Simulation of rice paddy systems in SWAT: A global synthesis of typical approaches, improved modified methods, and future development needs

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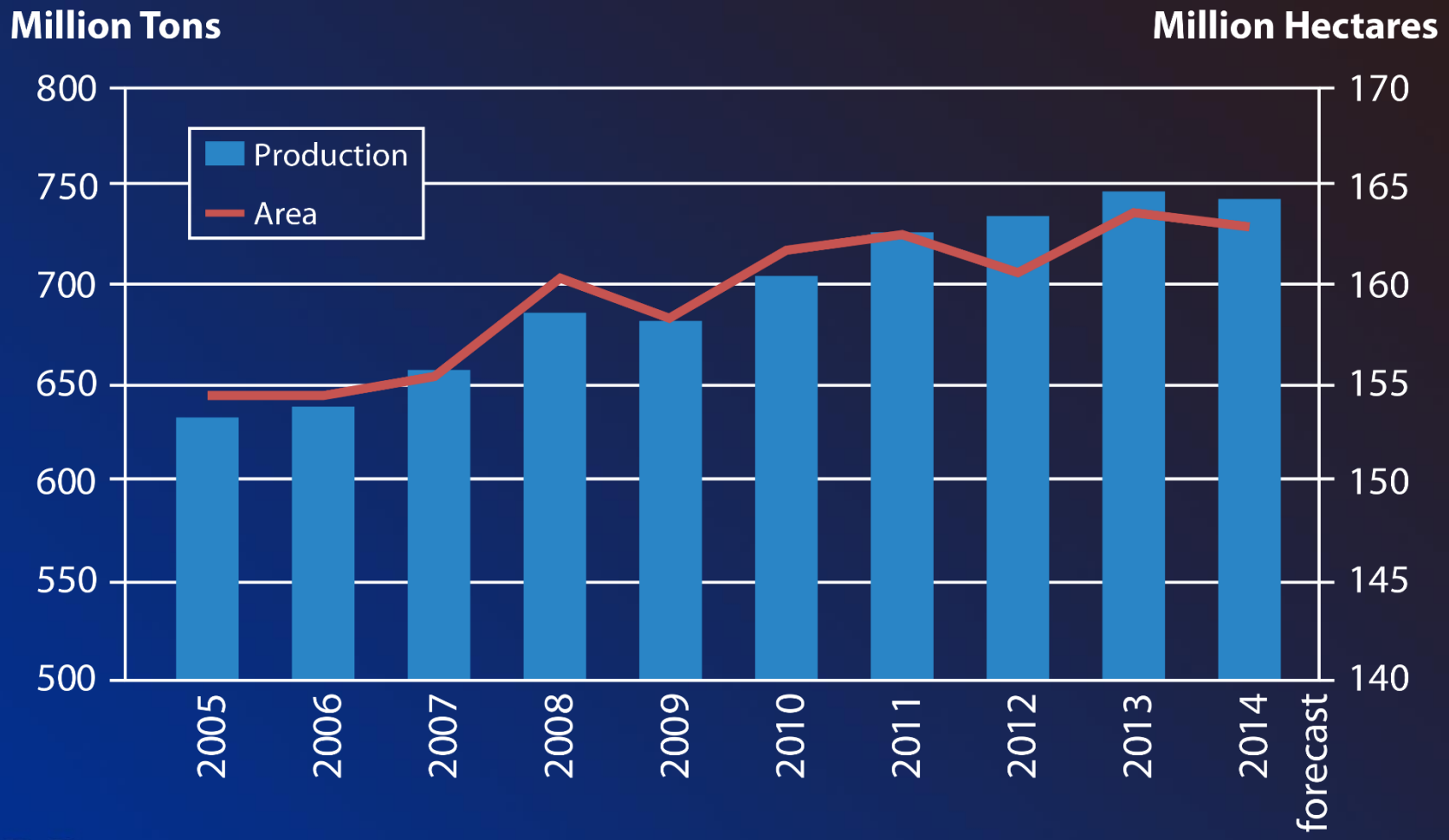
Overview of Presentation

- Brief look at global rice production and rice production systems
- Some background on “potholes” which figure prominently in key SWAT rice paddy studies
- Review several key SWAT rice paddy studies; focus on problems, modifications, etc.
- The way forward: SWAT rice simulation module

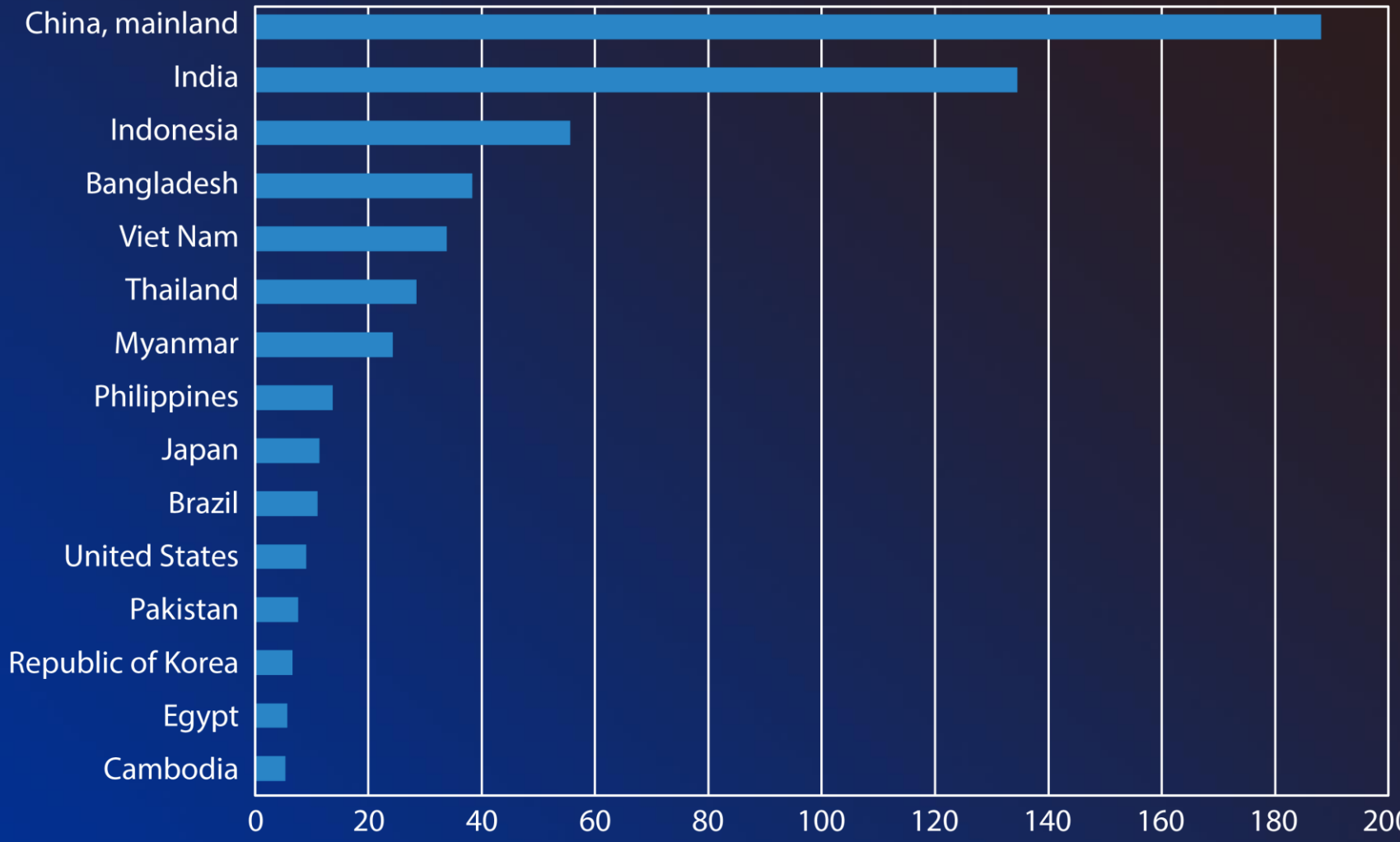
Global Rice Production Trends

(staple food for 50% of global pop.; 90% of that 50% live in Asia)



