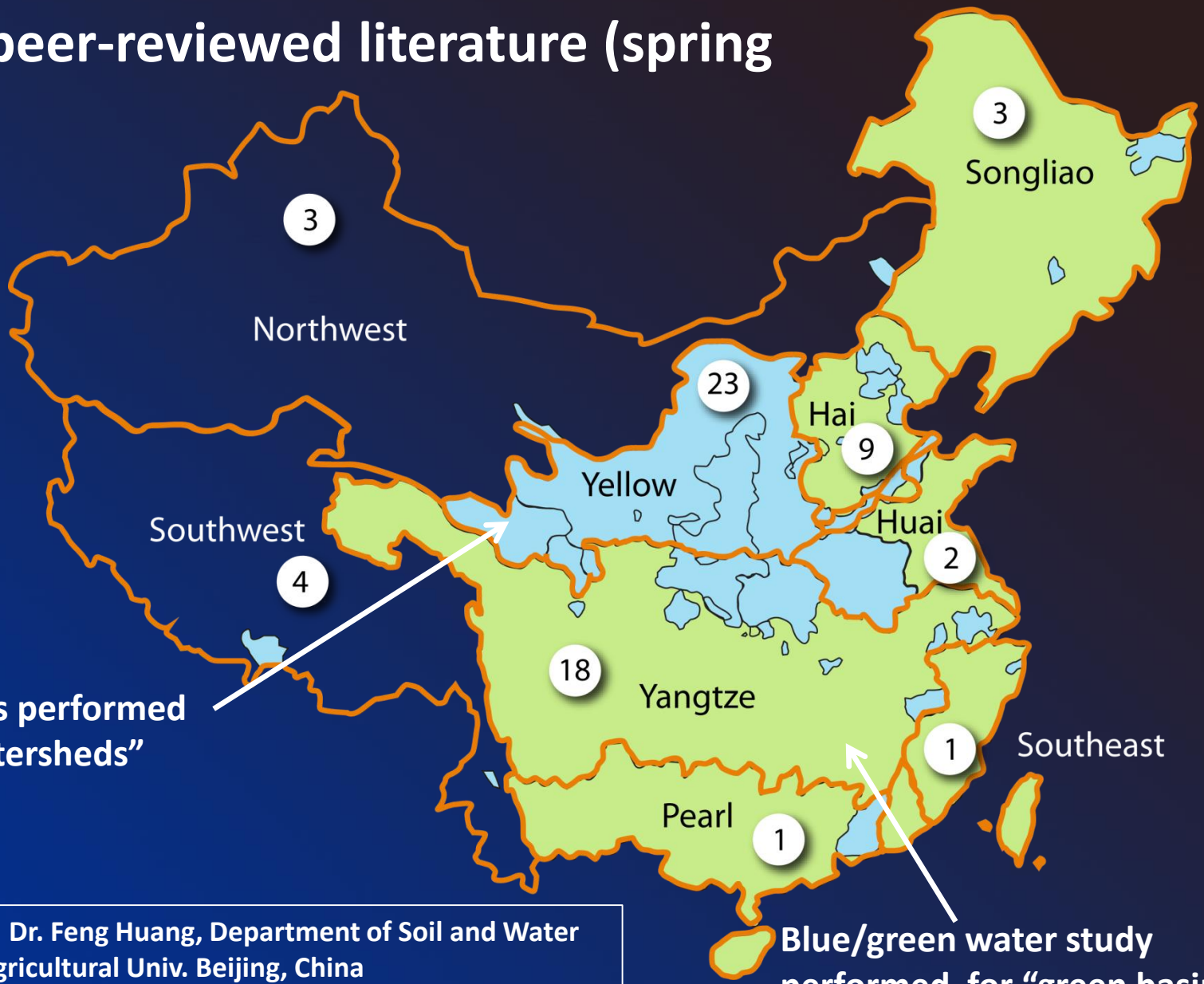


Approximate Number of SWAT Peer-Reviewed Studies Published in English by Country (October 13, 2015)



Source: https://www.card.iastate.edu/swat_articles/

Distribution of Chinese SWAT studies in English peer-reviewed literature (spring 2011)



SWAT studies performed for "blue watersheds"

Blue/green water study performed for "green basins"

Data compiled by Dr. Feng Huang, Department of Soil and Water Sciences, China Agricultural Univ. Beijing, China

