SWAT Global Impacts

Philip W. Gassman
Center for Agricultural and Rural Development, Iowa State Univ., Ames, IA, USA

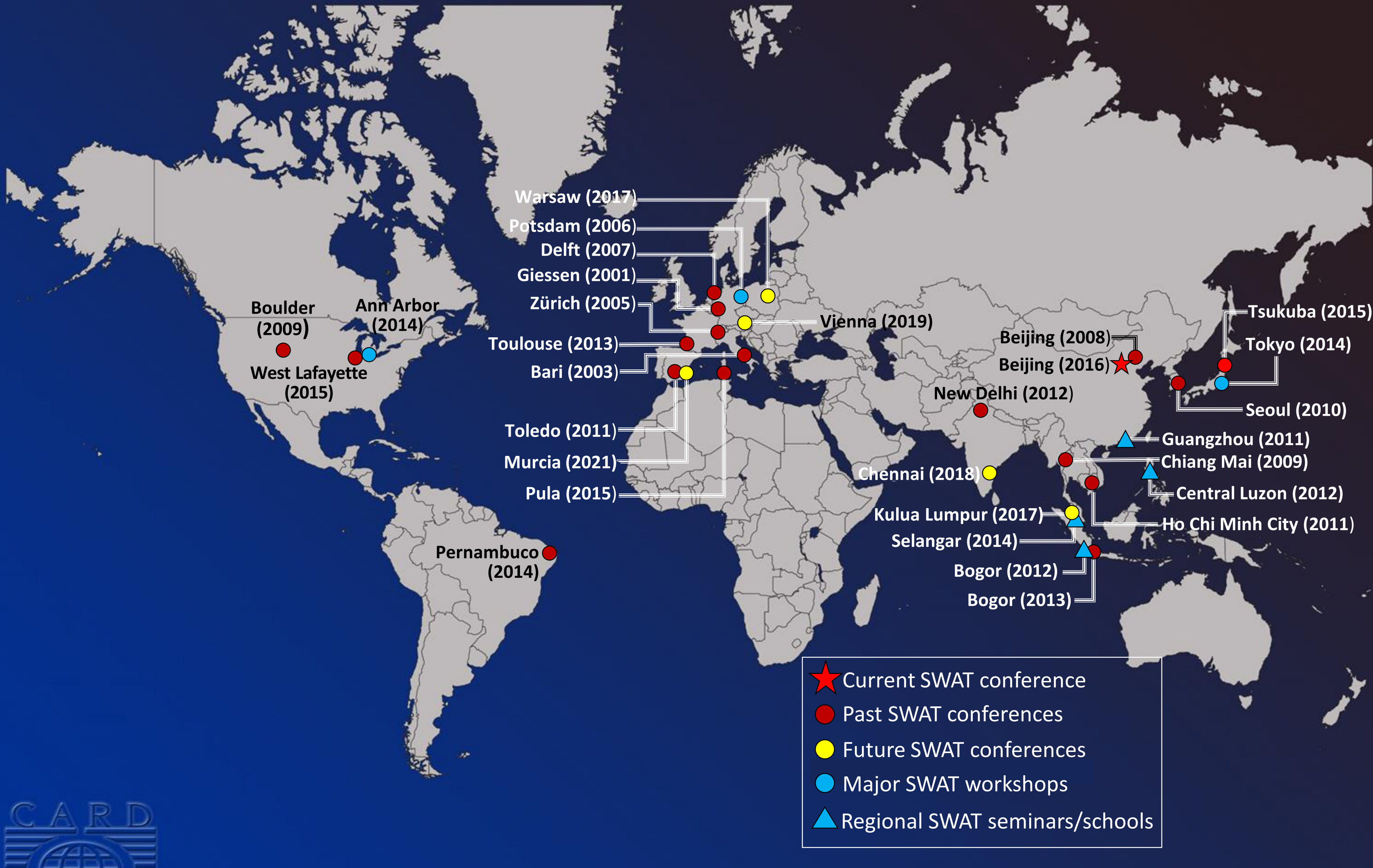
Jeffrey G. Arnold
USDA-ARS, Grassland, Soil and Water Research Laboratory, Temple, TX, USA

Raghavan Srinivasan
Spatial Sciences Laboratory, Texas A&M University, College Station, TX, USA