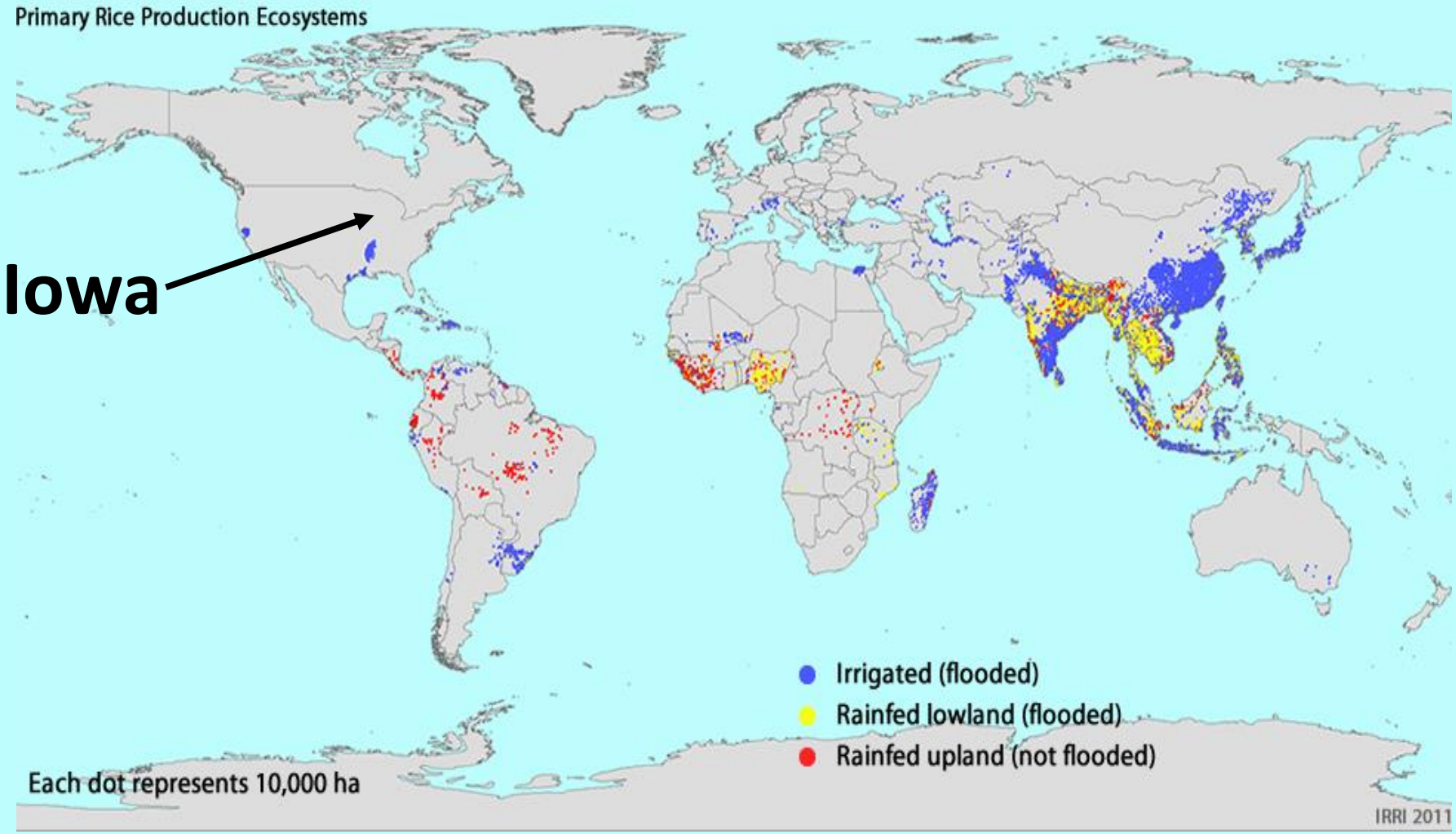
Source: http://www.fao.org/economic/est/publications/rice-publications/rice-market-monitor-rmm/en/

Top 15 Rice Production countries



Source: FAOSTAT. Food and Agriculture Organization of the United Nations, Statistics Division. Available at: http://faostat3.fao.org/browse/Q/QC/E

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

Irrigated Lowland Rice Production Systems

- Soil is submerged for part or all of growing season
- Typically involves puddling of soil
- 55-60% of global production area
- 75% of total global rice production

Sources: http://www.knowledgebank.irri.org/submergedsoils/index.php/rice-growing-environments/lesson-1; http://4.bp.blogspot.com/_zwaRuUhzrcM/ShGN51FZQFI/AAAAAAAABrI/FbtAEB9jXJo/s400/wet+rice+cultivation.jpg; http://www.payvand.com/news/09/oct/rice_cultivation_iran.jpg; http://cdn8.wn.com/ph/img/fb/4e/f20d3184708f8045af30eef4a127-large.jpg

Rainfed Lowland/Upland Rice Production Systems

- Rainfed lowland: not irrigated; can be submerged & puddling is used
  - ~30% of production area & ~20% of total production
- Upland production: soils are in aerobic state (not intentionally submerged)
  - ~10% of production area & <5% of total 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

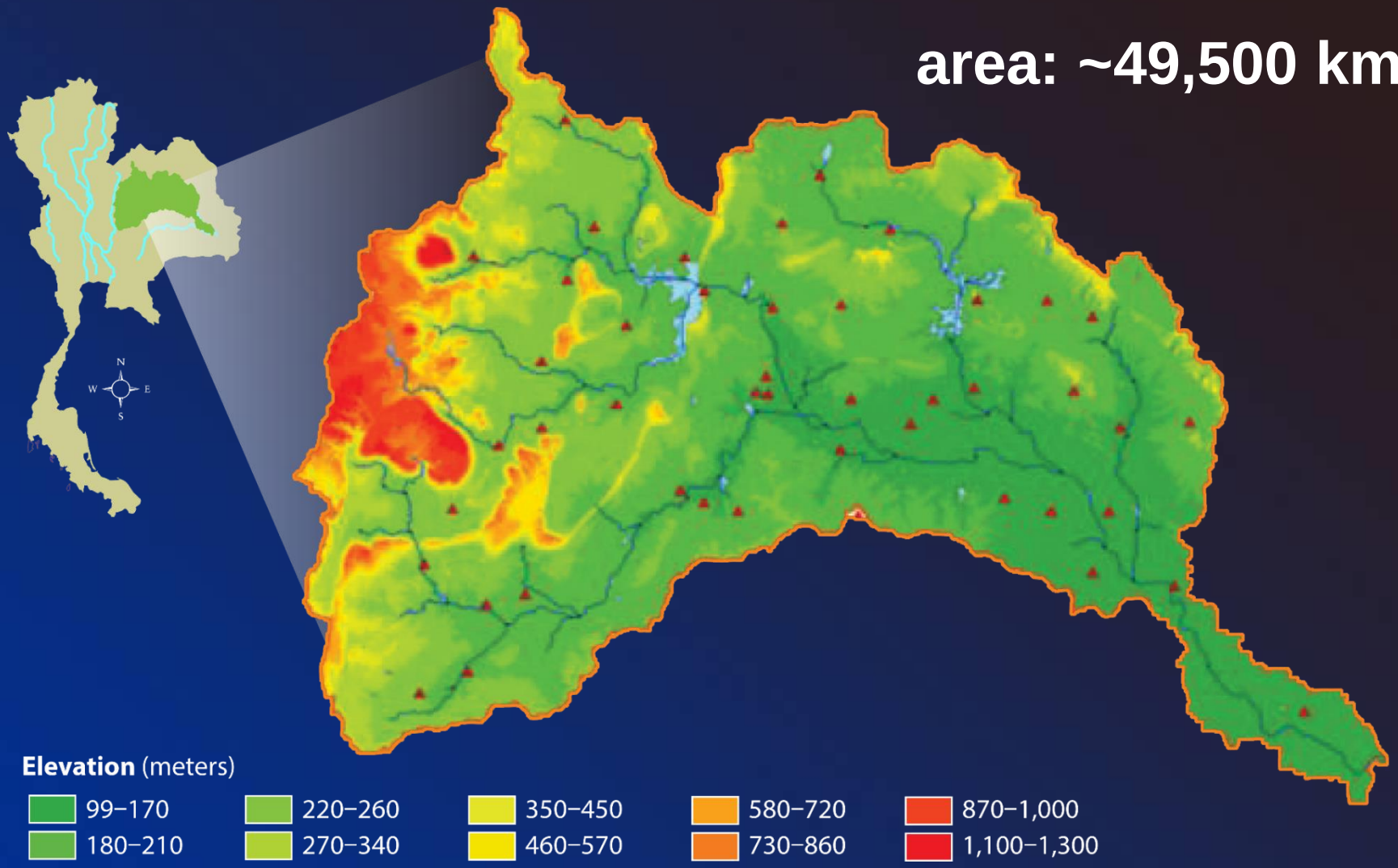
Laos lowland / highland rice fields (Source: http://www.pecad.fas.usda.gov/highlights/2011/12/Laos_13Dec2011/)

SWAT Rice Applications

- Over 60 SWAT studies report some level of rice production being incorporated in the application.
- The majority of these studies report only minor details (if any) as to how rice production was accounted for
  - rice was a major landuse some studies
- Rice paddy dynamics generally ignored in these studies
- Main exceptions: studies that investigated use of pothole module for representing rice paddies
- -note: very few SWAT studies report use of pothole module for any kind of application

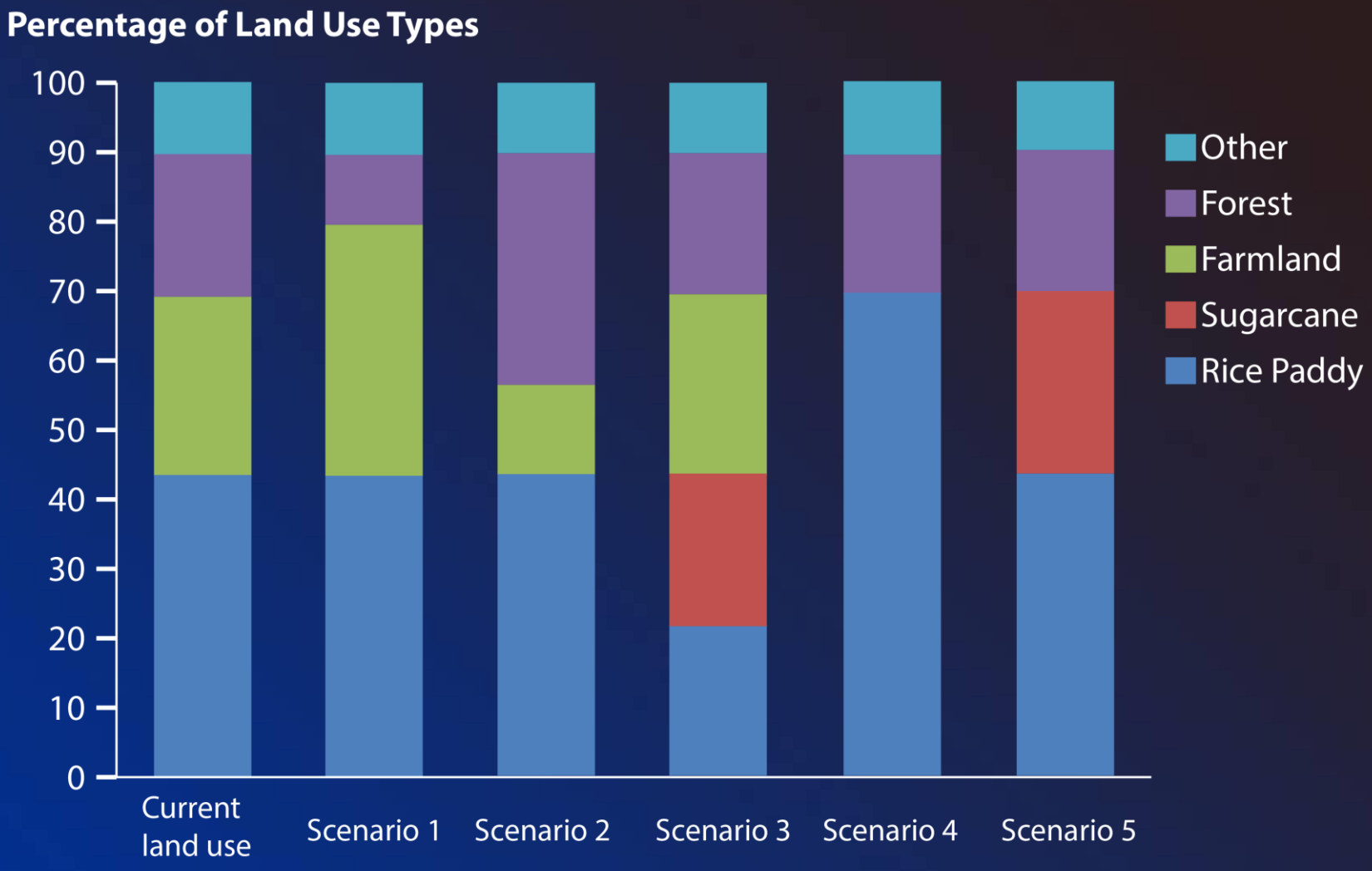
Chi River Basin, Thailand SWAT application