Overview of Applications/Statistics for Chinese Studies

Basins	No. of applications	Field and No. of Appl.	Cali. *NSE*	Cali. R^2	Valid. *NSE*	Valid. R^2
Yellow	23	Climate and land use change (6); hydrology assess(3); Auto-calibration(2); pollutant loading (2); input uncertainty (2);irrigation (2).crop growth (1);	0.58-0.94	0.54-0.88	0.46-0.87	0.76-0.84
Yangzte	18	Pollutant loading (7);input uncertainty (5);climate and land use change (2); hydrology assess (2);model compare (1); impoundment (1)	0.45-0.96	0.50-0.96	0.40-0.95	0.60-0.96
Hai	9	Hydrology assess (2);climate change (1);pollutant loading (1); irrigation (1); input uncert. (1);impoundment (1); interface (1);delineation (1)	0.62-0.95	0.76-0.97	0.67-0.91	0.61-0.93
Southwest	4	Climate and land use change (3); hydrology assess (1)	0.75	0.5	0.91	0.3
Northwest	3	Climate and land change (1);hydrology assess (1);input uncertainty (1)	0.85	0.73-0.89	0.82	0.68-0.85
Songliao	3	Hydrology assess (1); input uncertainty (1); delineation(1)	0.16-0.27	0.57-0.58	0.18-0.25	0.44-0.72
Huai	2	Impoundments (2)	-5.04-1.00	0.00-1.00	0.36-0.97	0.48-1.00
Southeast	1	Interface (1)				
Pearl	1	Pollutant loading(1)	0.87	0.87	0.86	0.87

Information compiled by Dr. F. Huang, Department of Soil and Water Sciences, China Agricultural Univ. Beijing, China

Stop! … What About Rice Paddies?

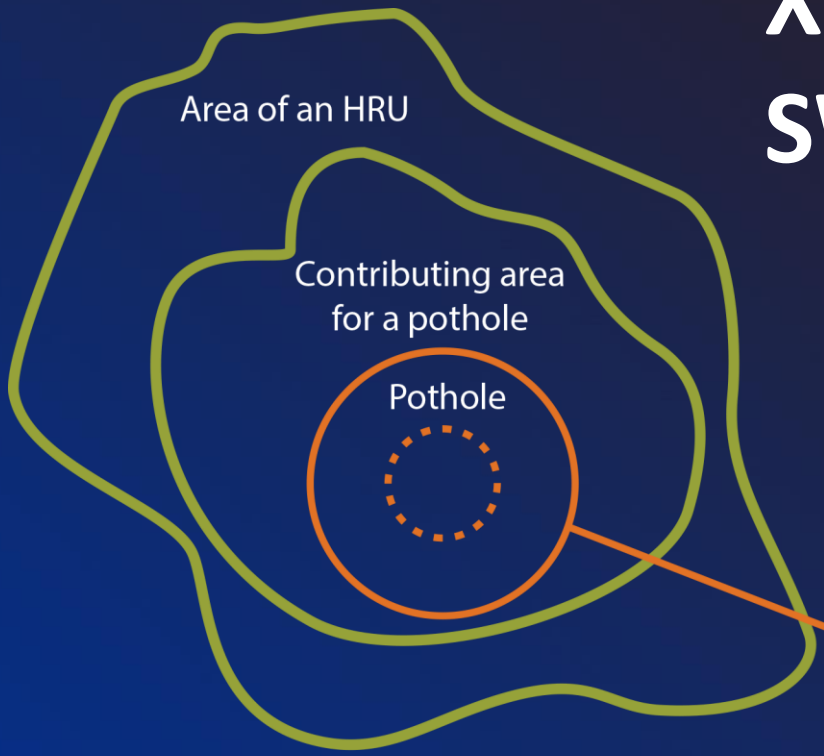
- Since SWAT2000: Recommended that pothole routine be used for rice paddies
- Most users ignore recommendation; in fact most ignore rice paddies all togther
- SWAT Studies in China and Japan now report results of using a modified pothole approach