Presentation Overview

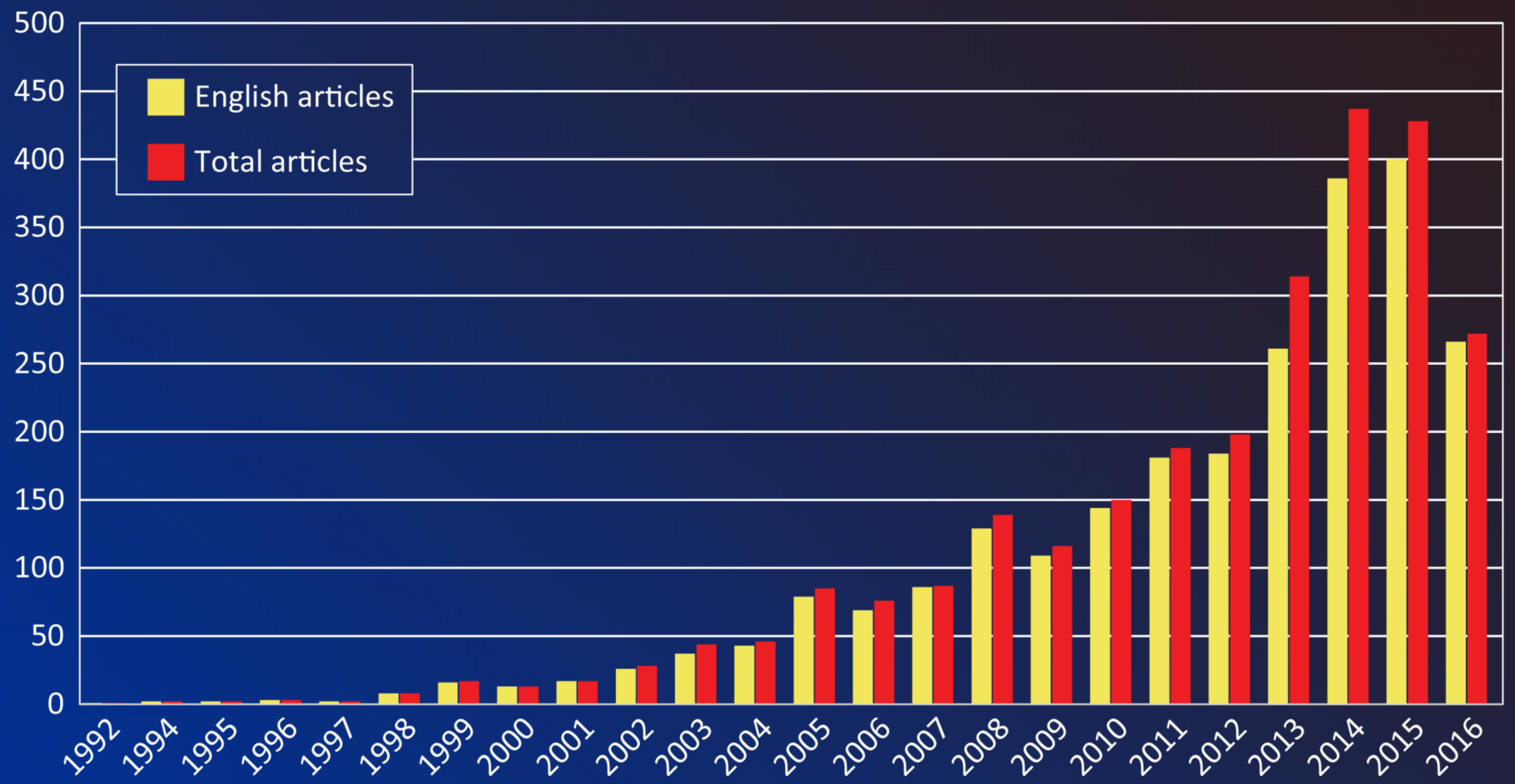
- Global & Asia SWAT conferences and other events
- Historical publication trends, special issues/sections & top-cited SWAT-related literature
- SWAT dominance revealed via Bibliometric analyses
- Impact of Moriasi et al. studies and example reviews of SWAT statistical results
- Need for evaluating model output using “soft data”

Locations/Years of Past, Present & Future SWAT Events



Locations of Selected Asia SWAT Events

Trends in SWAT-related articles in SWAT Literature Database (July_2016)



Source: https://www.card.iastate.edu/swat_articles/; data shown here includes both SWAT and modified SWAT applications as well as review articles

SWAT Special Issues/Sections

(http://swat.tamu.edu/publications/special-issues/)

Conference or other event	Publication Year	Journal
2001 Giessen	2005	Hydrological Processes
2006 Potsdam	2008	Hydrological Sciences Journal
2009 Boulder	2010	Transactions of the ASABE
2009 Chiang Mai	2009-2011	International Agricultural Engineering Journal
2010 Seoul	2011	Transactions of the ASABE
2011 Toledo	2014	Journal of Environmental Quality
2012 New Delhi	2015	Regional Environmental Change
2013 & 2014 conferences	2015	Hydrological Sciences Journal
2013 to 2015 conferences	2015	International Journal of Agricultural & Biological Engineering (IJABE)