area: ~49,500 km²



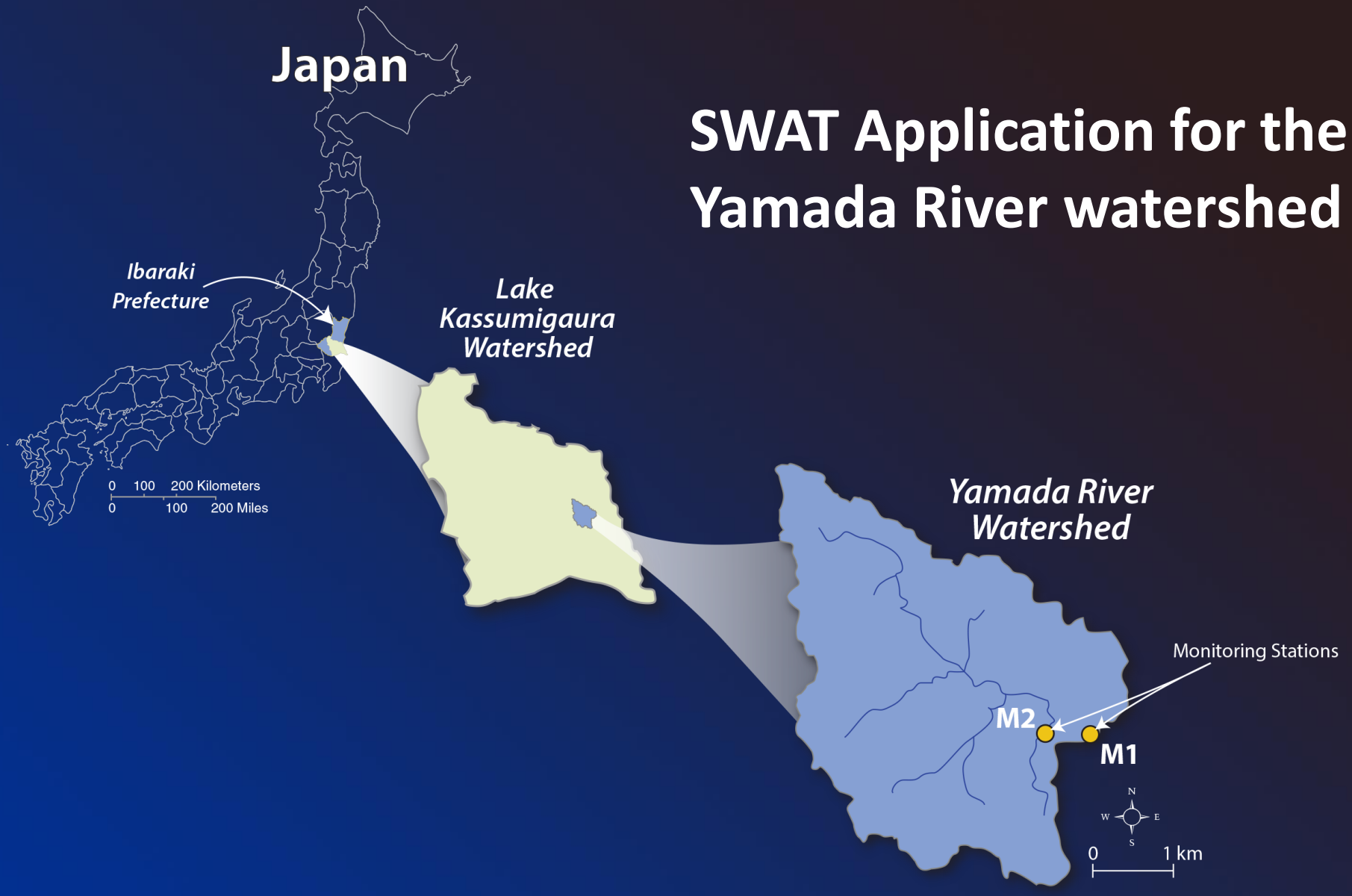
Source: Homdee et al. Impacts of land cover changes on hydrologic responses: A case study of Chi River Basin, Thailand. Annual J. of Hydraulic Engr., JSCE. 55: S31-S36.

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.

SWAT Application for the Yamada River watershed



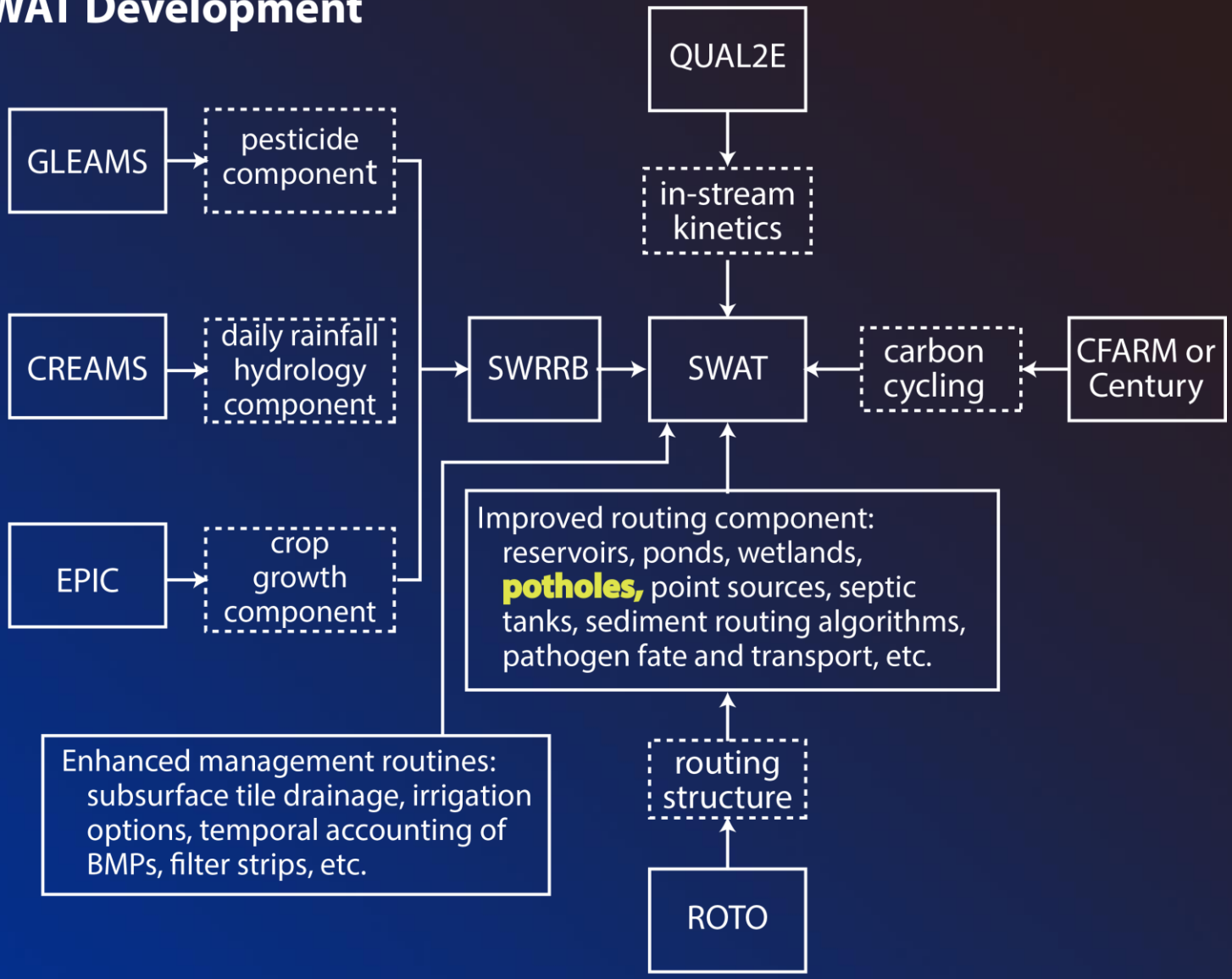
Source: Kato et al. 2011. International Agricultural Engineering Journal. 20(3): 40-49.

