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Application of the PCPF-1@SWAT model in the Sakura River basin in Japan and the Colusa Drain basin in California, USA

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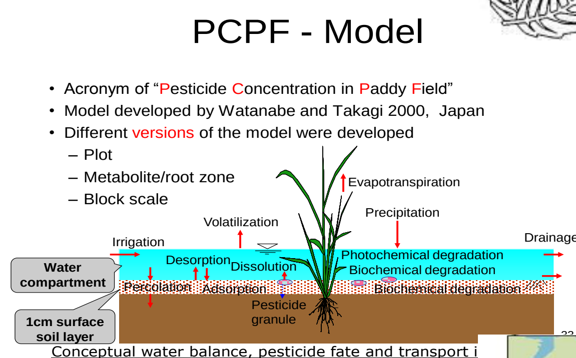
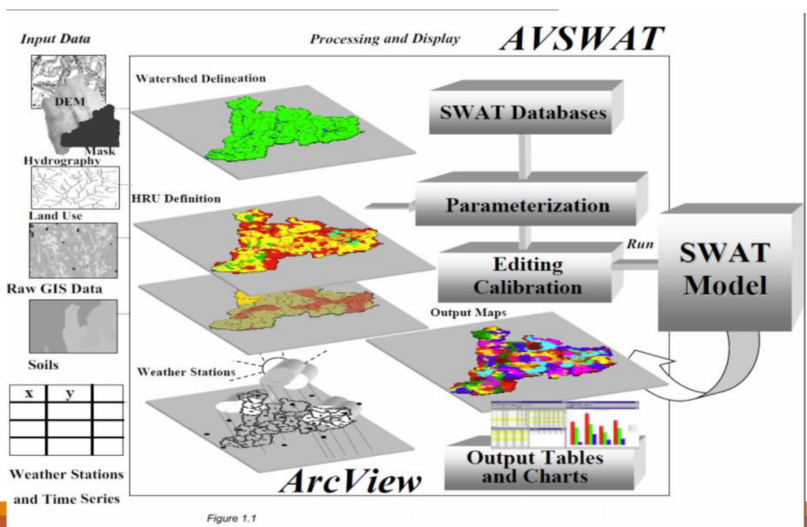
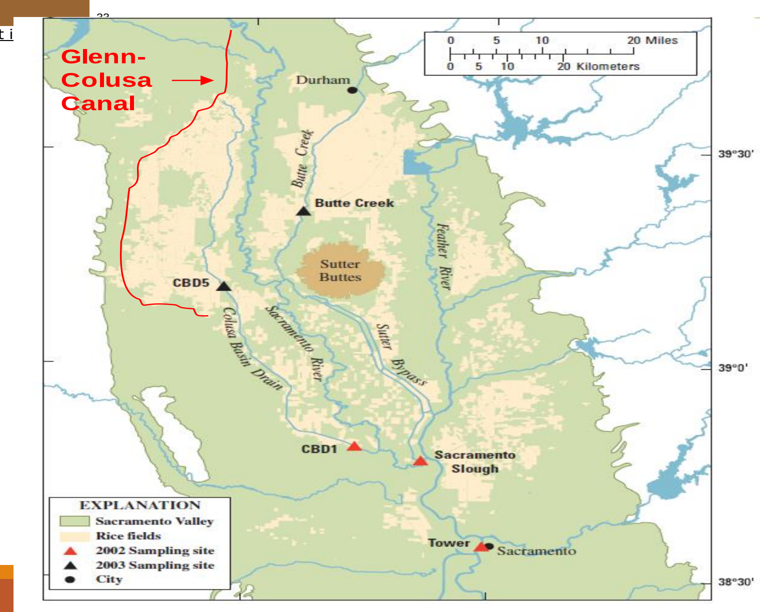
Development of the PCPF-1@SWAT model





SWAT 2000 User Guide



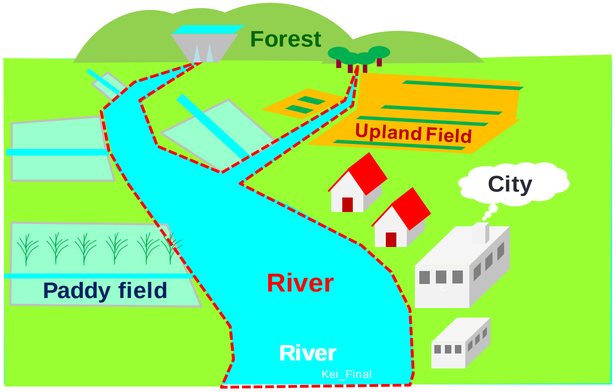
Background - Introduction

Modeling is often the only viable means of continuous screening

Modeling approach is also becoming important for pesticide registration, management, and mitigation

However, models are still limited to:

- Simulation of pesticide applied to rice paddy fields
- Simulation of pesticide applied to upland fields



- Rice field models: PADDY, PFAM, PCPF-1, RICEWQ
- Upland field models: SWAT, PRZM

Need for a model that can simultaneously simulate pesticide fate and transport in upland and rice fields

Objectives - Outline

1. Improve the existing pothole algorithm

- 1.1. Current state of the pothole
- 1.2. Modifications

2. Combine the SWAT model to the PCPF-1 model

- 2.1. PCPF-1 model
- 2.2. Implementation into SWAT

3. Application of the PCPF-1@SWAT model

- In the Sakura River basin, Japan

4. Application of the PCPF-1@SWAT model

- In the Colusa Drain basin, USA, California

1.1. Current state of the pothole

Simulations for paddy fields in the SWAT model are performed using pothole (as advise in the SWAT theoretical documentation)

- Deep closed depressional areas hydrologically similar to ponded areas
- A maximum of one pothole can be currently declared by sub-basin

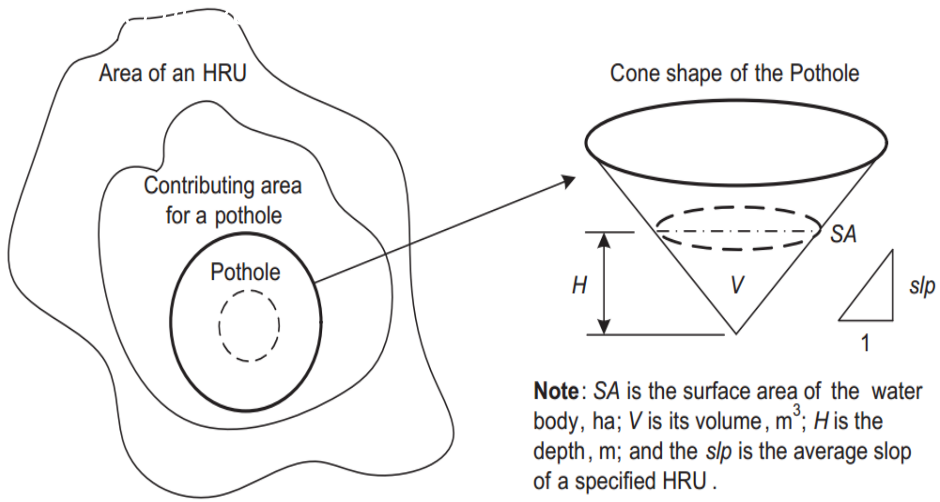


Fig. 2. Schematic diagram of the area of an HRU (left) and its related pothole with the cone shape (right).