Currently Developing SWAT Special Issues/Series

- Catalyst: 2015 conferences in Pula, Sardinia, Italy and West Lafayette, Indiana, U.S.
- Journal of the American Water Resources Association (JAWRA)
- Agricultural Water Management
- Sustainability of Water Quality and Ecology

Forthcoming Special Issues

- Catalyst: 2016 Beijing conference
- Water: http://www.mdpi.com/journal/water/special_issues/SWAT2016
- IJABE: https://www.ijabe.org/index.php/ijabe
- Hydrology and Earth System Sciences (pending)
- Environmental Modelling & Software (broader; includes non-SWAT studies)

Thomson Reuters Web of Science Publication Citation Database

Yahoo Finance!: Thomson Reuters Announces Definitive Agreement to Sell its Intellectual Property & Science Business to Onex and Baring Asia for $3.55 billion

Web of Science All-Time Top-Cited JAWRA Papers (July 22, 2016)

Authors (paper rank)	Year	Title	Model	Citations: All Databases	Citations: Core Collection
Arnold et al. (1)*	1998	Large area hydrologic modeling and assessment - part 1: Model development	SWAT	2,053	1,874
Santhi et al. (2)	2001	Validation of the SWAT model on a large river basin with point and nonpoint sources	SWAT	462	422
Arnold et al. (5)	1999	Automated methods for estimating baseflow and ground water recharge from streamflow records	-	361	329
White et al. (11)	2005	Sensitivity analysis, calibration, and validations for a multisite and multivariable SWAT model	SWAT	180	171

*Total Google Scholar citations = 4,112; total Scopus citations = 2,415

Web of Science All-Time Top Cited Trans. ASAE/ASABE Papers (July 22, 2016)

Authors (paper rank)	Year	Title	Model	Citations: All Databases	Citations: Core Collection
Moriasi et al. (1)*	2007	Model evaluation guidelines for systematic quantification of accuracy in watershed simulations	**SWAT**	1,585	1,517
Gassman et al. (2)	2007	The Soil and Water Assessment Tool: Historical development, applications, and future research directions	**SWAT**	793	741
Williams et al. (6)	1984	A modeling approach to determining the relationship between soil erosion and soil productivity	**EPIC**	561	508
Williams et al. (9)	1989	The EPIC crop growth-model	**EPIC**	415	377

***Total Google Scholar citations = 2,738; total Scopus citations = 1,767**

JSWC Article Describing Bibliometric Review of Nonpoint Source Modeling Research

- Citation: Li, S., Y. Zhuang, L. Zhang, Y. Du, and H. Liu. 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.

- Both authors of studies and terms in studies are ranked in JSWC article based on review of articles in Web of Science Core Collection
  - searched on terms in article titles, abstracts or keywords
  - a total of 2,179 nonpoint source (diffuse) pollution articles found; 148 were SWAT papers
  - SWAT: #4 key term and most widely used model

- Five indices used to rank authors
  - **total articles**, first or correspondence author, **total citations**, citations per publication, & author h-index based articles included in the analysis

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. 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 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.

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.

Other Bibliometric Studies that Highlight the Impact of SWAT

Topic	Analysis type	Citation
Total citations	Web of Science & Google searches	Refsgarrd et al. 2010. Hydrology Research 41(5): 355-377.
Non point source pollution	Keywords	Zhuang et al. 2012. Physics Procedia 33: 138-143.
Soil monitoring	Keywords	Wang et al. 2015. Acta Agriculturae Scandinavica, Section B — Soil & Plant Science.
GIS applications	Cluster analysis	Wei et al. 2015. The Professional Geographer.
River water quality	Keywords & cluster analysis	Wang et al. 2016. Scientometrics.
BMP research	Keywords	Zhuang et al. 2016. Journal of Soil and Water Conservation. 71(4): 98A-104A.

Citation data available in: https://www.card.iastate.edu/swat_articles/

Moriasi et al. (2007; 2015) Suggested Streamflow NSE Criteria

(NSE: Nash-Sutcliffe modeling efficiency)