Kato et al. Conclusions

- Difficult to represent paddy field water management; had to adjust AWC for irrigated vs. nonirrigated periods
- Relate Japanese soils by hydrologic soil group and develop improved CNs for paddy fields and other Japanese conditions
- Incorporation of paddy field algorithm in SWAT
- Improved ability to represent mosaics of small fields that are more representative of Japanese watersheds

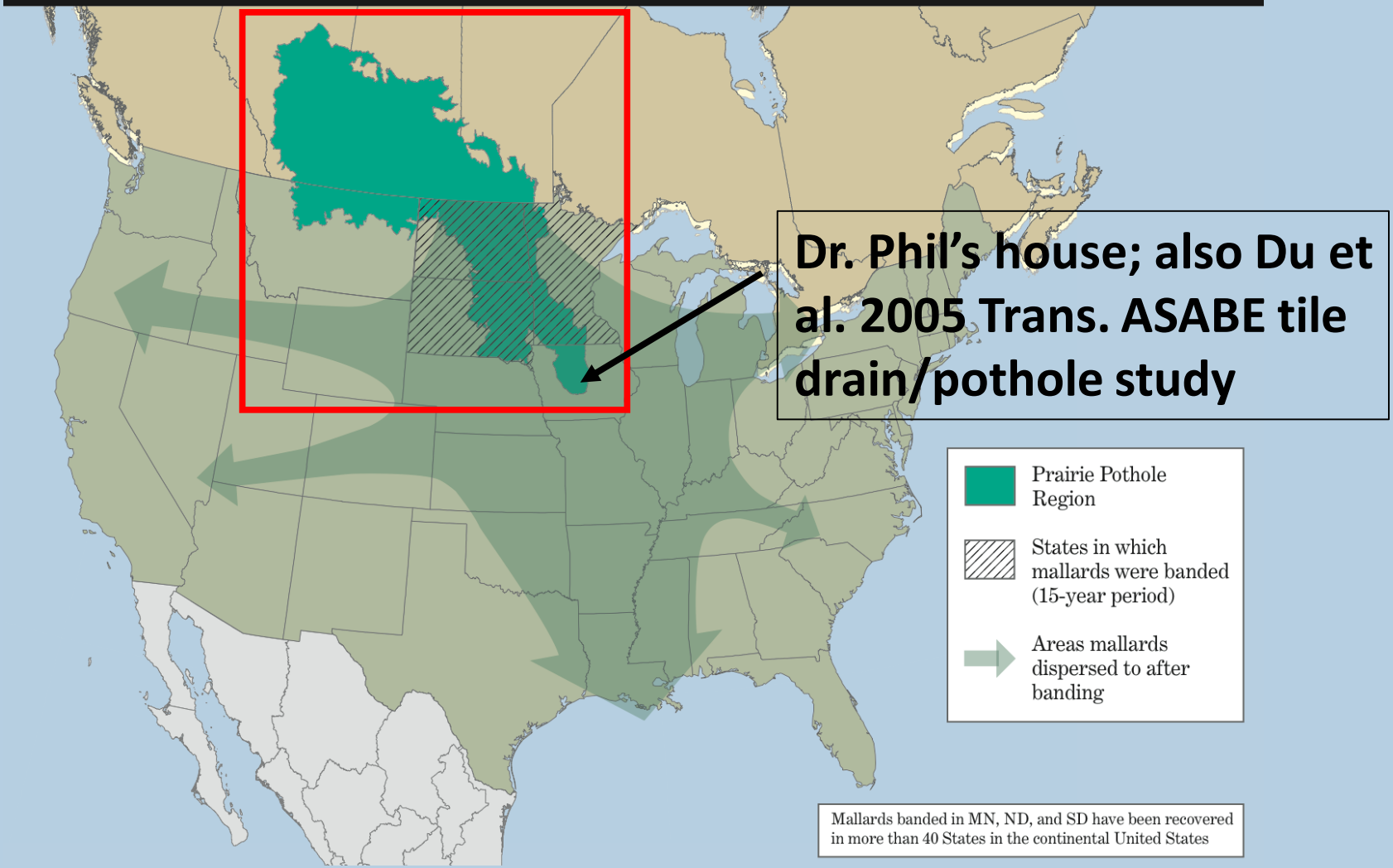
Kato et al. 2011. Simulation of nutrients from an agricultural watershed in Japan using the SWAT model. Int. Agric. Engr. J. 20(3): 40-49.

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

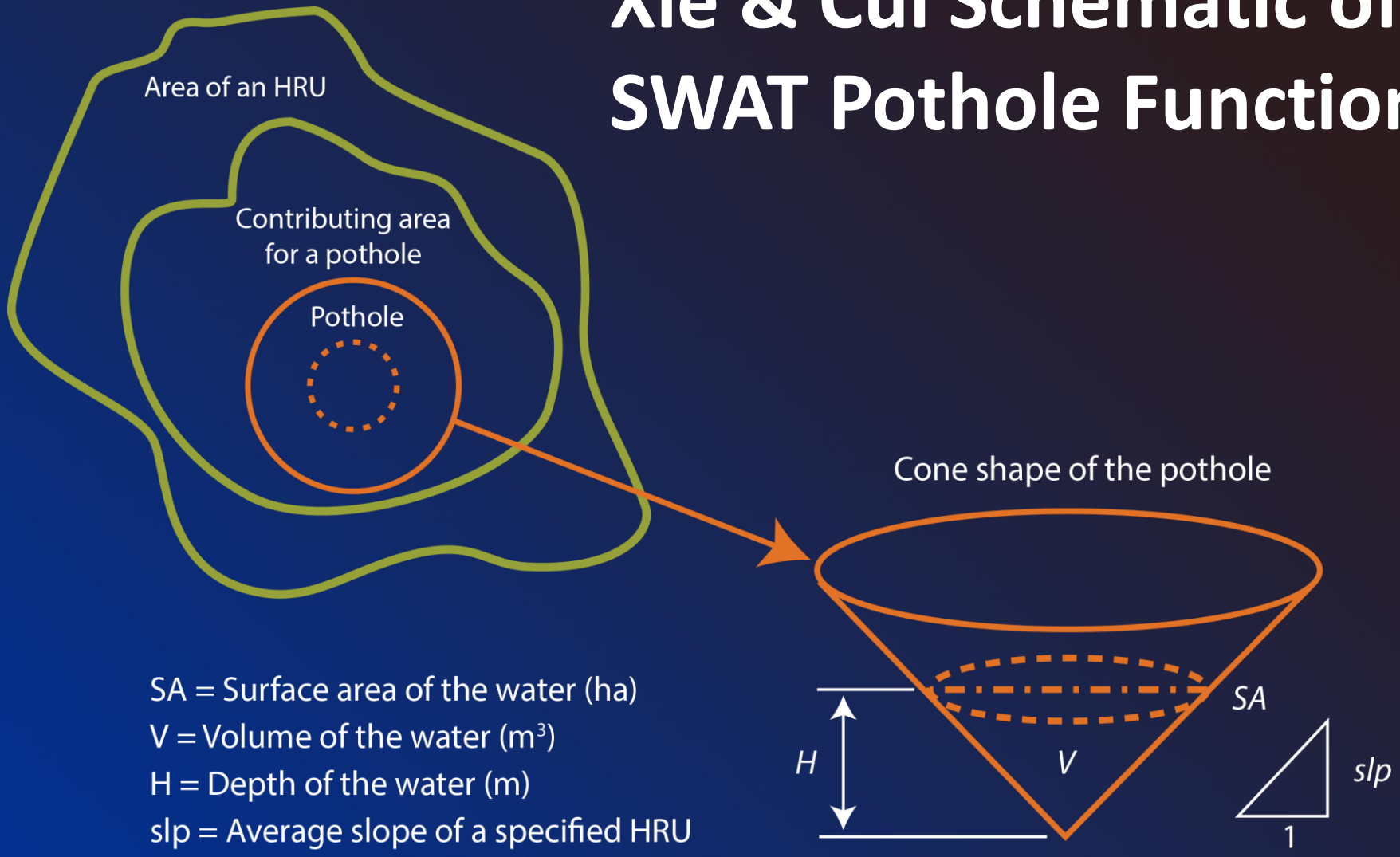


Source: Prairie Pothole Joint Venture. 2014. Available at: http://ppjv.org/resources/maps

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/

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 Modified SWAT Study in China

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

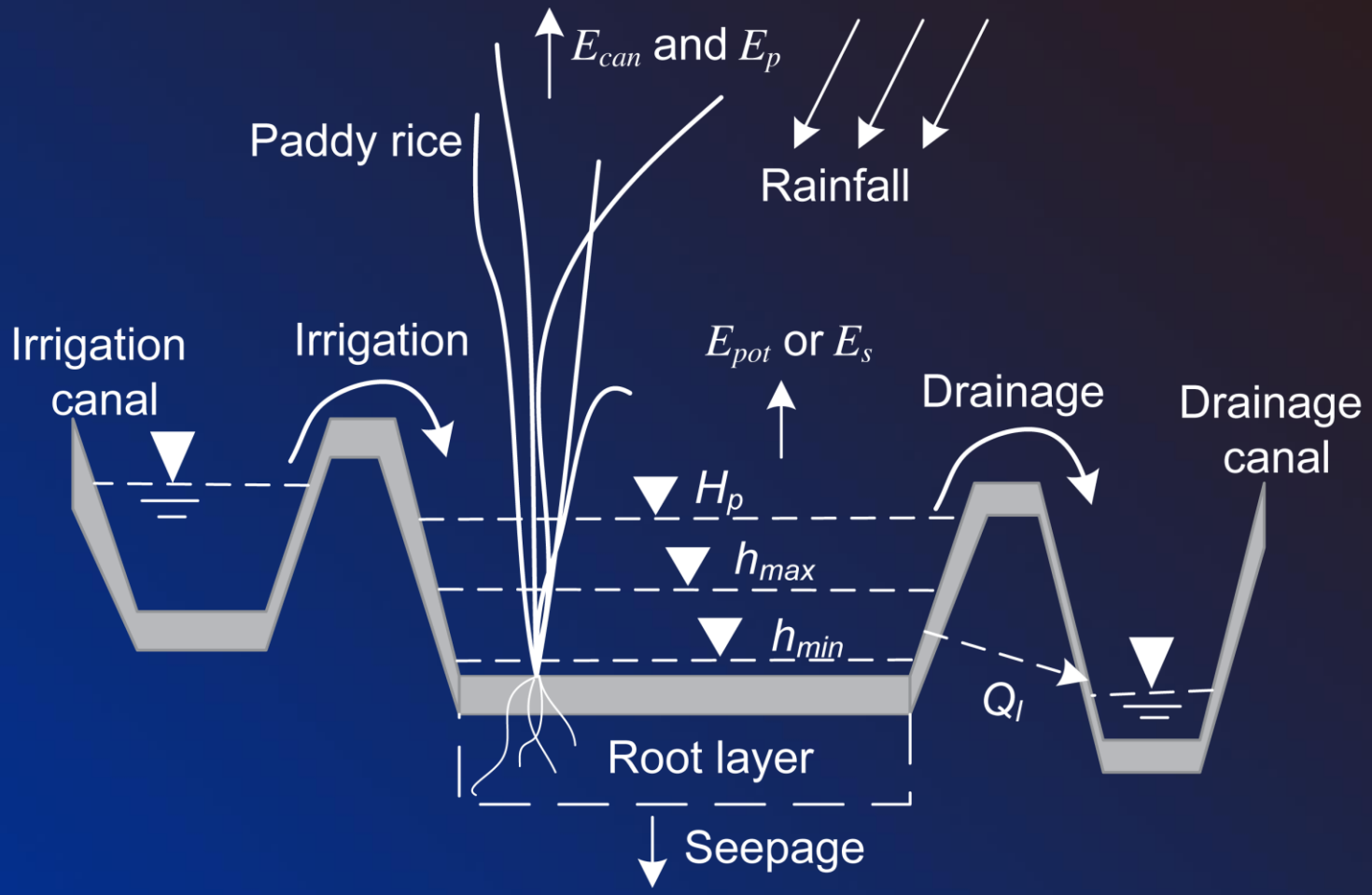
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Xie & Cui 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