- More appropriate for general closed depressional areas rather than real world paddy fields
- Often underestimate surface runoff loading to the main channel (Kang et al., 2006; Kim et al., 2003)

Currently **pesticide fate and transport** is NOT simulated in rice fields

1.2. Modifications

Shape of the pothole

- Cone to cuboid shape (Kang et al., 2006, Xie and Cui, 2011)

Percolation algorithm

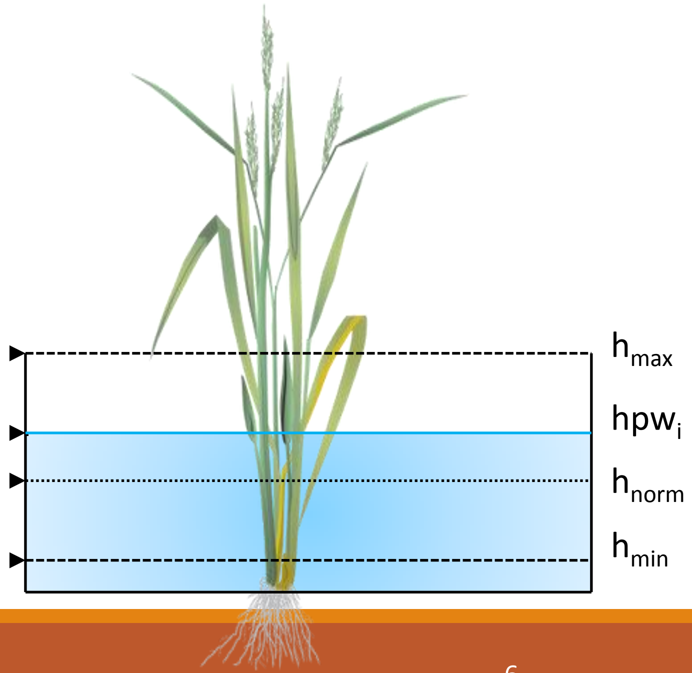
- Average daily percolation rate (Kang et al., 2006)

Irrigation and drainage scheme are usually implemented in order to save irrigation water

- A technique introduced by Guo (1997) was used
- Previously successfully implemented into SWAT (Xie and Cui, 2011)

Re-use of water scheme

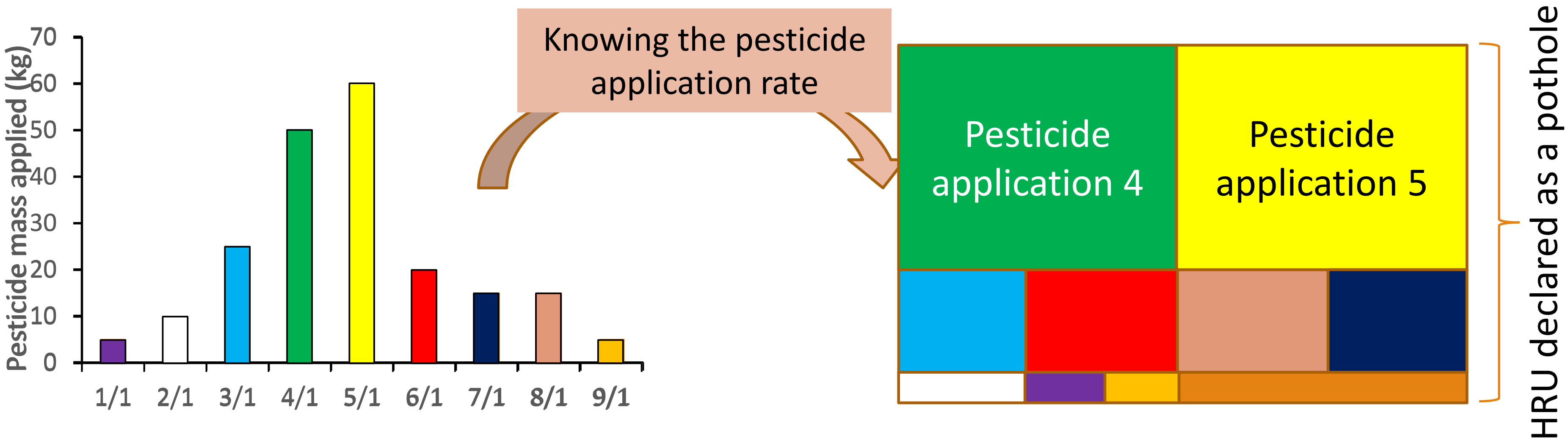
- A certain amount of water loss via drainage can be re-use as irrigation water



1.2. Modifications

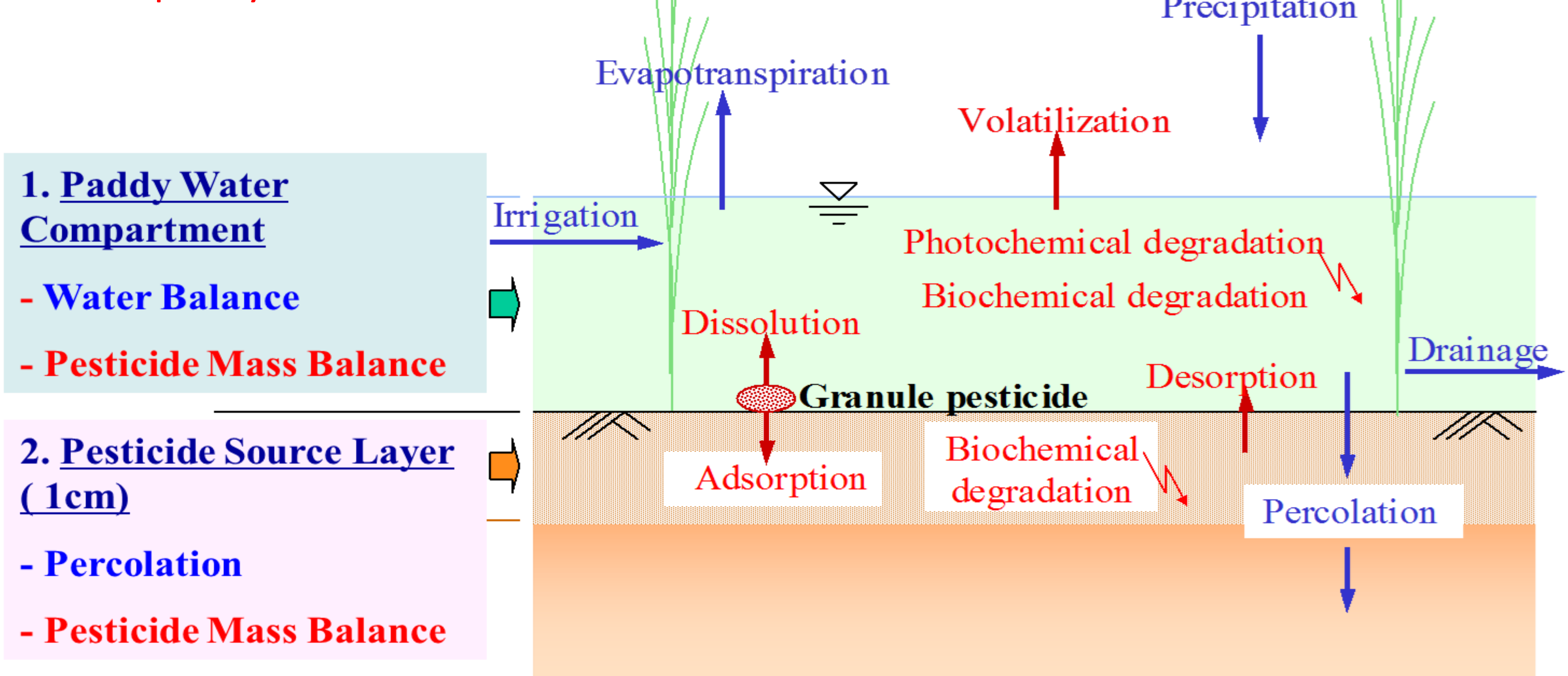
Pesticide application scheme

- Usually only application date is known
- No information about location (where the pesticide is actually applied)
- Fields or surfaces were pesticide was applied the same day are lumped together