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

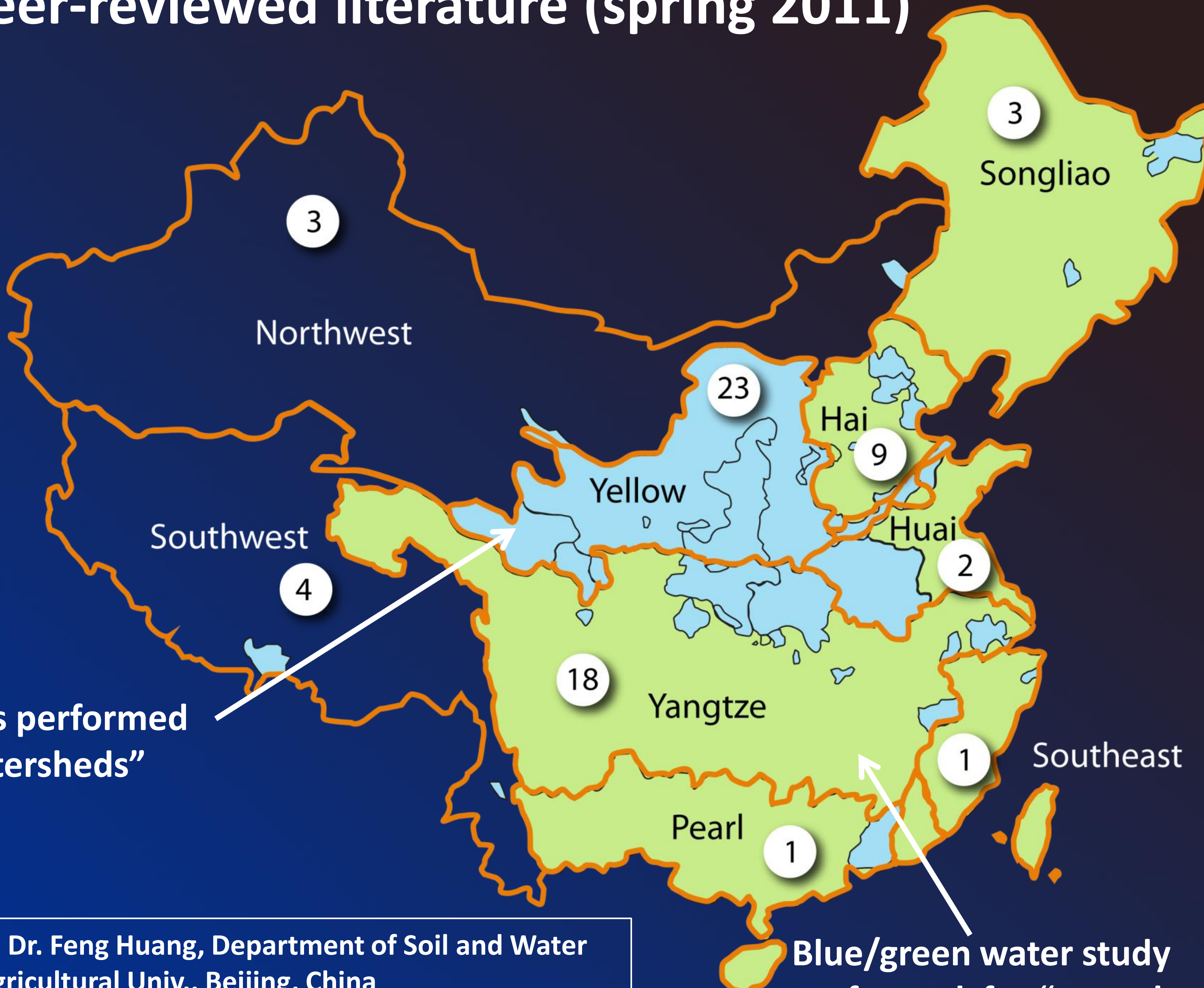
Sources: Moriasi et al. 2007. Transactions of the ASABE. 50(3): 885-900. Doi: 10.13031/2013.23153. & Moriasi et al. 2015. Transactions of the ASABE. 58(6): 1763-1785. Doi: 10.13031/trans.58.10715.

Frequency of SWAT Daily Streamflow Statistical Results (combined from 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
0.3 – 0.39	0	7	3	10
0.0 – 0.29	5	12	5	9
< 0.0	0	9	0	18

*(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

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”