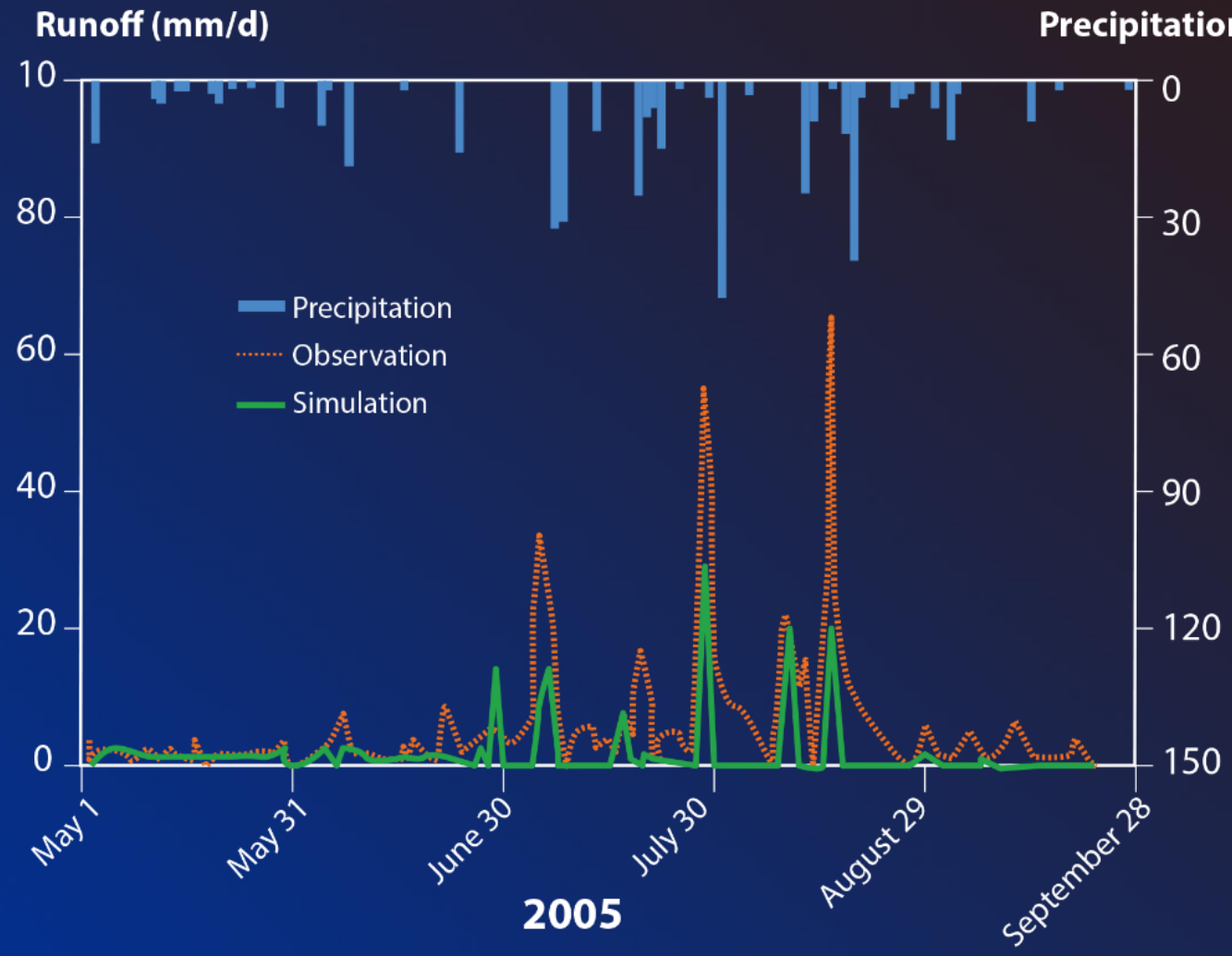
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

Schematic of Rice Paddy Water Balance Dynamics



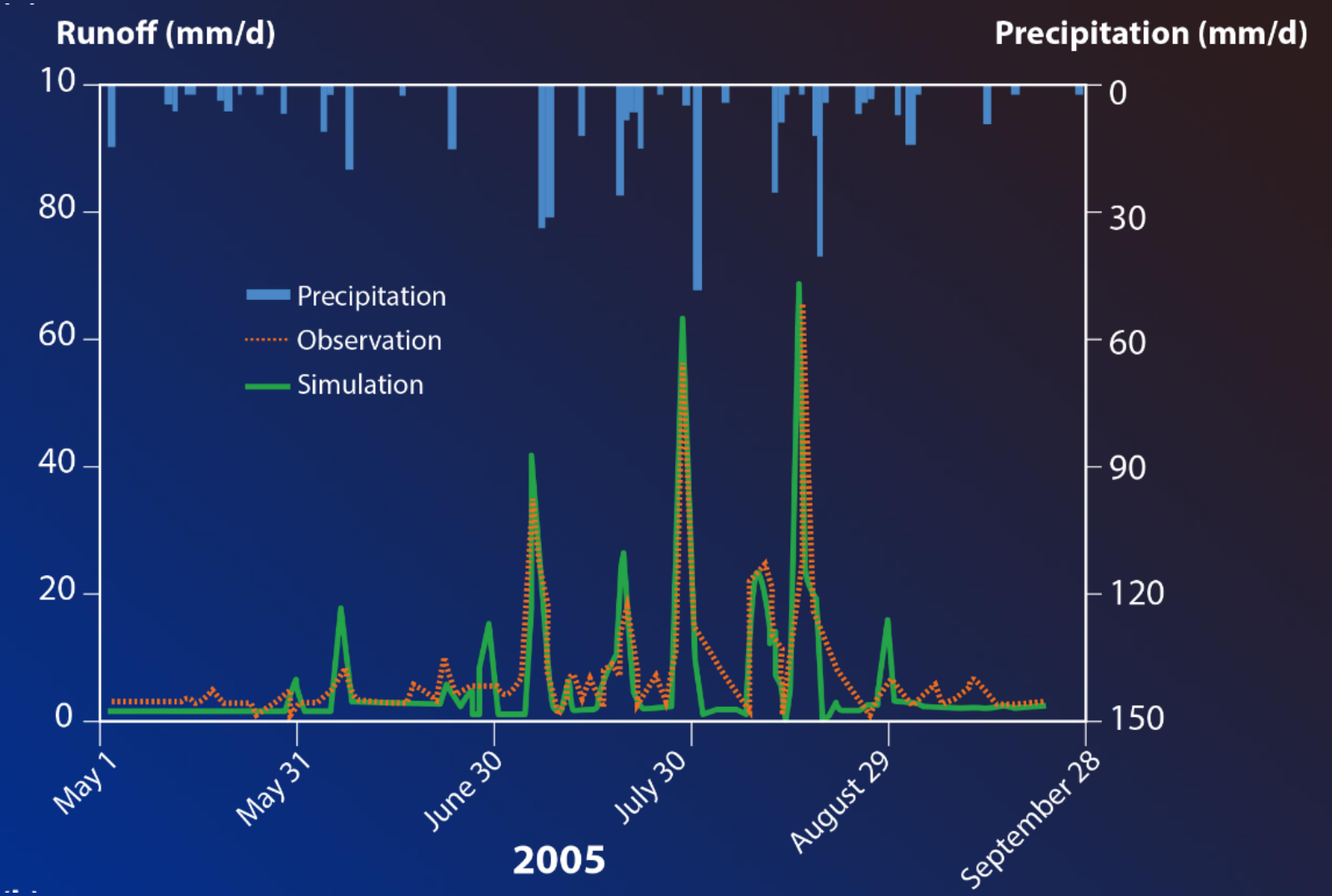
Source: Xie & Cui 2011. Journal of Hydrology 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