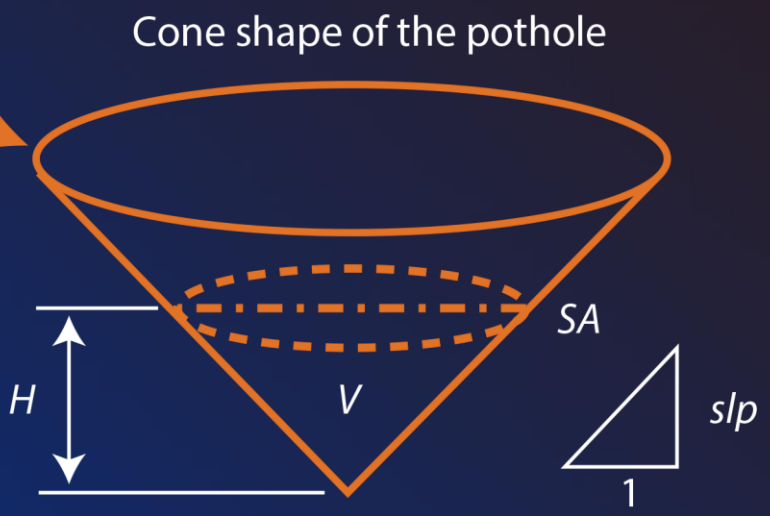
Xie & Cui Modified SWAT Study in China

~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

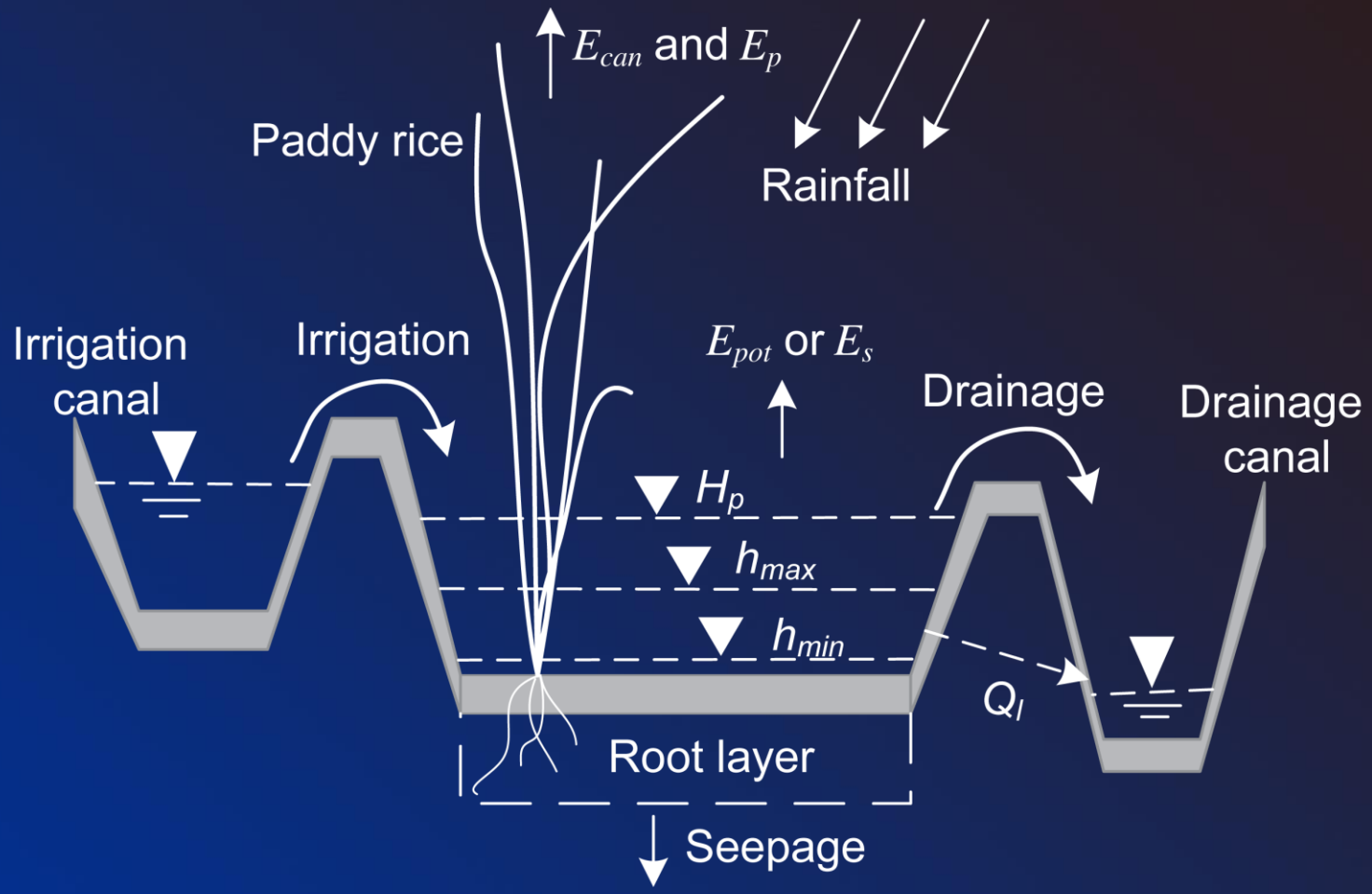
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