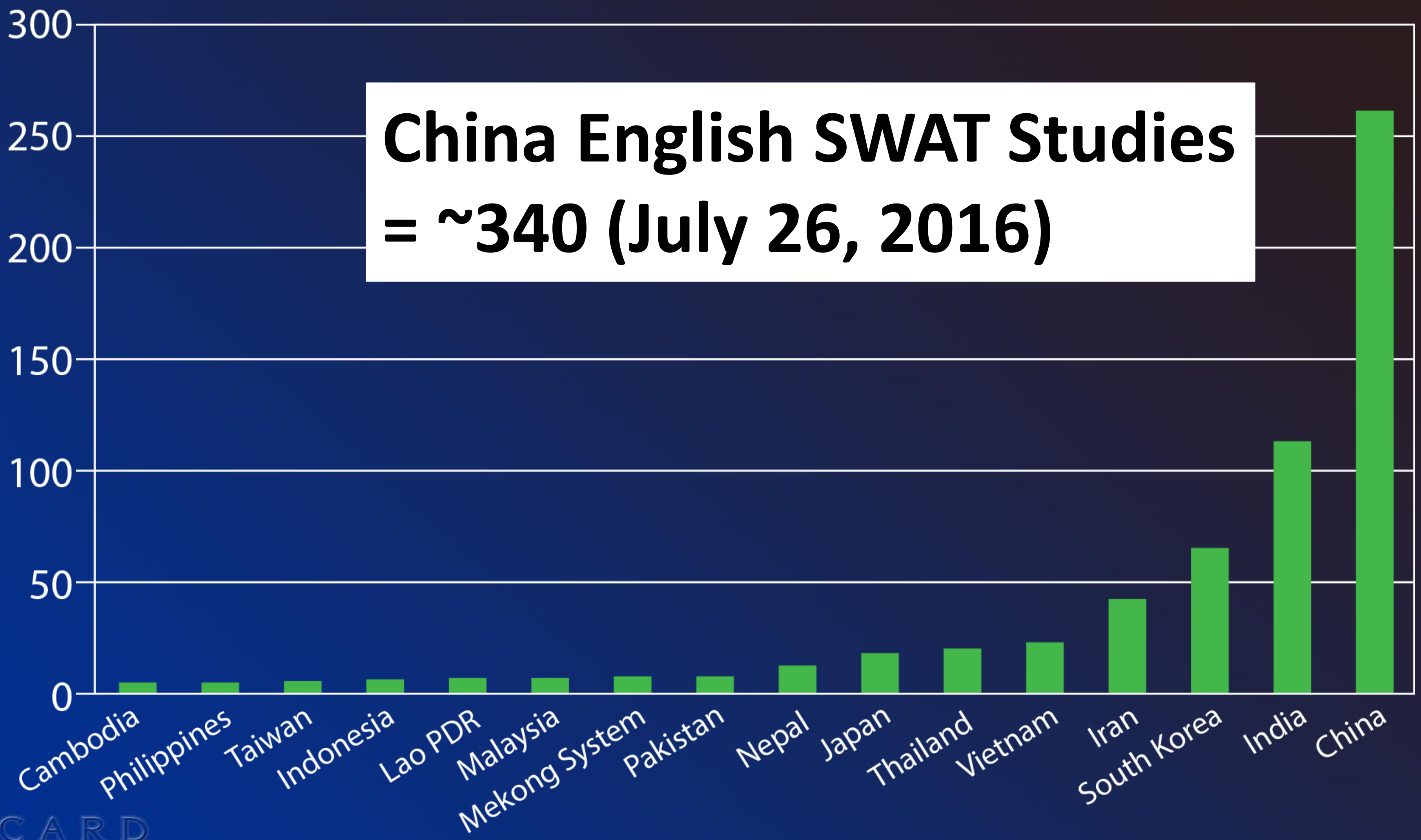
Data compiled by Dr. Feng Huang, Department of Soil and Water Sciences, China Agricultural Univ., Beijing, China