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



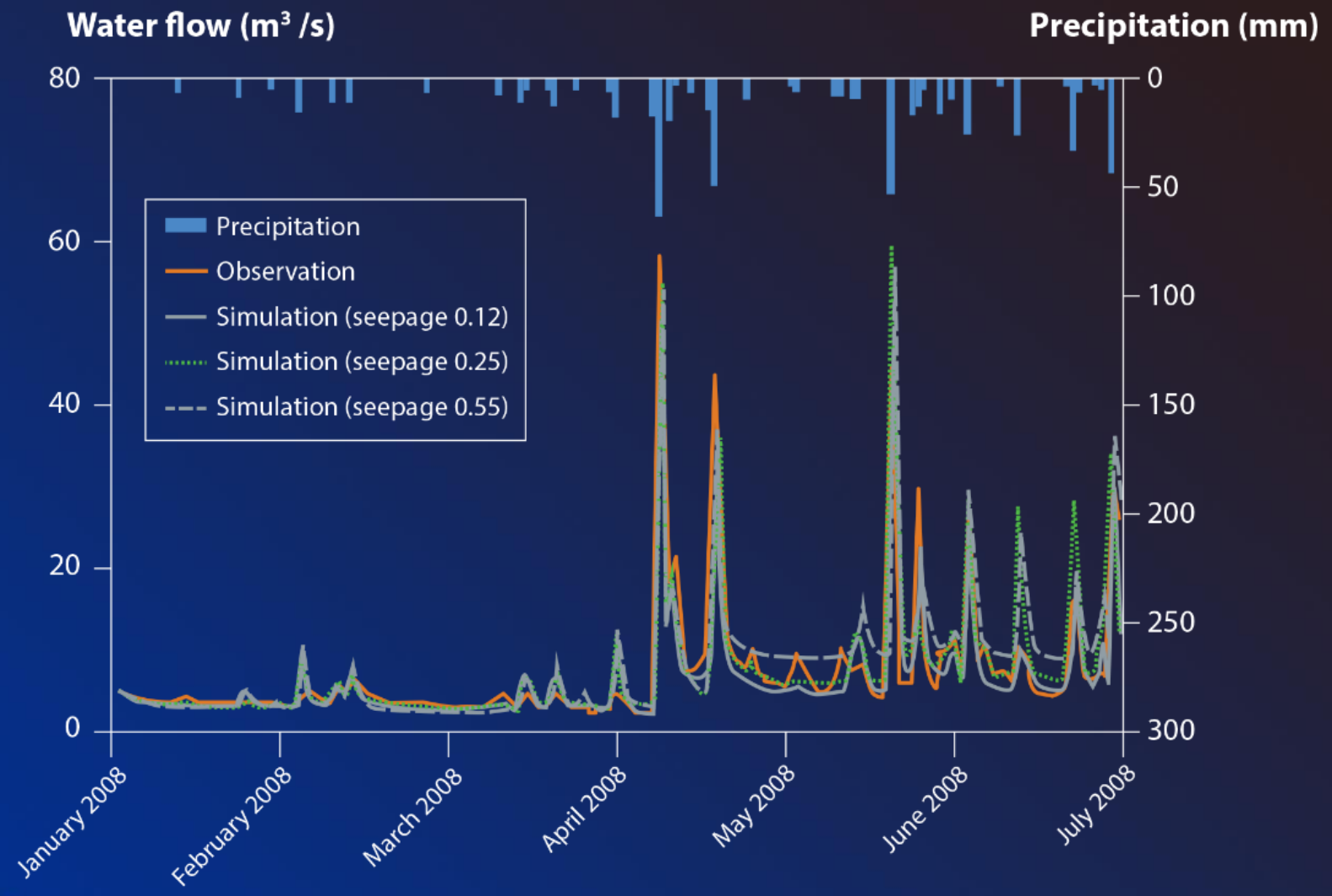
Source: Xie & Cui. 2011. *Journal of Hydrology* 396(1-2): 61-71. Doi: 10.1016/j.jhydrol.2010.10.032.

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

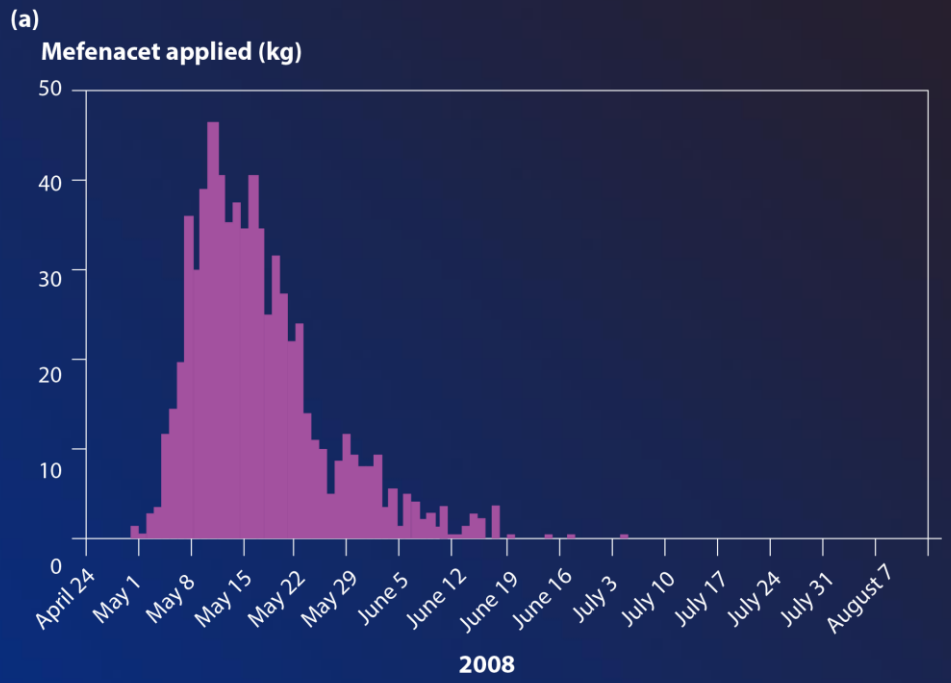
Source: Boulange et al. 2014. Journal of Hydrology. 517: 146-156. Doi: 10.1016/j.hydrol.2014.05.013

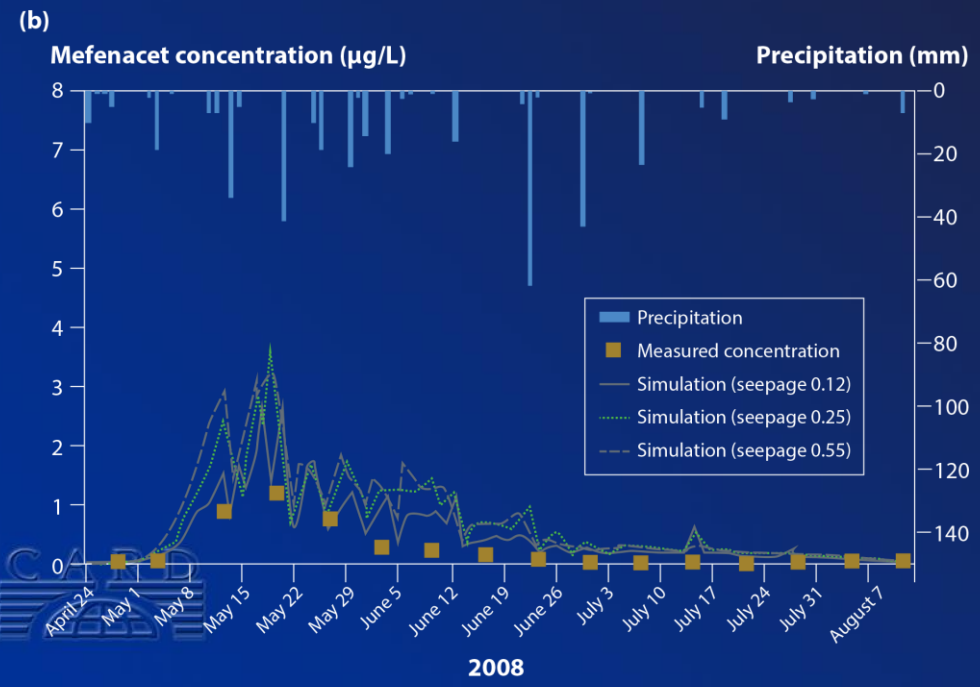
Boulange et al. Validation Streamflow Results



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

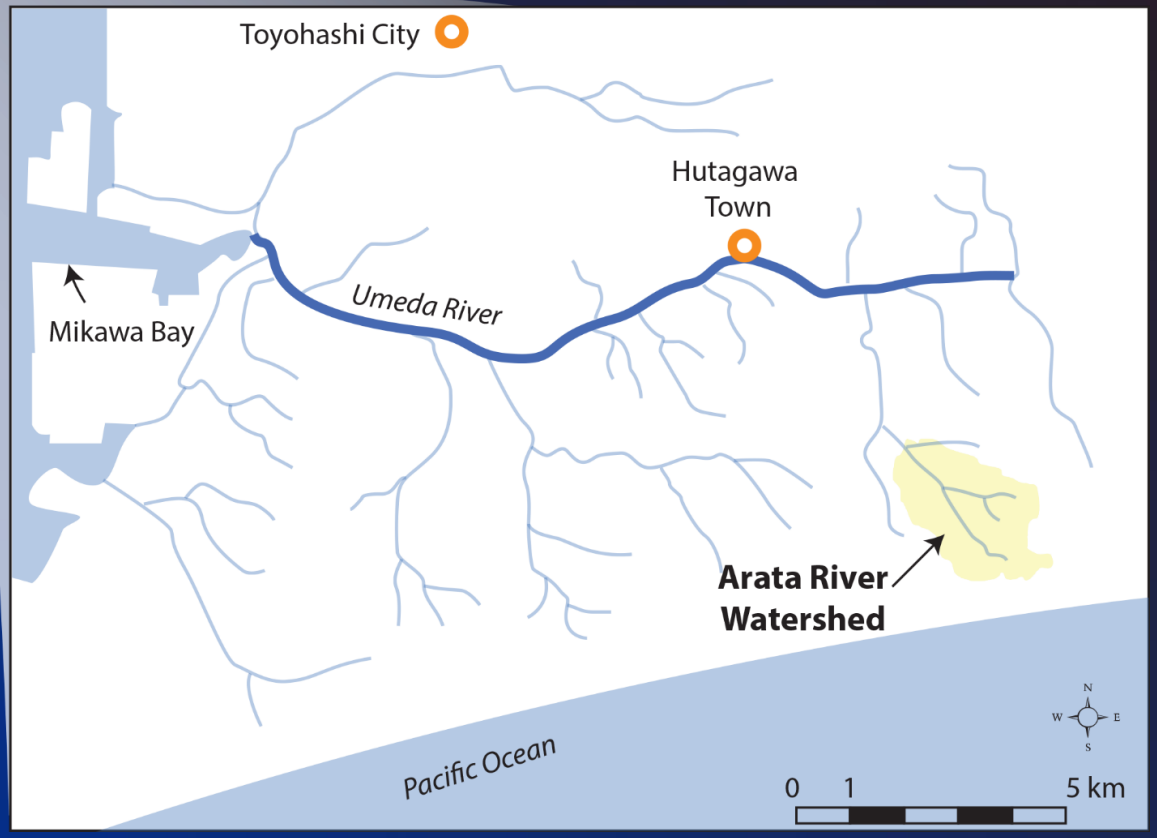




Results reflect uncertainty of application timing and seepage rate; best results were obtained with seepage = 0.12

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

Sakaguchi et al. SWAT Applications for the Arata River Watershed



Source: Sakaguchi et al. 2014. Soil Science and Plant Nutr. 60: 551-564. Doi: 10.1080/00380768.2014.919834.