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

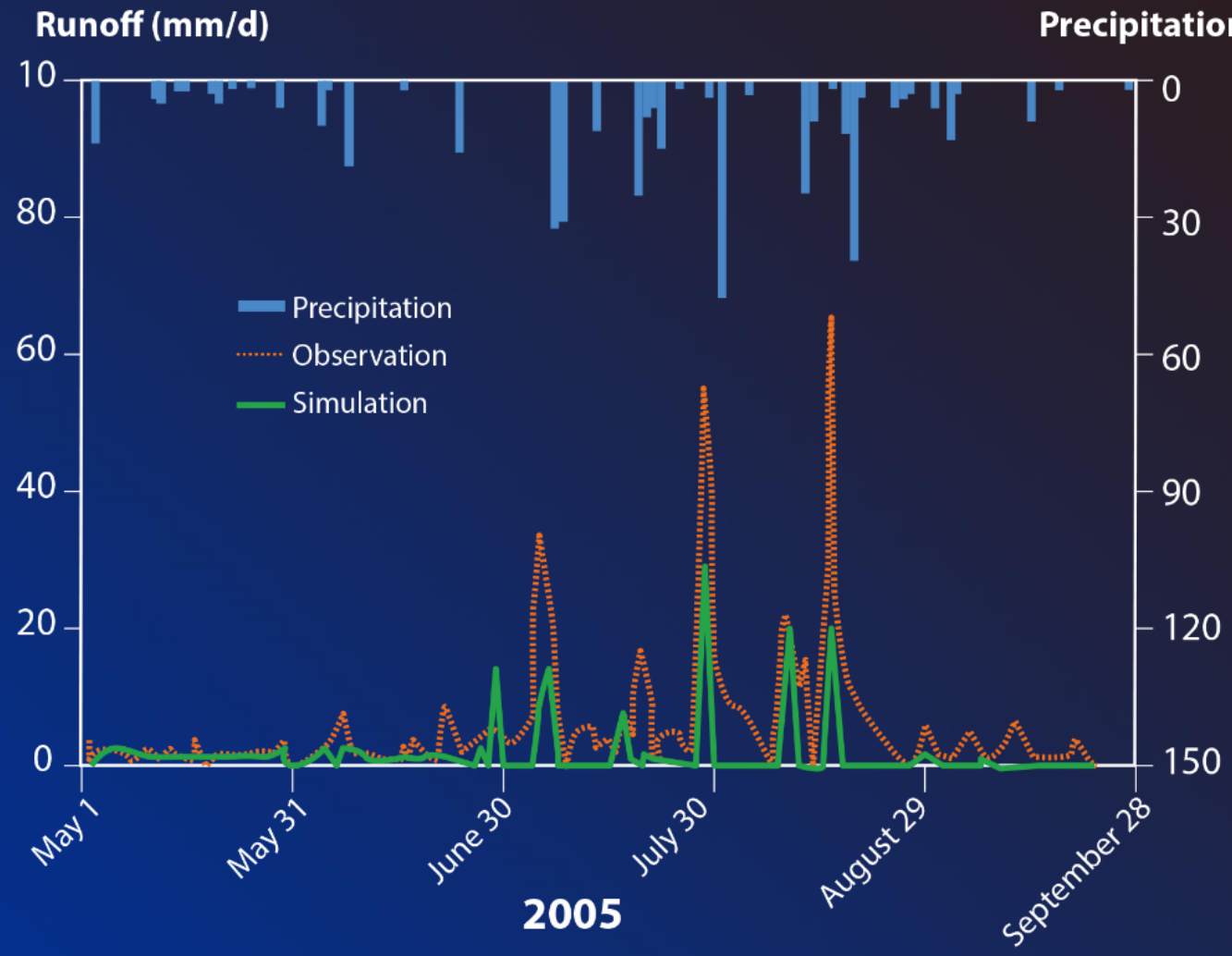
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Schematic of Rice Paddy Water Balance Dynamics



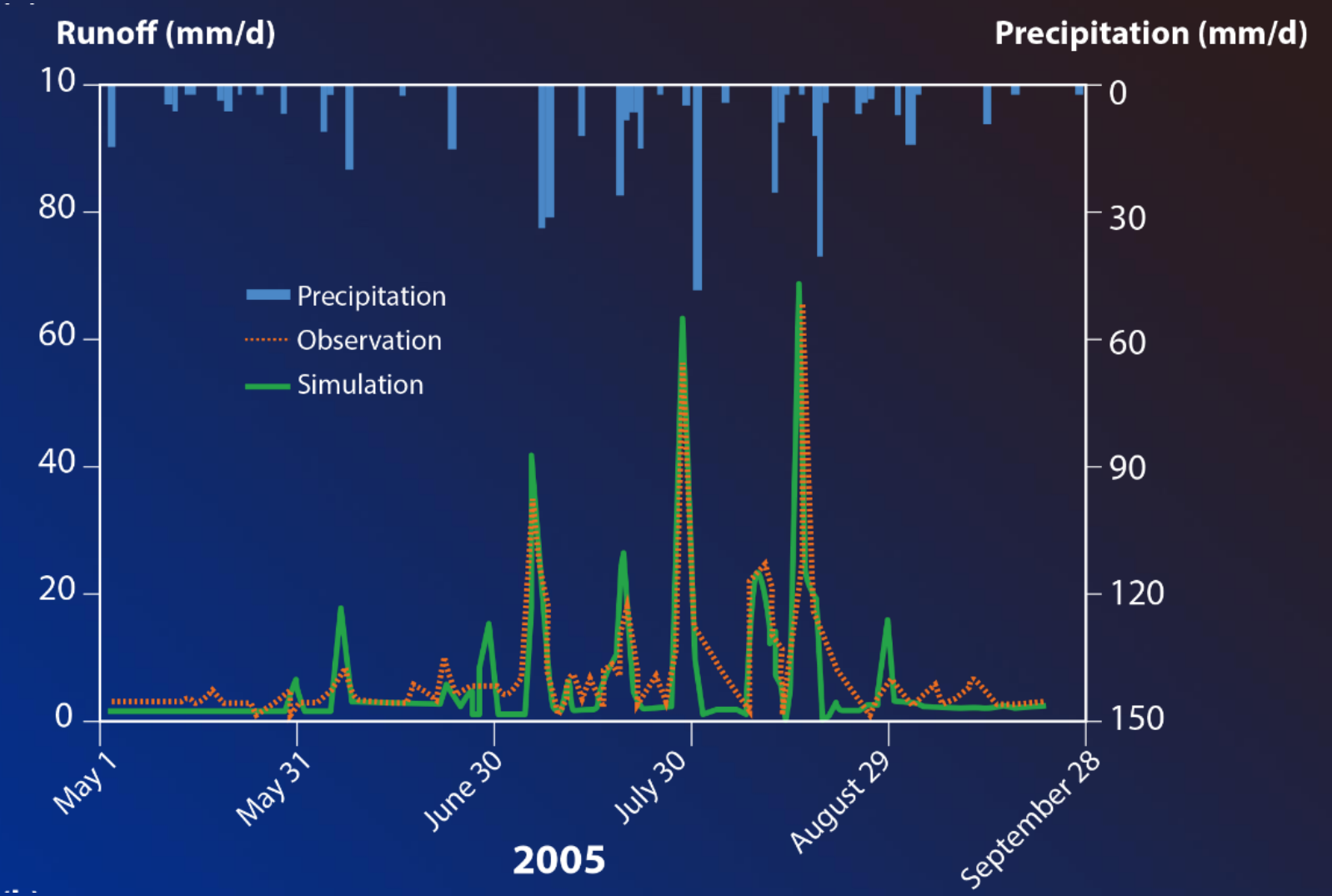
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