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

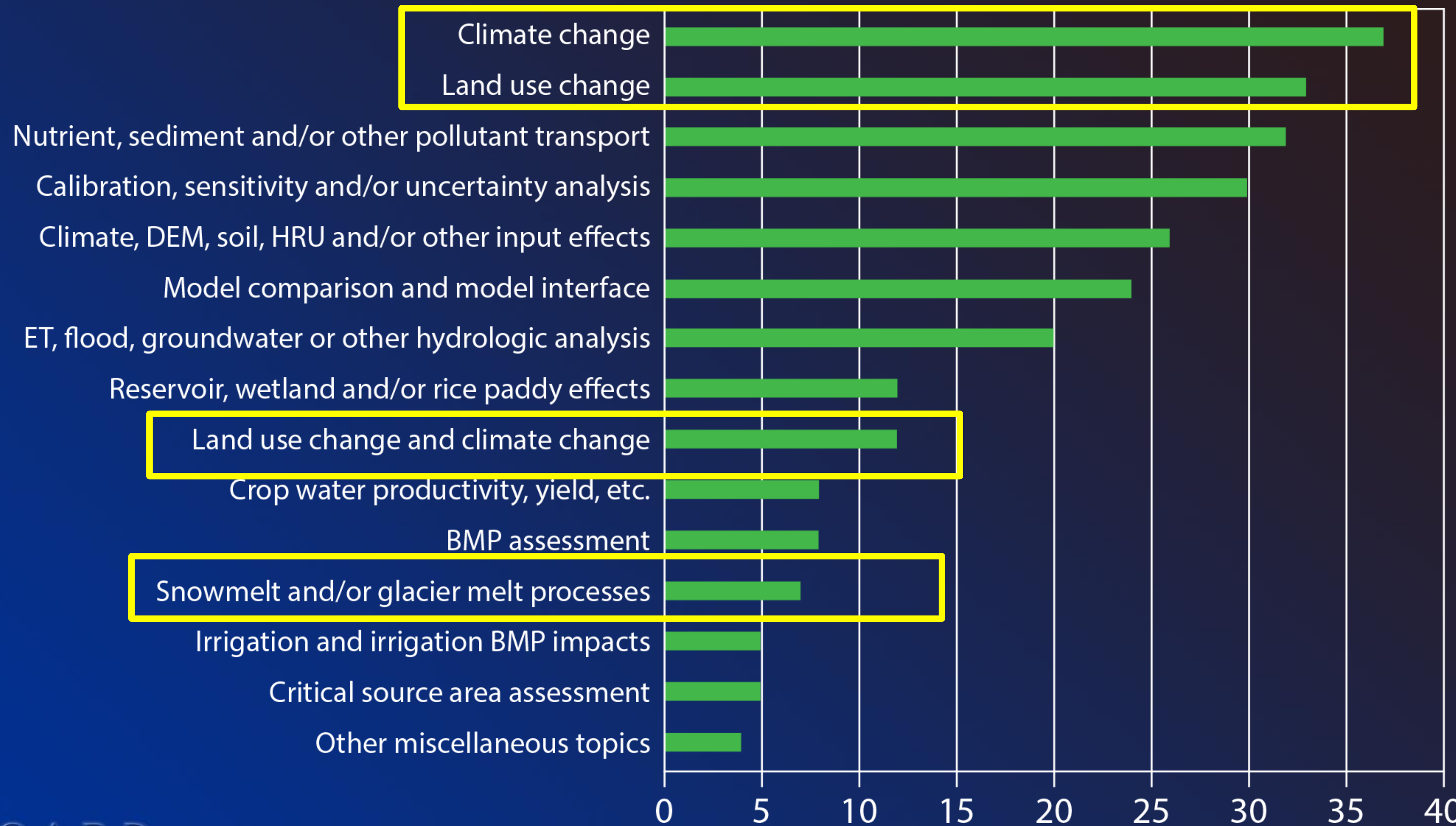
Information compiled by Dr. F. Huang, Department of Soil and Water Sciences, China Agricultural Univ. Beijing, China

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



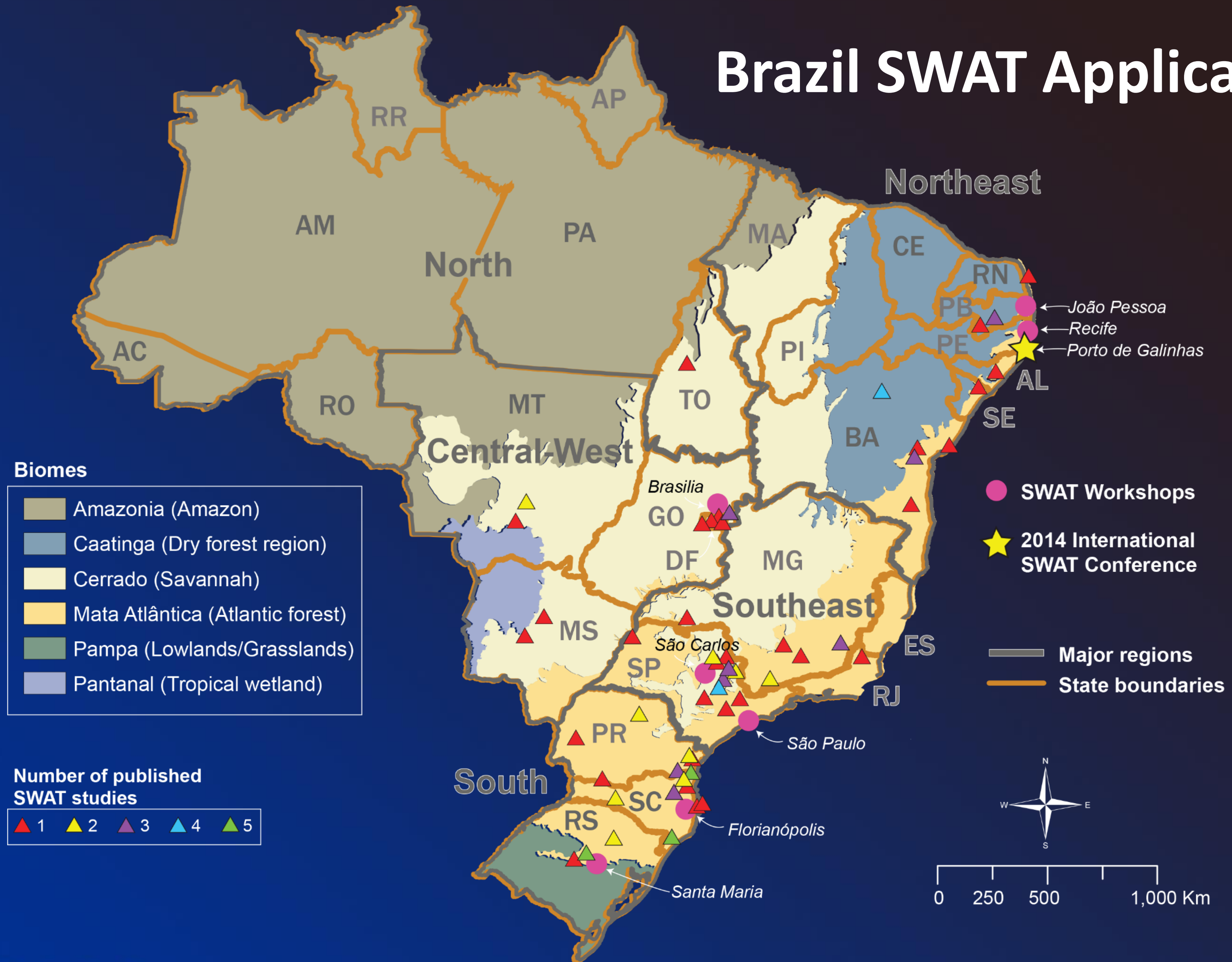
Source: SWAT Literature Database (https://www.card.iastate.edu/swat_articles/)