Land Use Map for 3 km^2 Arata River Watershed

Legend

- 56.4% upland fields
- 18.0% paddy fields
- 10.7% urban areas
- 6.3% forest
- 3.6% tea
- 3.1% orchards
- 1.4% grassland
- 0.5% water

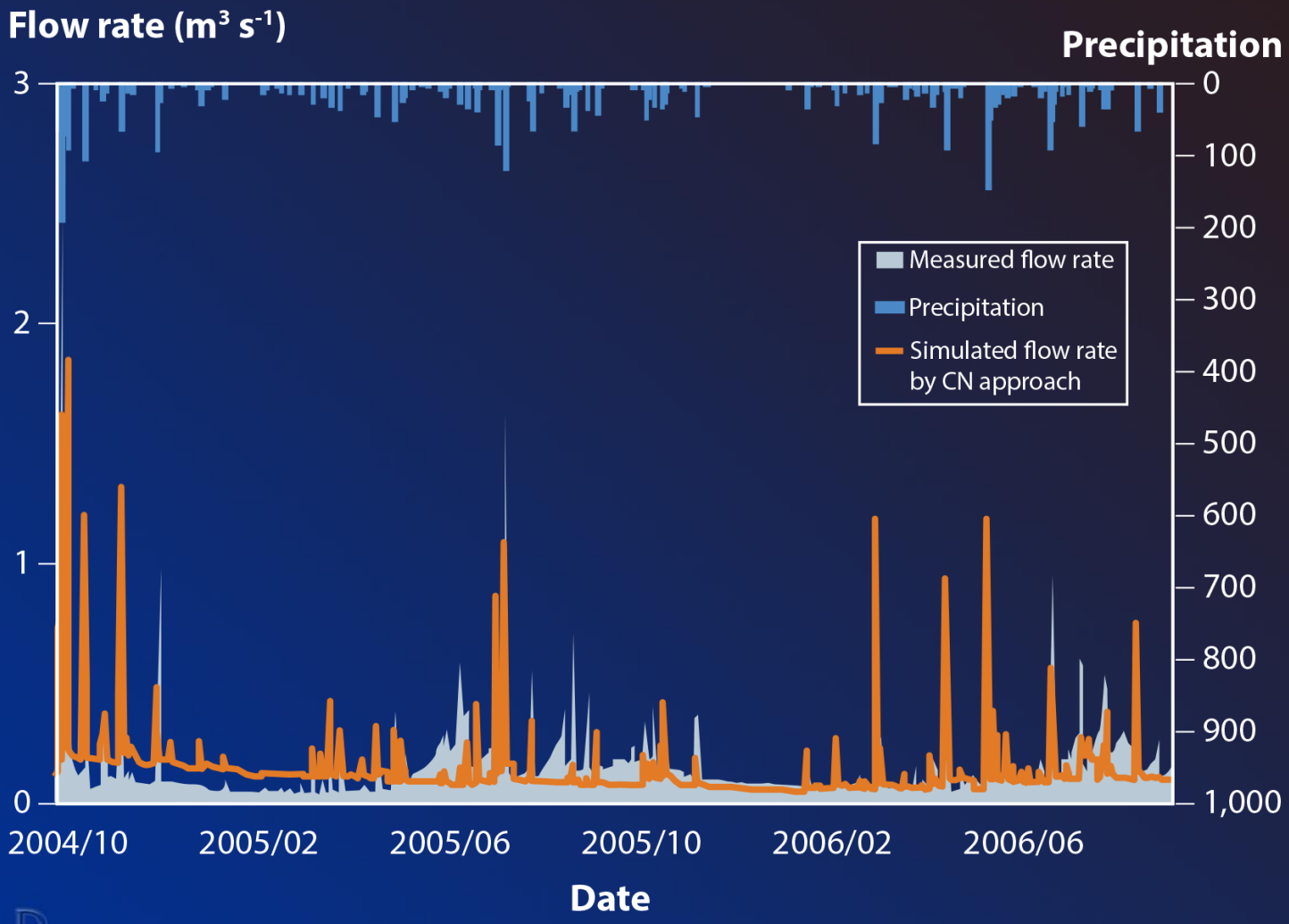
N
W E
S

1 km

CARD

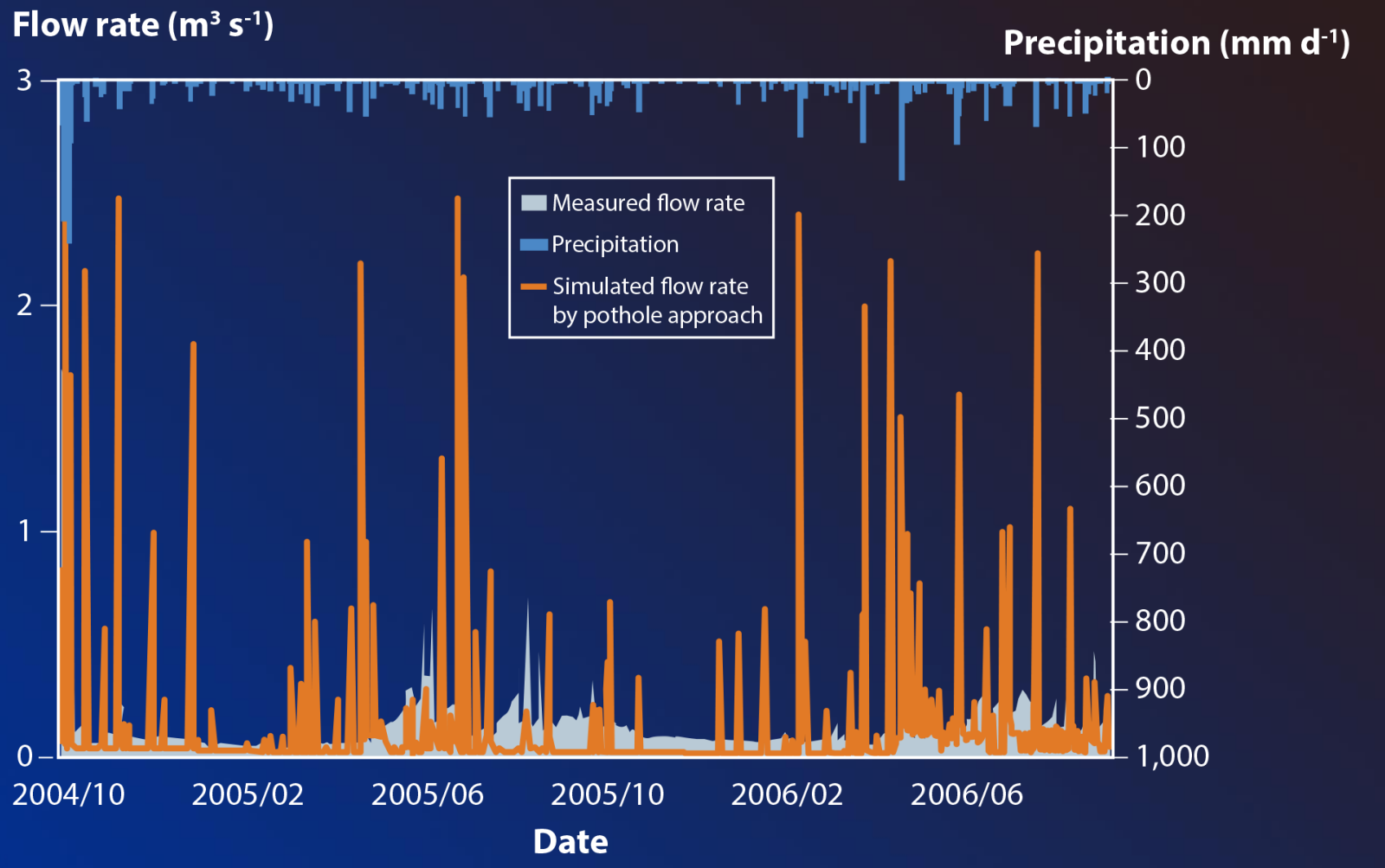
Source: Sakaguchi et al. 2014. Agric. Water Manage. 137: 116-123. Doi: 10.1016/j.agwat.2014.01.009.

Streamflow Results Based on CN Approach



Source: Sakaguchi et al. 2014. Soil Science and Plant Nutr. 60: 551-564. Doi: 10.1080/00380768.2014.919834.

Streamflow Results Based on Pothole Approach



Source: Sakaguchi et al. 2014. Soil Science and Plant Nutr. 60: 551-564. Doi: 10.1080/00380768.2014.919834.