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



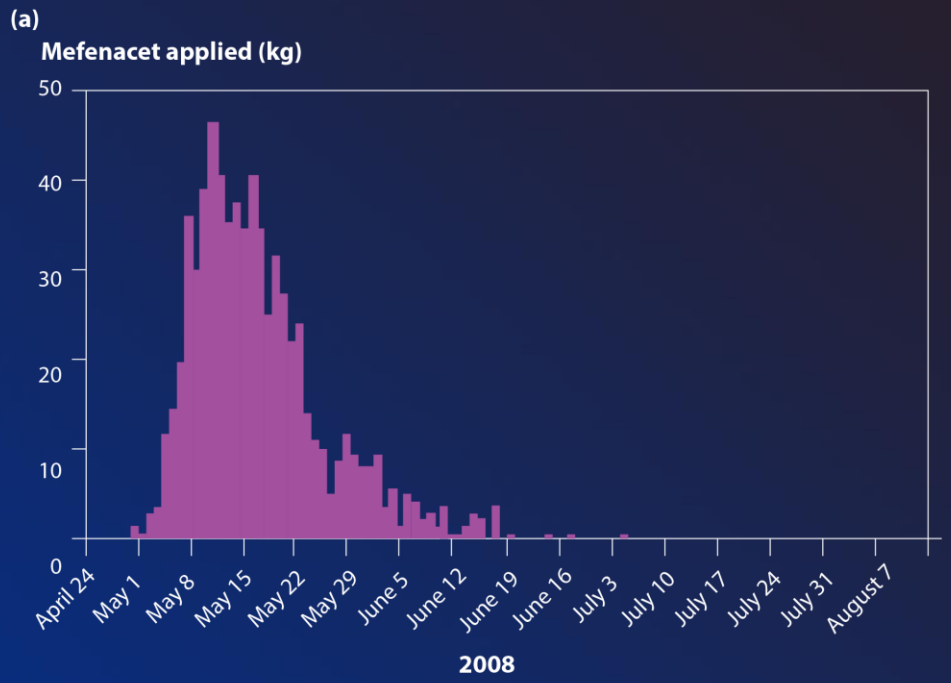
Source: Xie & Cui. 2011. *Journal of Hydrology* 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