2.1 PCPF-1 model

Deterministic model that simulates pesticide fate and transport in paddy field



Conceptual pesticide fate in a paddy field (Watanabe et al., 2006)

2.1. PCPF-1 model

Pesticide fate and transport processes considered in paddy water are:

- Pesticide dissolution, desorption, from surface soil layer, dilution through precipitation and irrigation, concentration by evapotranspiration, transport through percolation, seepage and drainage, and dissipation biochemical and photochemical degradations

$$
\frac{dC_{pw}}{dt} = \left|
\begin{aligned}
& k_{DISS}(C_{SLB} - C_{pw}) + \frac{1}{h_{pw}} \times \left[C_{pw} \frac{dh_{pw}}{dt} \right]_{DISS} \\
& + \frac{1}{h_{pw}} \times d_{PSL} \times \rho_{b-PSL} \times k_{DES} \times C_{S-PSL} \\
& + \frac{1}{h_{pw}} \times IRR \times C_{w-IRR} - \frac{1}{h_{pw}} \times (DRAIN + LSSEP + PERC) \times C_{pw} \\
& - \frac{1}{h_{pw}} \times k_{L-A} \times C_{pw} + (-k_{PHOTO} \times f_{US} \times R_{S-a} \times (1 - f_{F-abt}) - k_{BIOCHEM-PW}) \\
& \times C_{pw} - \frac{1}{h_{pw}} \times \frac{dh_{pw}}{dt} \times C_{pw}
\end{aligned}
\right. \qquad \text{Eqn. 1}
$$

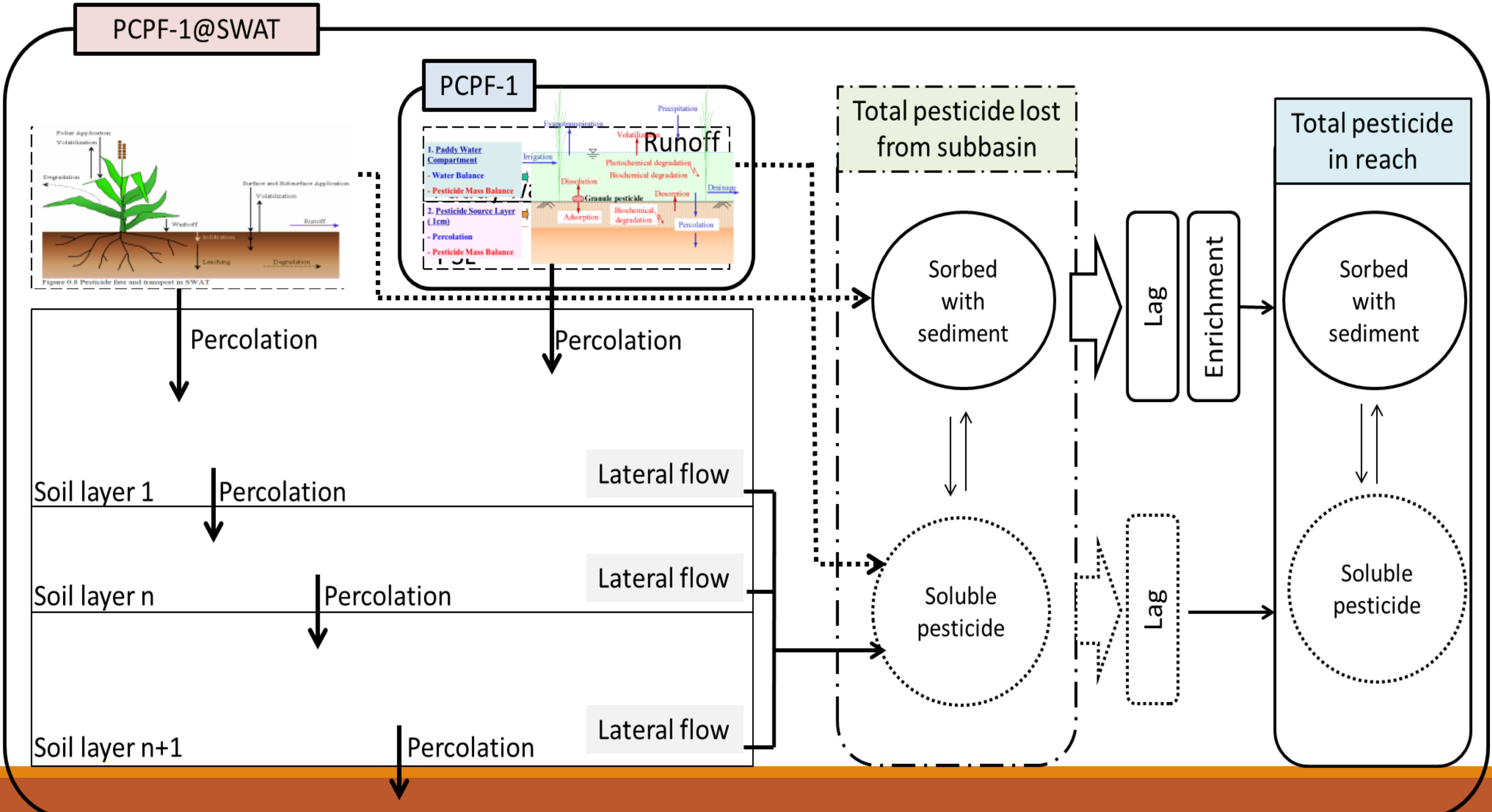
2.1. PCPF-1 model

In the 1 cm pesticide soil layer, the pesticide fate and transport considered are:

- Adsorption into soil, transport through percolation, and dissipation by biochemical degradation

$$\frac{dC_{S-PSL}}{dt} = \left| \begin{array}{l} k_{d-PSL} \times k_{DISS} \times (C_{SLB} - C_{pw}) + k_{d-PSL} \times \left[\frac{C_{pw}}{d_{PSL}} \frac{d(d_{PSL})}{dt} \right]_{DISS} \\ + \frac{k_{d-PSL}}{(\theta_{Sat-PSL} + \rho_{b-PSL} \times k_{d-PSL})} \times \frac{1}{d_{PSL}} \times PERC \times (C_{pw} - \frac{1}{k_{d-PSL}} C_{S-PSL}) \\ - \frac{k_{d-PSL}}{(\theta_{Sat-PSL} + \rho_{b-PSL} \times k_{d-PSL})} \times \rho_{b-PSL} \times k_{BIOCHEM-PSL} \times C_{S-PSL} \\ - \frac{k_{d-PSL}}{(\theta_{Sat-PSL} + \rho_{b-PSL} \times k_{d-PSL})} \times \rho_{b-PSL} \times k_{DES} \times C_{S-PSL} \\ - \frac{C_{S-PSL}}{d_{PSL}} \frac{d(d_{PSL})}{dt} \end{array} \right. \qquad \text{Eqn. 2}$$

2.2. PCPF-1 implementation into SWAT



3. Sakura River basin - **Watershed**

Sakura River watershed is located in southern Ibaraki Prefecture

Encompasses an area of 350.3 km^2

- Main stream: Sakura River (63.41 km long)