Current Trends of SWAT Applications in China (October 13, 2015)



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

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 Brazilian SWAT Studies Reporting Calibration Results (based on Moriasi et al. 2007)

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): 9-35. Doi: 10.3965/j.ijabe.20150803.1765.

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.

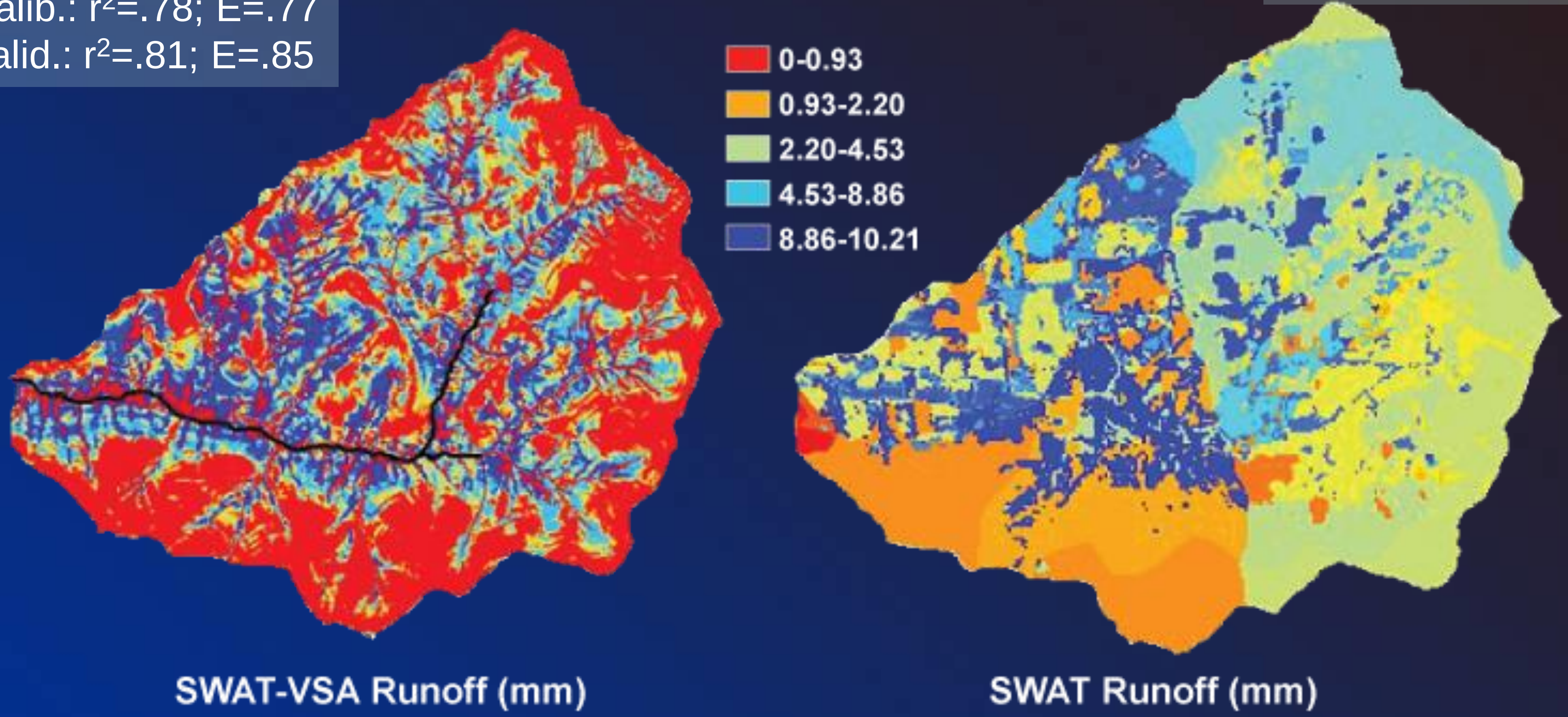
  -Dominated by “Variable Source Area” (VSA) or saturation excess hydrology