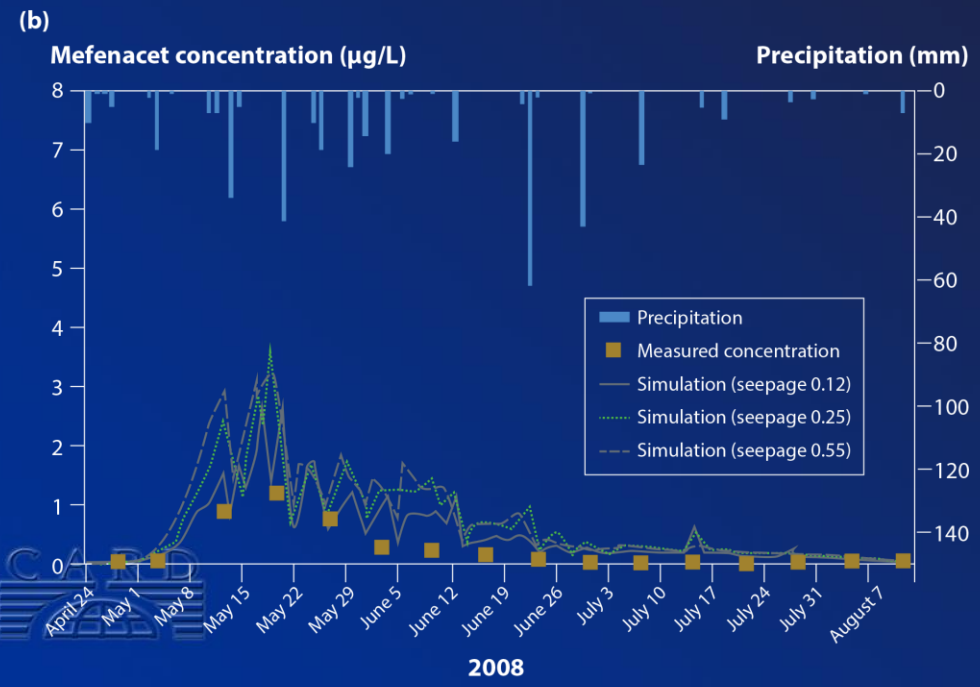
Boulange et al. PCPF-1@SWAT Study

- Interfaced PCPF-1 paddy model with SWAT to simulate watershed-scale pesticide (mefenacet) transport
- Applied approach to 345 km^2 Sakura River basin in Japan; 68.7 km^2 "active paddy fields" (8.1% received mefenacet)
- Adapted Xie & Cui pothole cuboid shape and three critical paddy water depths
- Used percolation rate of 1.0 cm/day for ponded paddy soils
- Tested lateral seepage rates of 0.12, 0.25 & 0.55 cm/day

Source: Boulange et al. 2014. Journal of Hydrology. 517: 146-156. Doi: 10.1016/j.hydrol.2014.05.013

Boulange et al. Pesticide Transport Validation Results





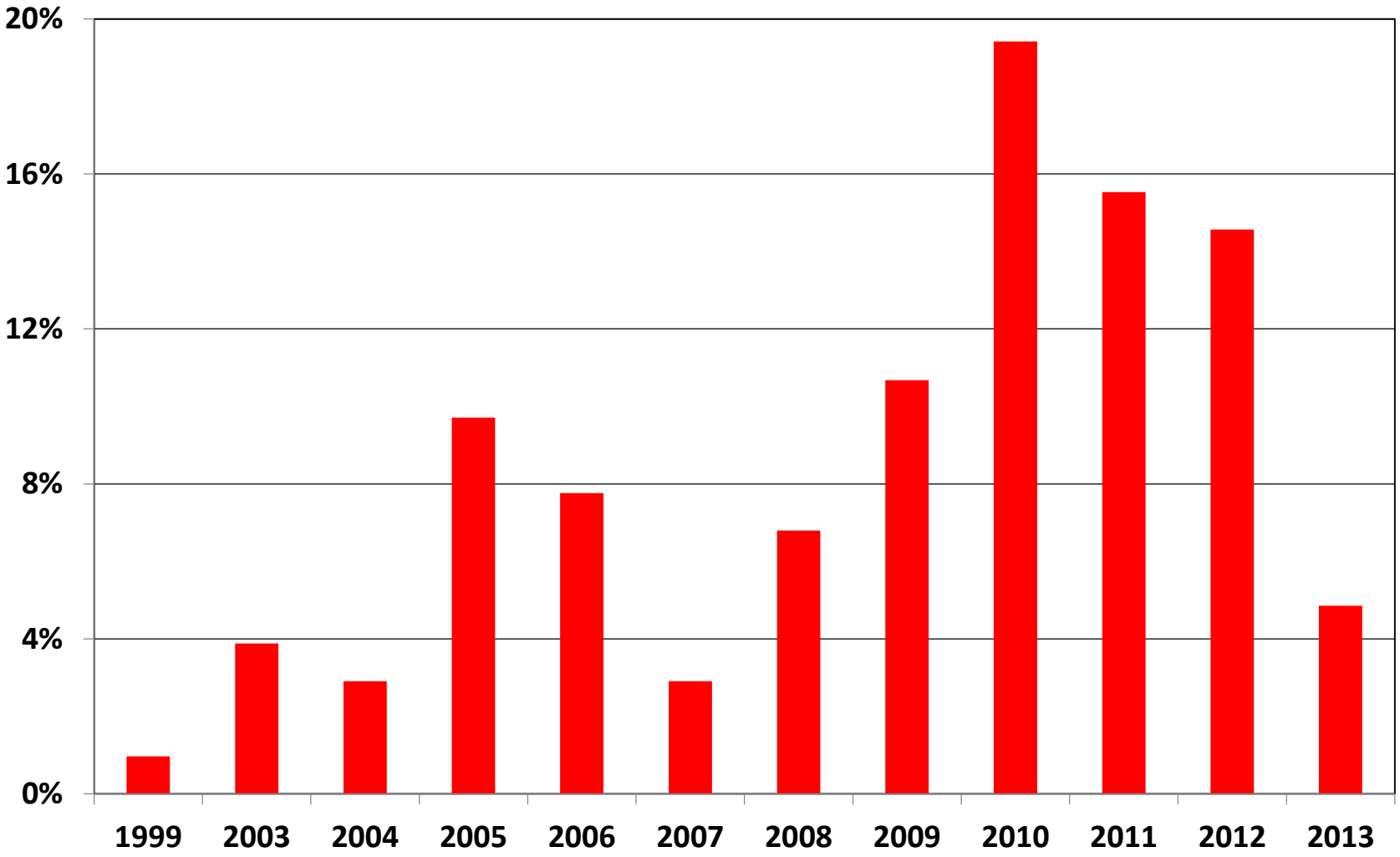
Results reflect uncertainty of application timing and seepage rate; best results were obtained with seepage = 0.12