The river was periodically monitored

- The herbicide mefenacet has been detected at relatively high concentration compared with other pesticides

The first year of the simulation (2006) was used to warm up the model

2007 was used to calibrate the water flow

2008 was used to evaluate water flow and pesticide concentration predictions

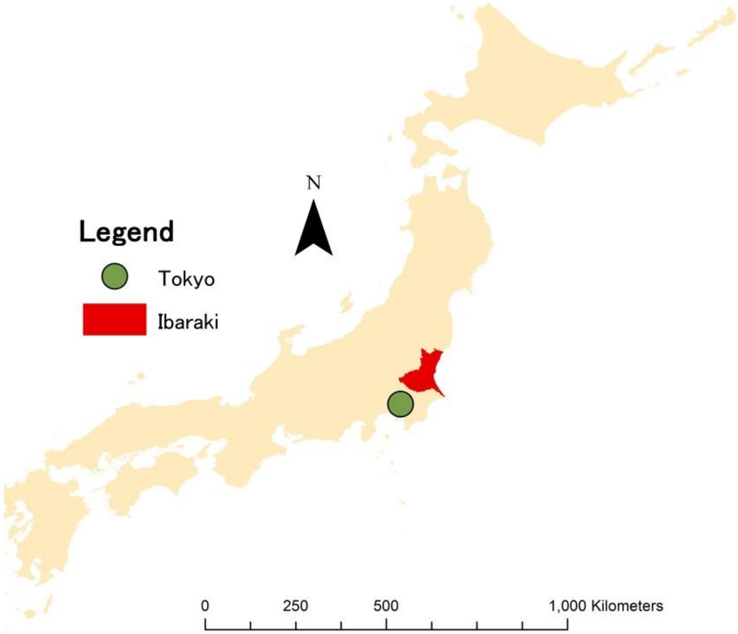
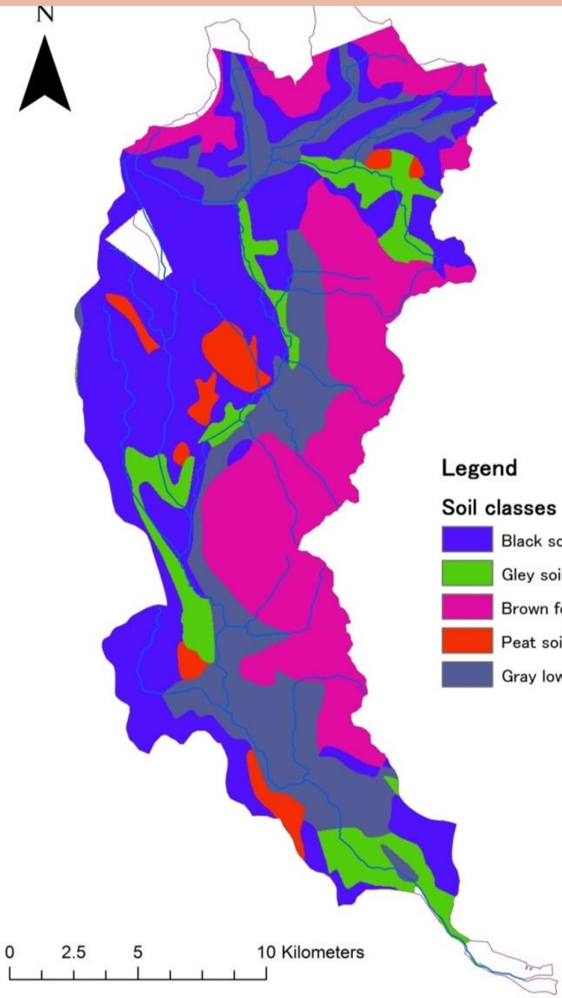


Fig.1: Location of Ibaraki prefecture

3. Sakura River basin - **Data**

Soil data (NIAES, 2007):



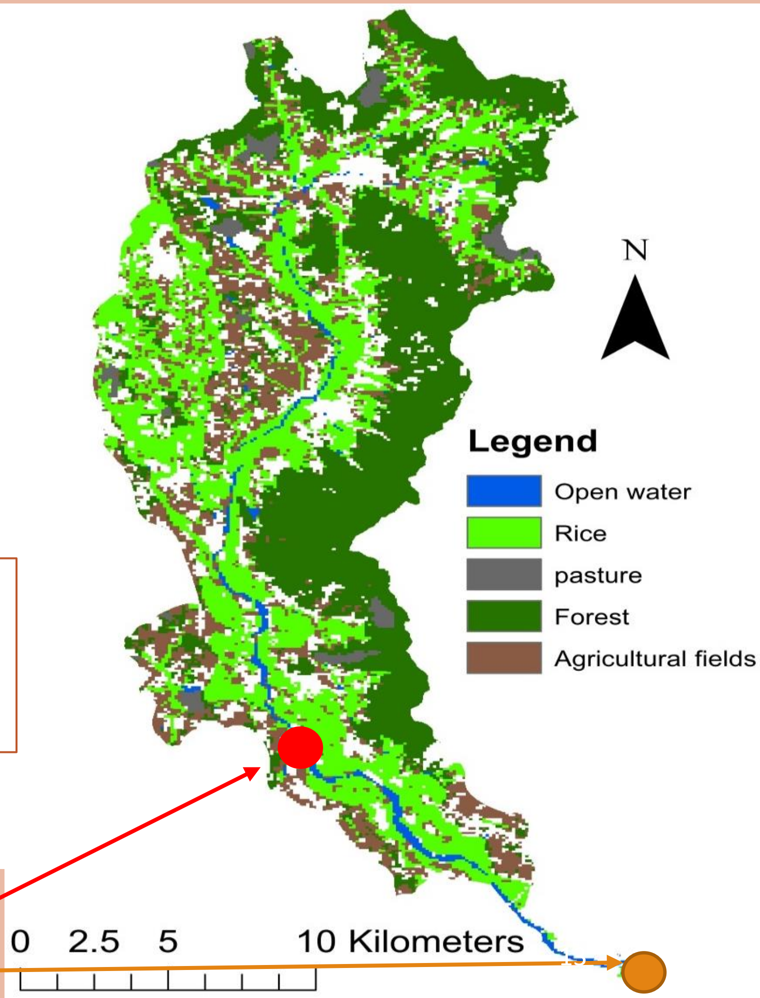
Lower and upper part of the watershed:

- Mainly Gray Lowland or Gley soils

Remaining mostly Andosols

Forest	**32.5%**
Paddy field	**27.8%**
Agricultural land	**17.0%**

Land use data (MLIT, 2008):



Pesticide concentration

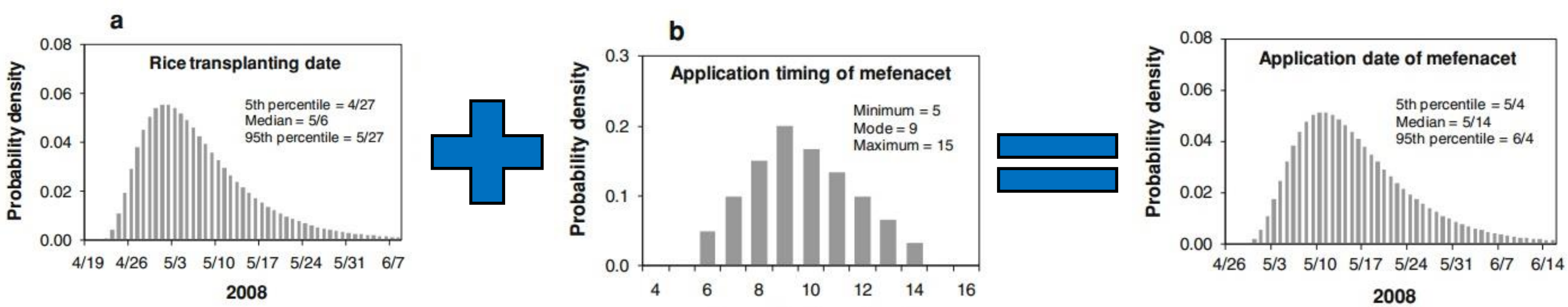
Water flow data

3. Sakura River basin – Pesticide data

Physicochemical properties of mefenacet assumed to be equal among sub-basins and reaches