- 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

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

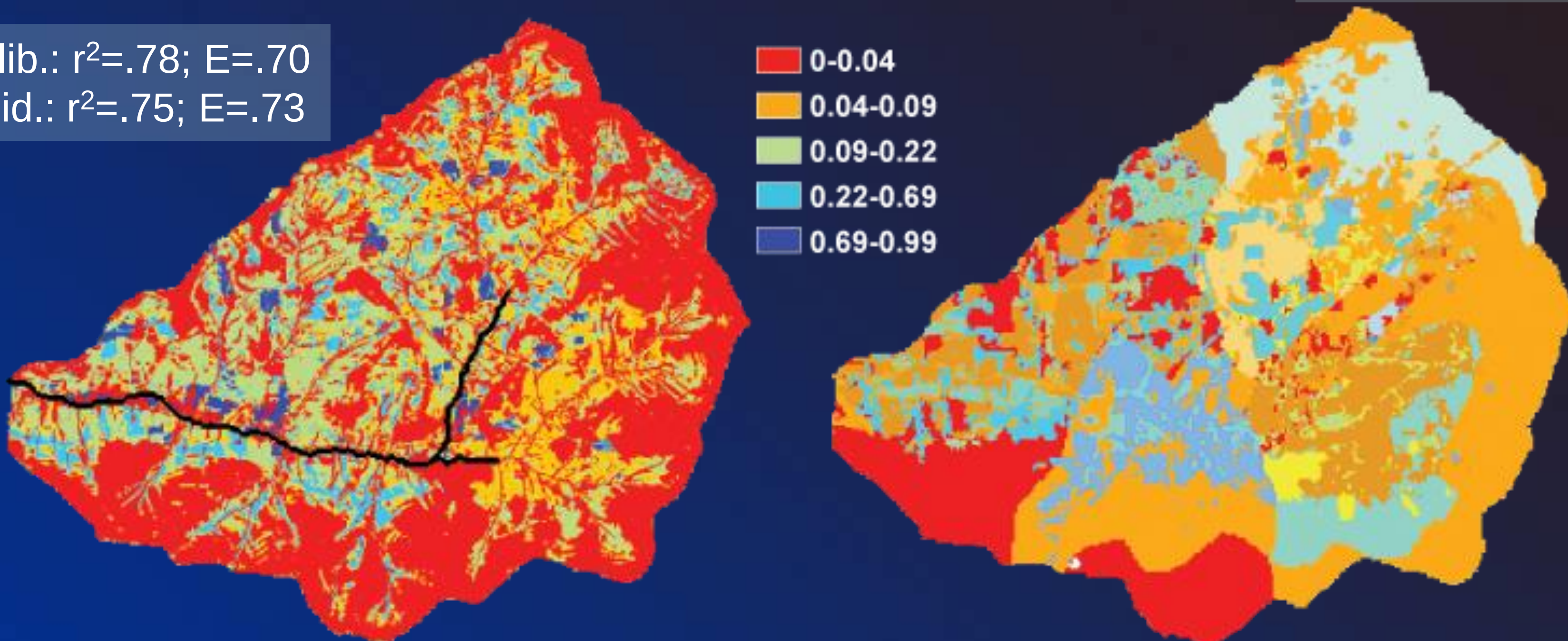


Easton et al. 2008. Re-conceptualizing the soil and water assessment tool (SWAT) model to predict runoff from variable source areas. *Journal of Hydrology* 348(3-4): 279– 291.

SWAT-VSA RCN Approach

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

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



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

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.

Some Concluding Thoughts

- SWAT has proven to be a useful model worldwide

- Global 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