Source: Boulange et al. 2014. Journal of Hydrology. 517: 146-156. Doi: 10.1016/j.hydrol.2014.05.013

Future SWAT Rice Paddy Module

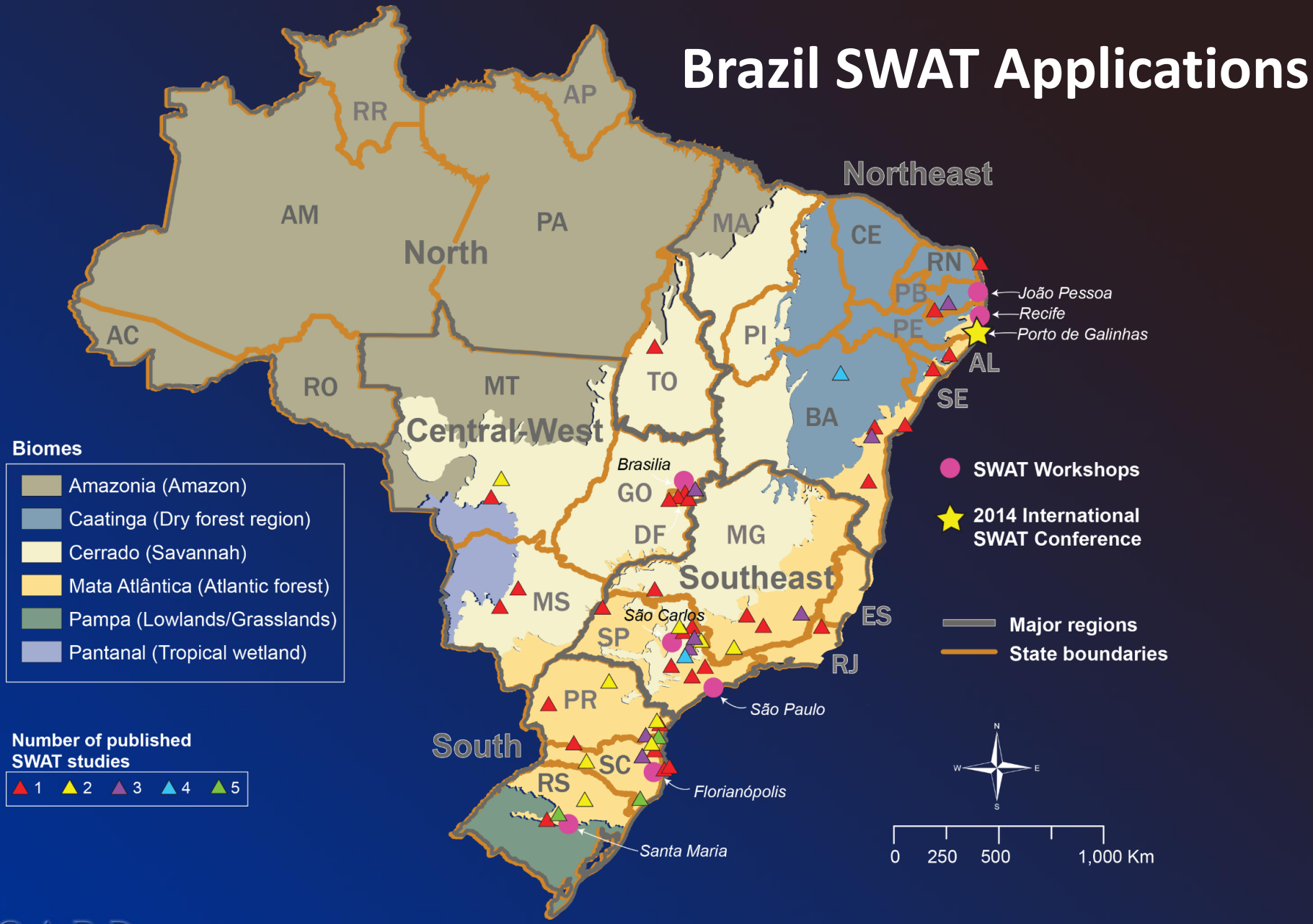
- SWAT Rice Paddy Review paper underway
- Jaehak Jeong APEX rice paddy algorithms serving as foundation for SWAT rice paddy module
  - work ongoing at Tokyo Univ. of Agriculture & Technology
- Other efforts from previous modified SWAT pothole approaches will also contribute (and new concepts)

Distribution of 102 Brazilian SWAT Studies Surveyed from Jan. 1999 to March 2013



Source: Bressiani et al. 2015. A review of Soil and Water Assessment Tool (SWAT) applications in Brazil: Challenges and prospects. IJABE 8(3) Doi: 10.3965/j.ijabe.20150803.1765.