The mefenacet usage in the watershed was estimated to be 8.1% of the rice-cropping area by Iwasaki et al. (2012)

Similarly, the mefenacet application dates were selected using the method reported by Iwasaki et al. (2012)



3. Sakura River basin - **Scenario**

The PCPF-1 is, as other pesticide fate and transport models, sensitive to paddy field water balance (Kondo et al., 2012)

- Crucial to develop a realistic rice scenario

Modeling scenario was generated to be representative for typical rice practices in Japan (Sakthivadivel, 1997)

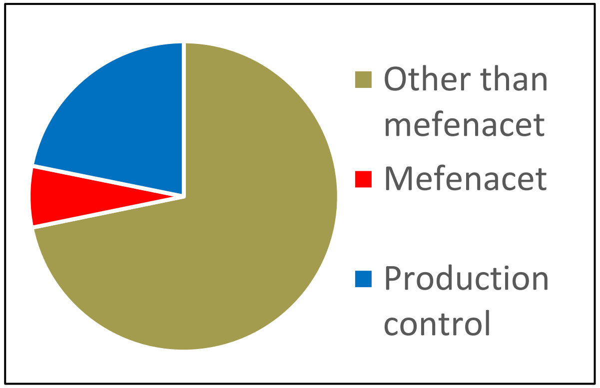
3. Sakura River basin - **Scenario**

Operation	Month	Day	Notes/Explanation
Plowing	04	15	Land leveling
Impound	04	20	Start water ponding in rice paddy fields
Fertilizer application	04	25	Application of basal fertilizer of N:P:K at 40:80:80 kg/ha
Puddling	04	26	Soften the soil for transplanting, mix fertilizer, flatten the soil surface for uniform soil condition, prevent weed and water leakage
Transplanting	05	01	Transplant the young rice plant into the field
Mefenacet application	05	01	First rice pesticide application
Mid-summer drainage	07	01	Promote subsurface draining through drying cracks to increase the bearing capacity of the soil
Harvest and kill	10	01	End of the rice growing season

3. Sakura River basin – **Water flow calibration**

In Japan, Ministry of Environment requires 7 days of WHP after pesticide application

- WHP was assigned to all paddy fields used for rice cultivation



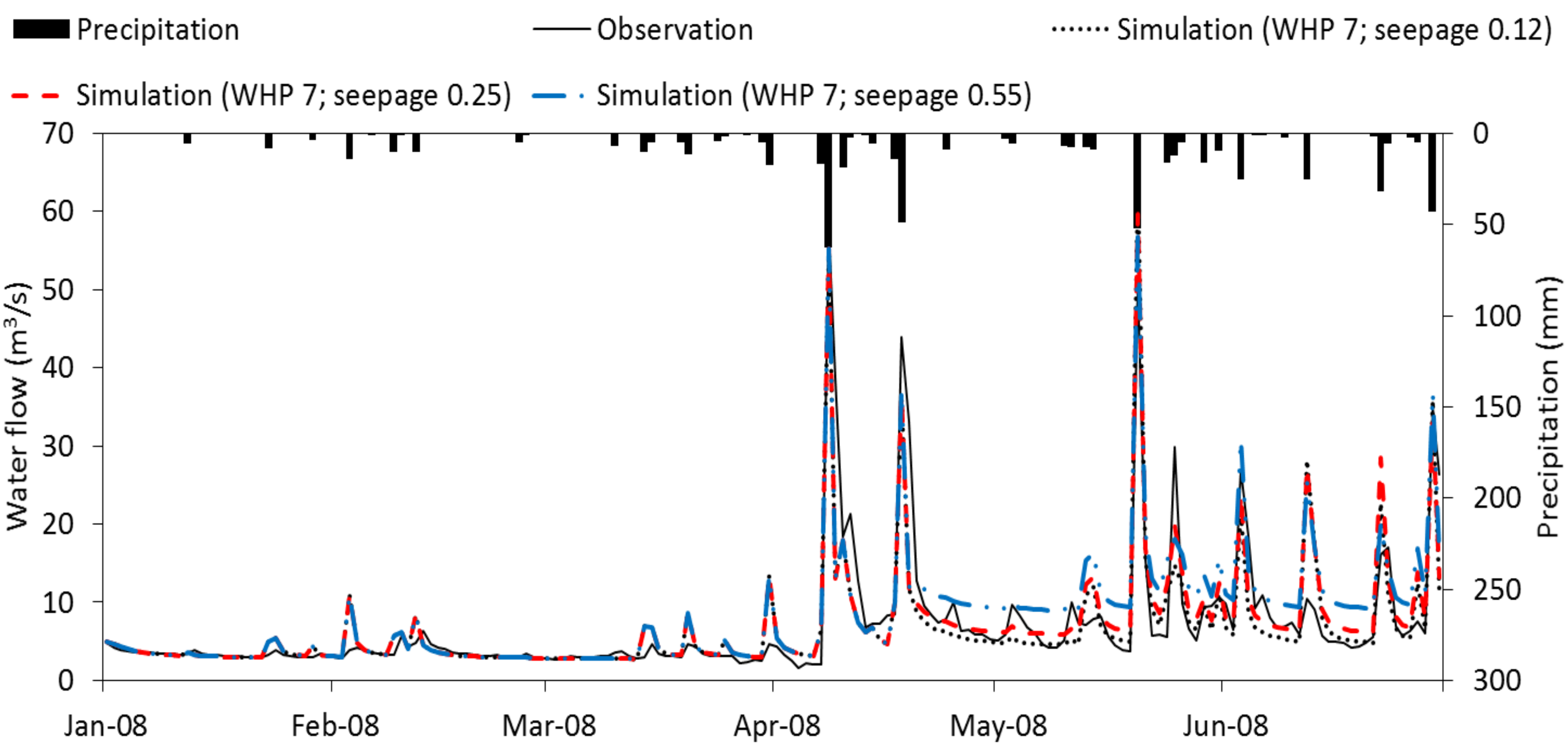
Typical discharge rate of paddy water into rivers ranges from 0.12 to 0.55 cm day^{-1} (Iwasaki et al., 2012)