Conclusions for CN & Pothole Methods

- CN method: N_{SE}=0.58; captured ratios of simulated streamflow to rainfall reasonably well.
- Pothole: N_{SE}=-4.02; ratios of simulated streamflow to rainfall were simulated ok
- CN problems: could not differentiate rainfall runoff between ponded and drained conditions and could not capture continuous percolation below paddies
- Pothole problems: seepage did not occur from ponded paddies into soil on most days; percolation below the soil also occurred infrequently; unrealistically small ET levels

CARD

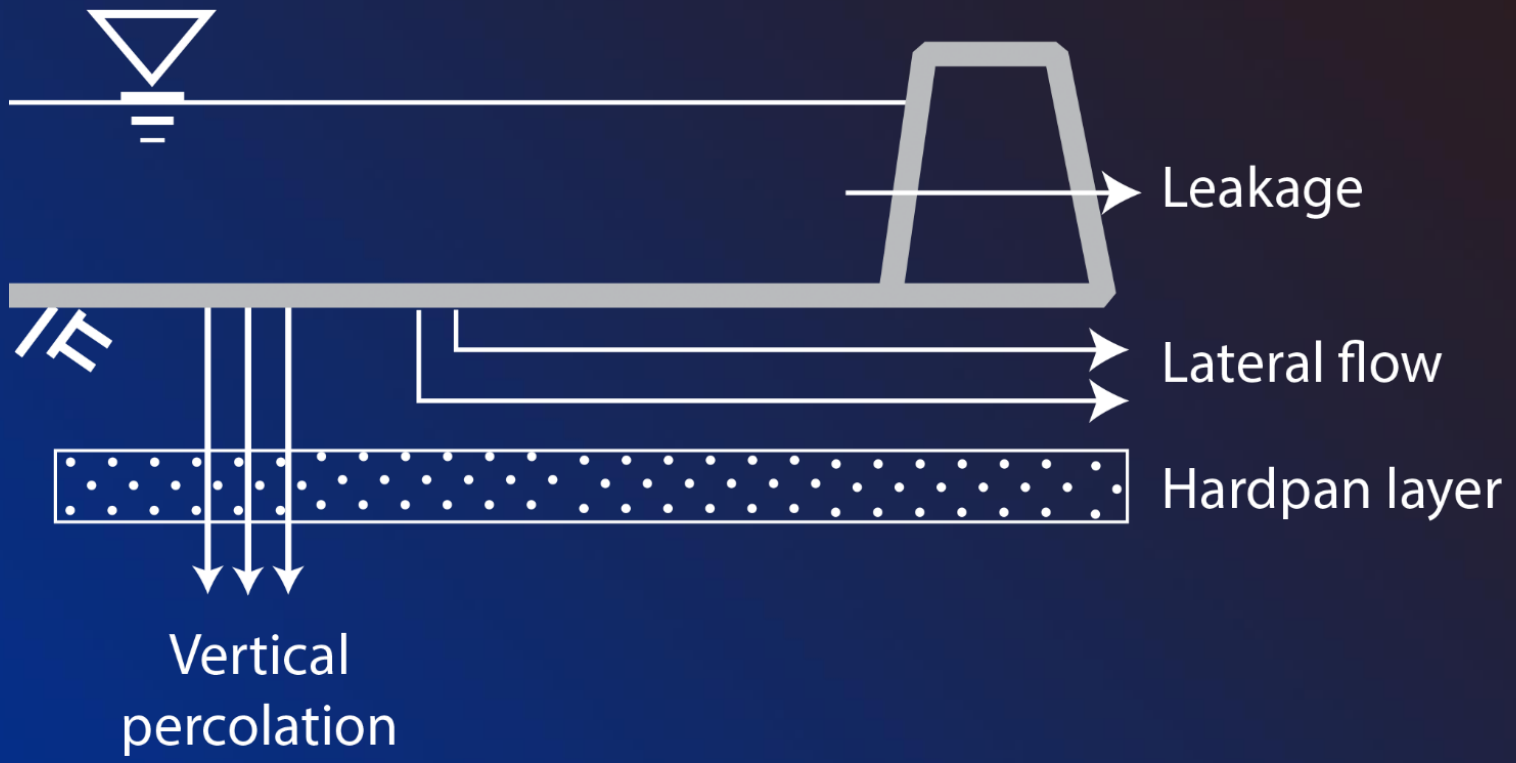
Source: Sakaguchi et al. 2014. Soil Science and Plant Nutr. 60: 551-564. Doi: 10.1080/00380768.2014.919834.

Sakaguchi et al. Modified Pothole Method

- Study again performed for Arata River Watershed
- Modified 5 pothole features: shape (cuboid again) and the percolation, irrigation, release, and evaporation algorithms
- Introduced a new parameter: "potential percolation rate of paddy fields" (calibration parameter)
- Percolation was a function of three pathways
- Irrigation algorithms changed to prevent non-typical overflow of simulated impoundments

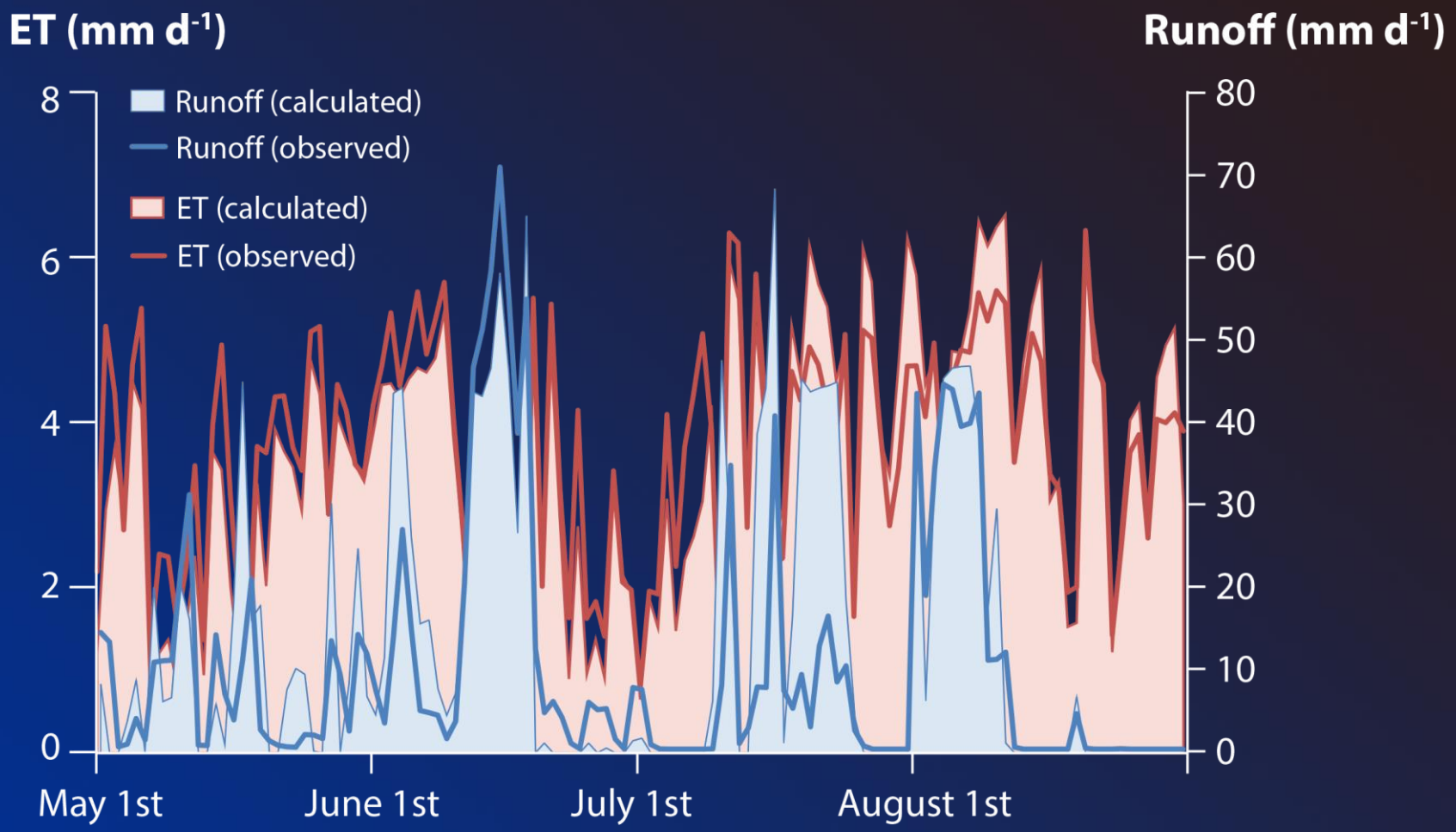
Source: Sakaguchi et al. 2014. Agric. Water Manage. 137: 116-123. Doi: 10.1016/j.agwat.2014.01.009.

Sakaguchi et al. Percolation Components



Source: Sakaguchi et al. 2014. Agric. Water Manage. 137: 116-123. Doi: 10.1016/j.agwat.2014.01.009.

Simulated vs. Observed ET and Runoff



Source: Sakaguchi et al. 2014. Agric. Water Manage. 137: 116-123. Doi: 10.1016/j.agwat.2014.01.009.

Sakaguchi et al. Conclusions

- N_{SE}/R^2 = 0.73/0.74 (calibration) & 0.56/0.66 (validation)

- Modified approach successfully replicated hydrology

- Advantages of this approach
- can estimate comprehensive percolation rate of paddies
- can use actual daily irrigation canal flow rates
- applicable to both ponded and drainage periods

Source: Sakaguchi et al. 2014. Agric. Water Manage. 137: 116-123. Doi: 10.1016/j.agwat.2014.01.009.

The Way Forward

- Recent research points to the need for a standard rice paddy module in SWAT
- Include options for simulating different types of paddy/depressional/ponded areas
- Incorporate specific paddy dynamics rather than trying to modify the pothole module
- Adopt “landscape version” of SWAT that allows refined spatial representation, routing between HRUs, etc.

The Way Forward

- Development of new module already underway
- Approach based on rice paddy modifications introduced by Jaehak Jeong into APEX
- Tasuku Kato's student has coded APEX algorithms into a modified version of SWAT
  - Atsushi Sakaguchi, Julien Boulange, Balaji Narasimhan & others will also contribute
- Review paper describing history presented here and the new approach is partially drafted
  - targeted for Int. J. of Agricultural & Biological Engineering