Brazil SWAT Applications



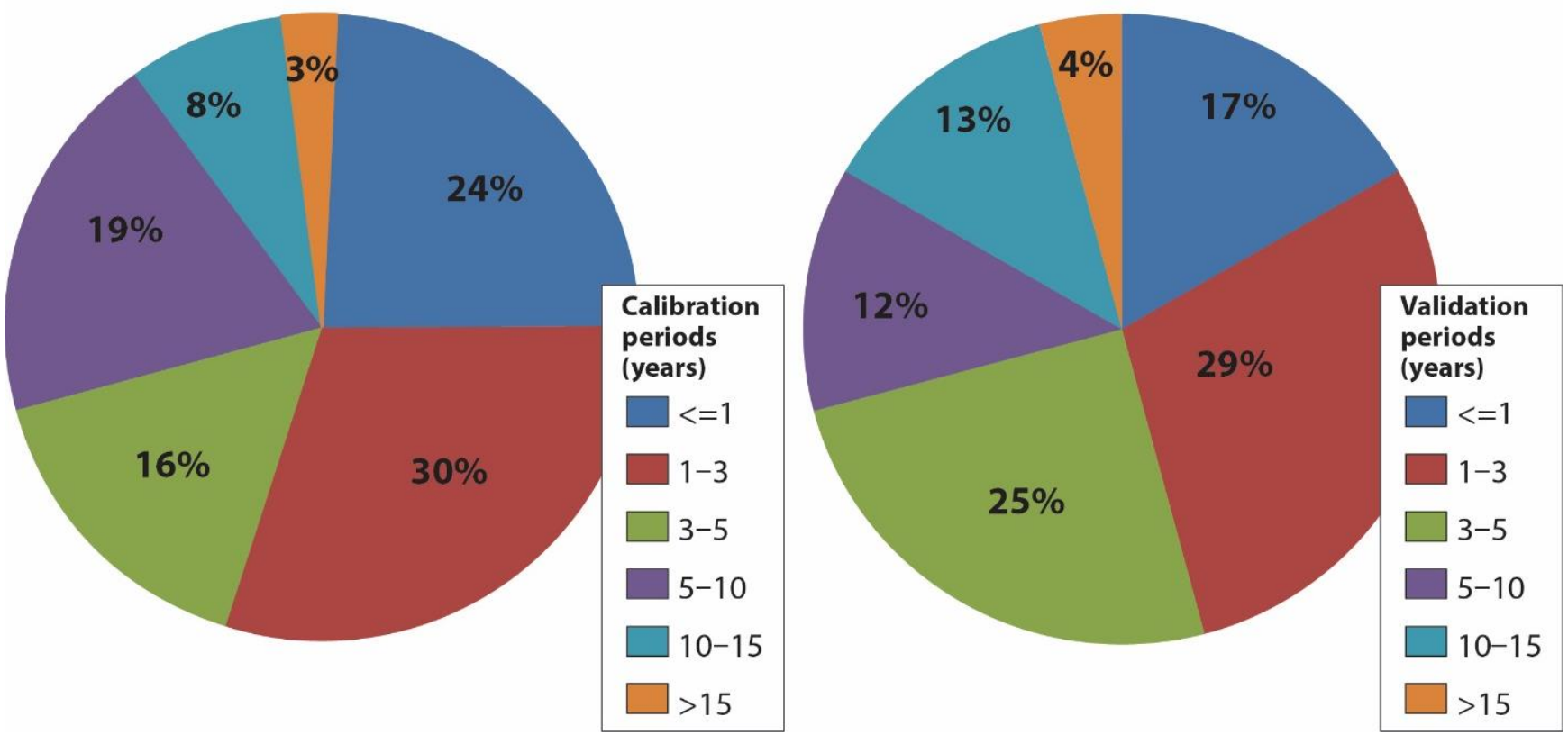
Bressiani et al. 2015. A review of Soil and Water Assessment Tool (SWAT) applications in Brazil: Challenges and prospects. IJABE 8(3) Doi: 10.3965/j.ijabe.20150803.1765.

NSE Statistical Results for Subset of Brazilian SWAT Studies

Performance Rating	NSE Criteria	Monthly NSE (31 studies)	Daily NSE (26 studies)
Very good	0.75<NSE≤1.00	61%	25%
Good	0.65<NSE≤0.75	29%	18%
Satisfactory	0.50<NSE≤0.65	3%	25%
Unsatisfactory	NSE≤0.50	6%	25%

Bressiani et al. 2015. A review of Soil and Water Assessment Tool (SWAT) applications in Brazil: Challenges and prospects. IJABE 8(3) Doi: 10.3965/j.ijabe.20150803.1765.

Distribution of Calibration & Validation Time Periods for Subset of Brazilian SWAT Studies



Source: Bressiani et al. 2015. A review of Soil and Water Assessment Tool (SWAT) applications in Brazil: Challenges and prospects. IJABE 8(3) Doi: 10.3965/j.ijabe.20150803.1765.

Conclusions

- A lot of people in various parts of the world are finding SWAT to be a very useful model

- Global testing results indicate that SWAT can accurately replicate streamflow, etc. for many different kinds of conditions.

  - good statistics can mask structural problems

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