- Three conditions of daily seepage (0.12, 0.25, and 0.55 cm day^{-1}) were used

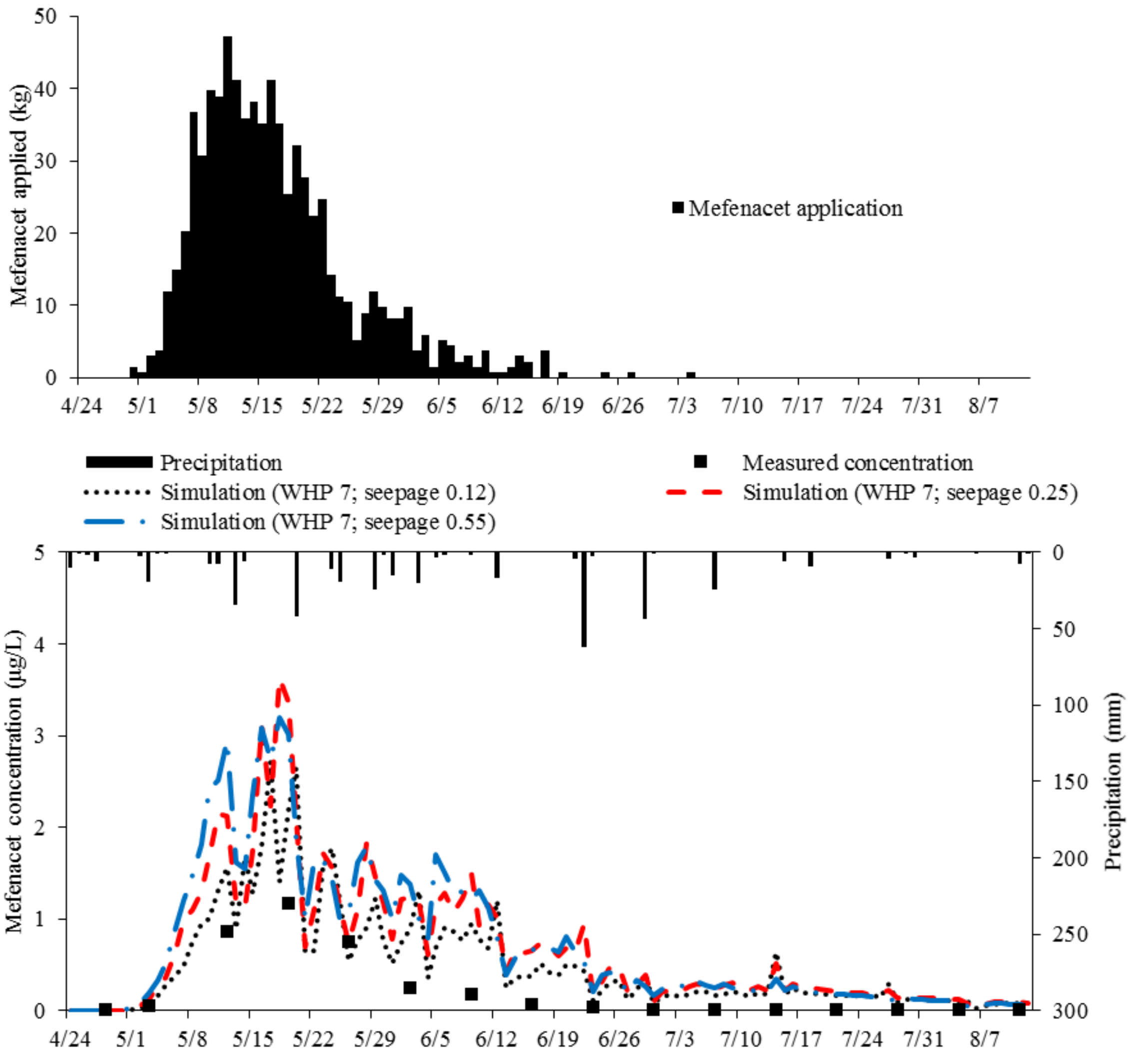
Percolation in paddy fields was set to be constant 1.0 cm day^{-1} for all paddy fields (Watanabe et al., 2007)

3. Sakura River basin – **Water flow validation**

High seepage rate resulted in a general overestimation of the water flow at the watershed outlet



3. Sakura River basin – Pesticide concentration in river



- Mefenacet concentration in paddy field similar to the range reported in literature
- Simulated mefenacet concentrations sensitive to major rainfall events
  - Significant paddy field runoff
- Concentration decline sharply
  - Water dilution by increased discharge from other crop and non-crop areas
- R^2 between 0.7 and 0.8
- RMSE between 1.1 and 2.1

3. Sakura River basin - Conclusion

Achieve accurate simulations of paddy field hydrology and mefenacet fate and transport in the Sakura River watershed (Ibaraki, Japan)

- Paddy fields conditions can be modified from flooded to dry
- Complicated and realistic scenario can be used to grow rice

Clear and accurate information regarding pesticide use in the watershed is required to have reliable simulations

4. Colusa Drain Basin - **Watershed**

US: 12th largest rice producer in the world

California is the 2nd largest rice-growing state in the U.S.

- Maintained the highest yield per hectare in the nation

About 90% of California rice is grown in the Sacramento Valley

In late 1970s and early 1980s, fish kills were reported in the Colusa Basin agricultural drains

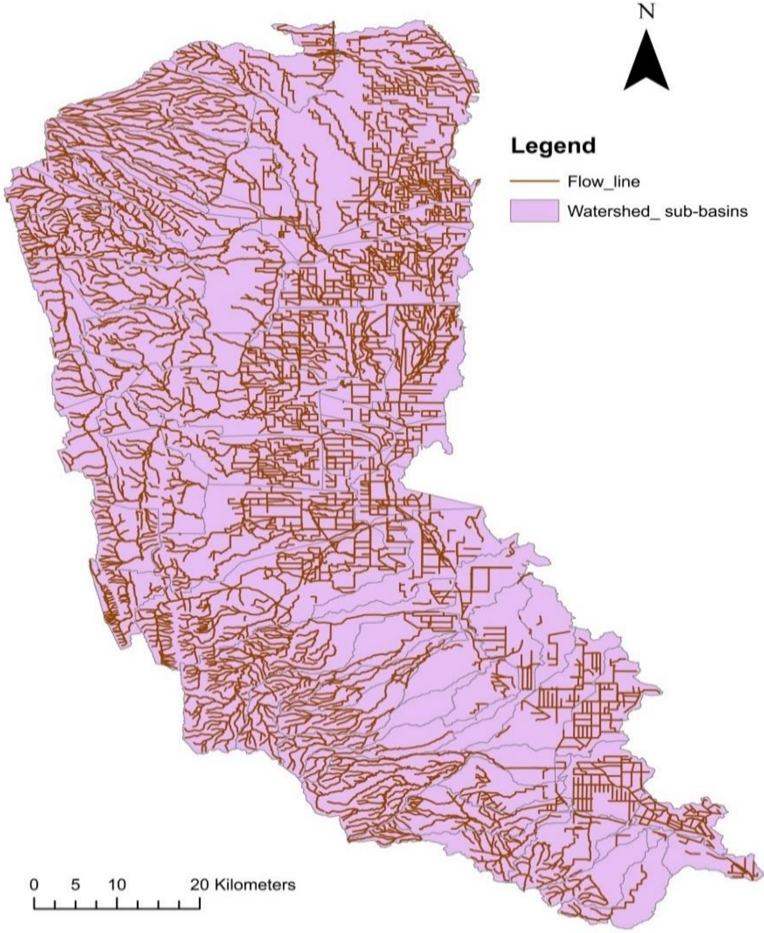
Focus on two compounds, <u>molinate</u> and <u>thiobencarb</u>

4. Colusa Drain Basin - **Data**

River network:

Irrigation system of the watershed is very complex

System had to be simplified



Topographical data:

Downloaded from the U.S. geological survey

Little topographic relief

4. Colusa Drain Basin - **Data**

River network:

Irrigation system of the watershed is very complex

System had to be simplified

Location 1

Colusa drain at Knights landing

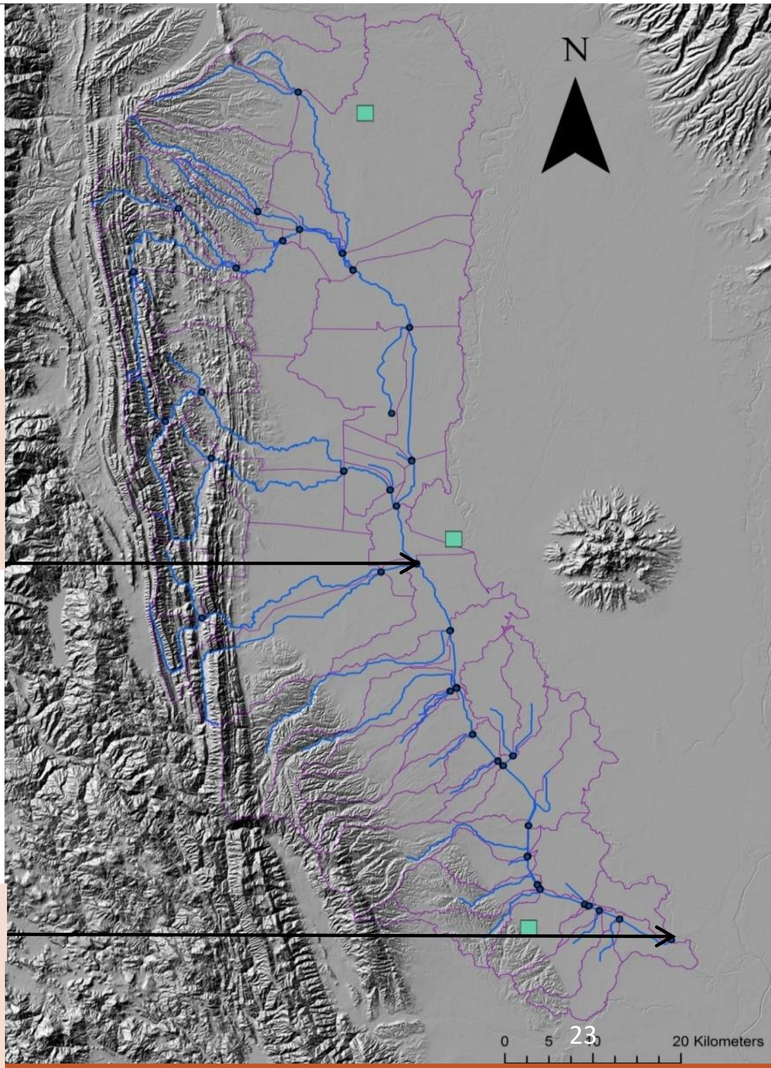
Topographical data:

Downloaded from the U.S. geological survey

Little topographic relief

Location 2

Colusa drain in Highway 20



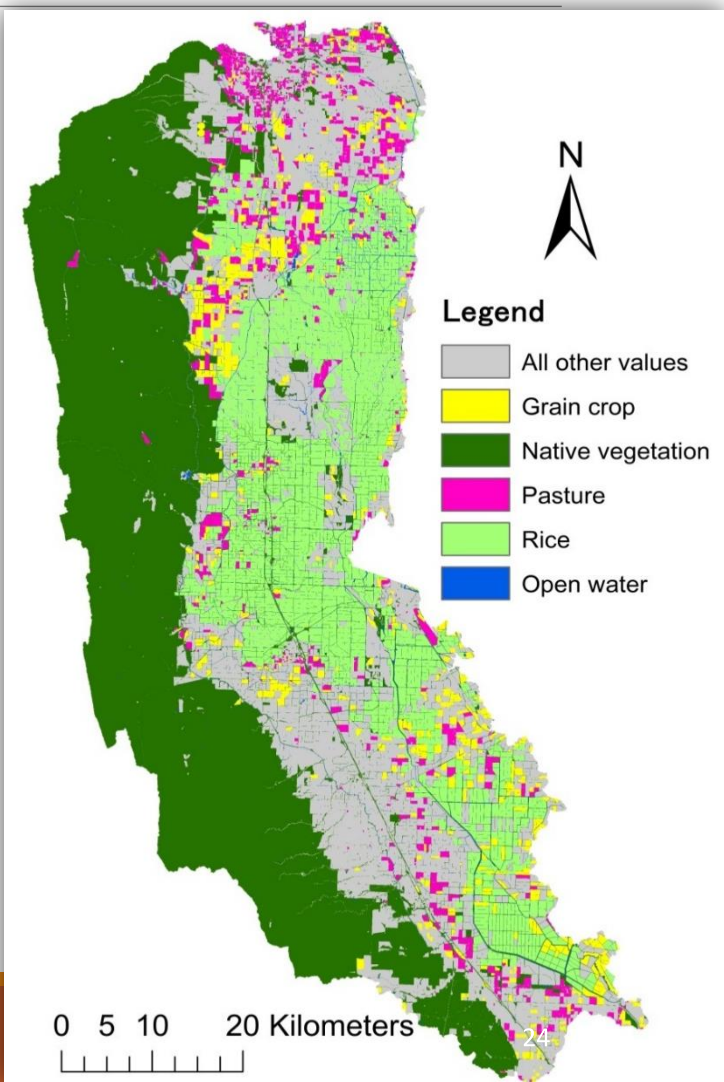
4. Colusa Drain Basin - **Data**

Land use data:

Vast majority of the watershed is rural

Main types of land use in the watershed were:

- Native vegetation (41%)
- Rice fields (20%)
- Pasture (5%)



4. Colusa Drain Basin - **Pesticide data**

Detailed information on pesticide use report (PUR)

- Total area covered by paddy fields in the counties was estimated to be:
- 597.32, 157.33, and 144.89 km^2 for Colusa, Glenn, and Yolo counties

Year	1992	1993	1994	1995	1996
Molinate	0	185101.6	205128.2	174103.3	141648.5
Thiobencarb	31140.0	30240.1	50855.5	79261.6	103480.3

Table 1. In Colusa county (amount in kg active ingredient)

Pesticide application timing was estimated from the pesticide use report of 2001

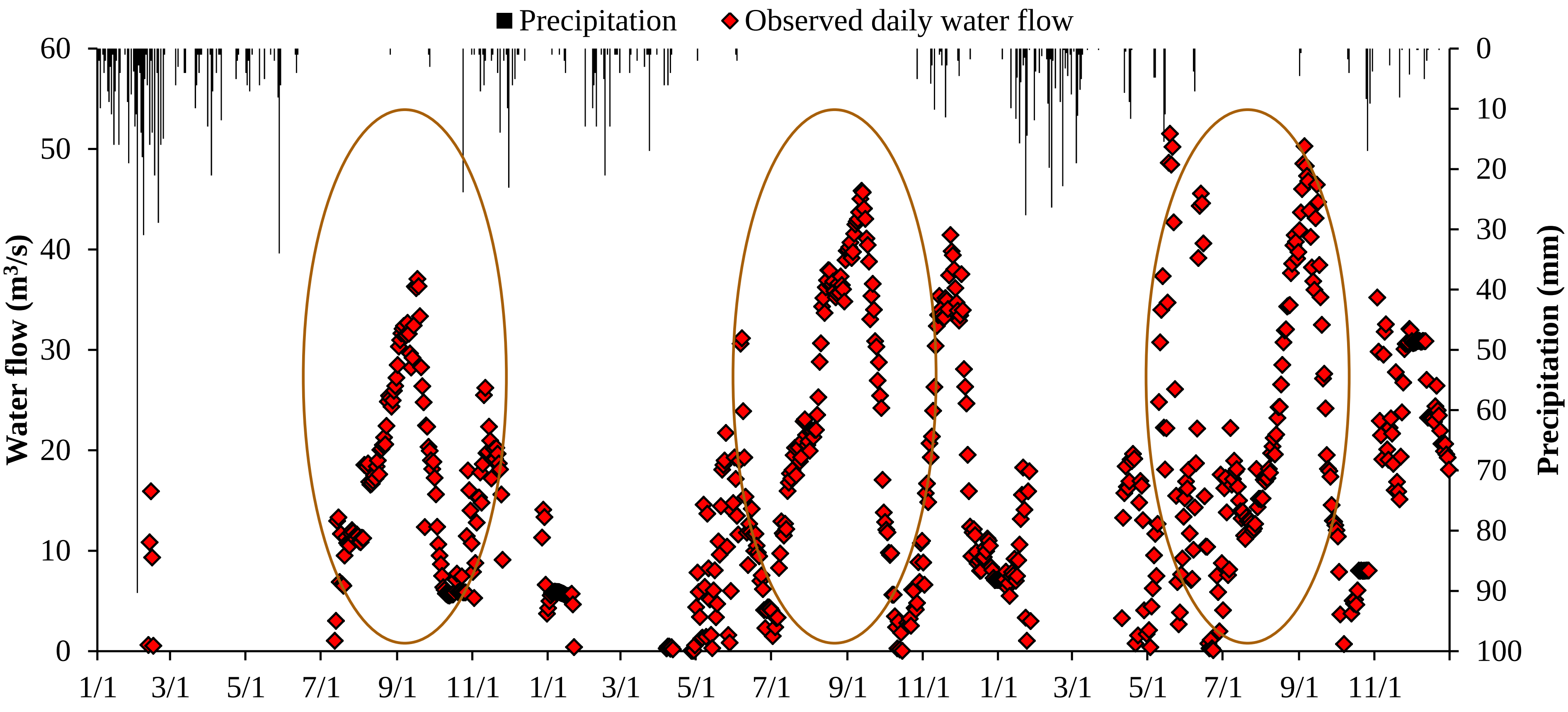
- Mainly during May
- Thiobencarb applications were more scattered in time
- Molinate application in April were minor

4. Colusa Drain Basin - **Scenario**

Timing	Operations	Explanations
Late April/early May	Apply fertilizer	Aqua-amonia is injected into the soil to a depth of 5-10 cm
Late April/early May	Apply fertilizer	P and K are typically added by broadcasting to the soil surface
Late April/early May	Ponding	Field are flooded (10 to 13 cm) and seeded by airplane
Until 40 days after the initial flood	Drainage	Field may be drained and re-flooded to promote seedling establishment and/or to allow herbicide application
Mid-June	Continuous irrigation	Keep the water level at a depth of 10-13 cm
40-55 days after seedling	Fertilizer application	Some growers apply additional N fertilizer by air
Mid-August	Drainage	Field are drained completely to allow for harvest

4. Colusa Drain Basin - Results

Flow not always related to daily precipitation

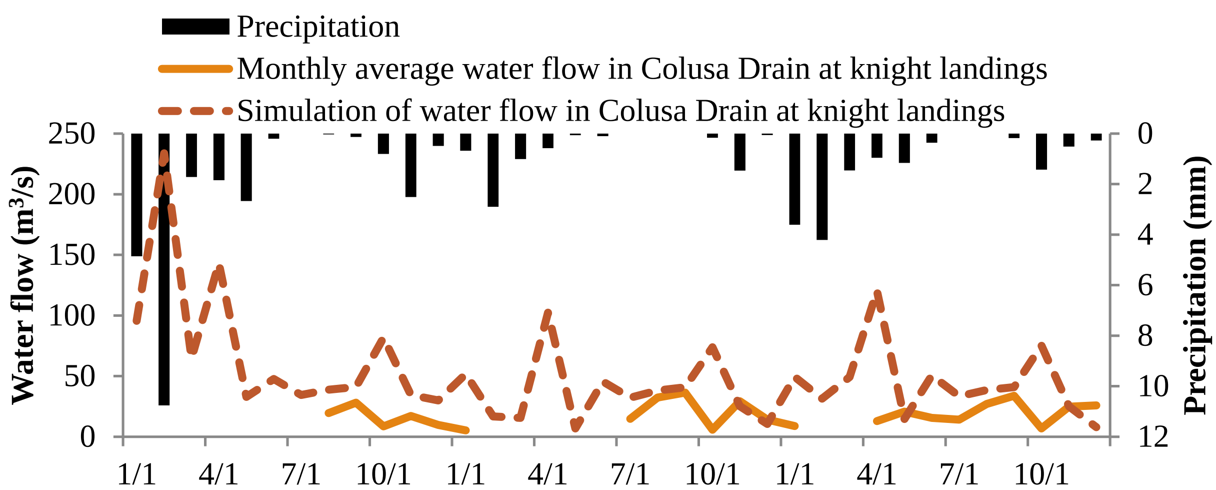


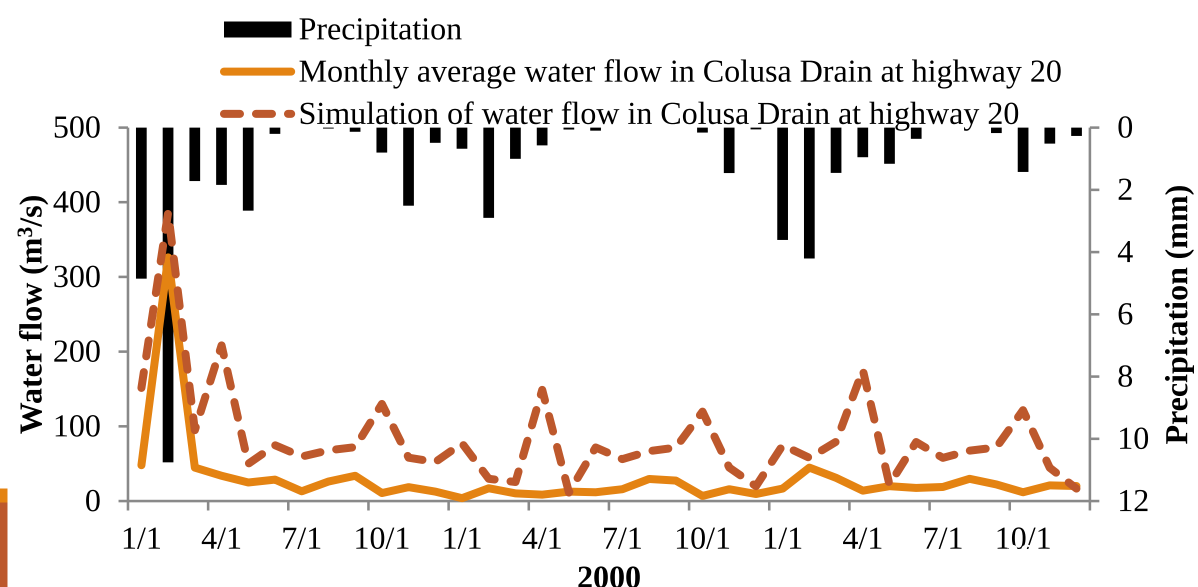
4. Colusa Drain Basin - Results

Calibration to reduce the amount of surface runoff was not sufficient

Simulated base flow was to high

Amount and timing of water transfer between subbasins need to be investigated



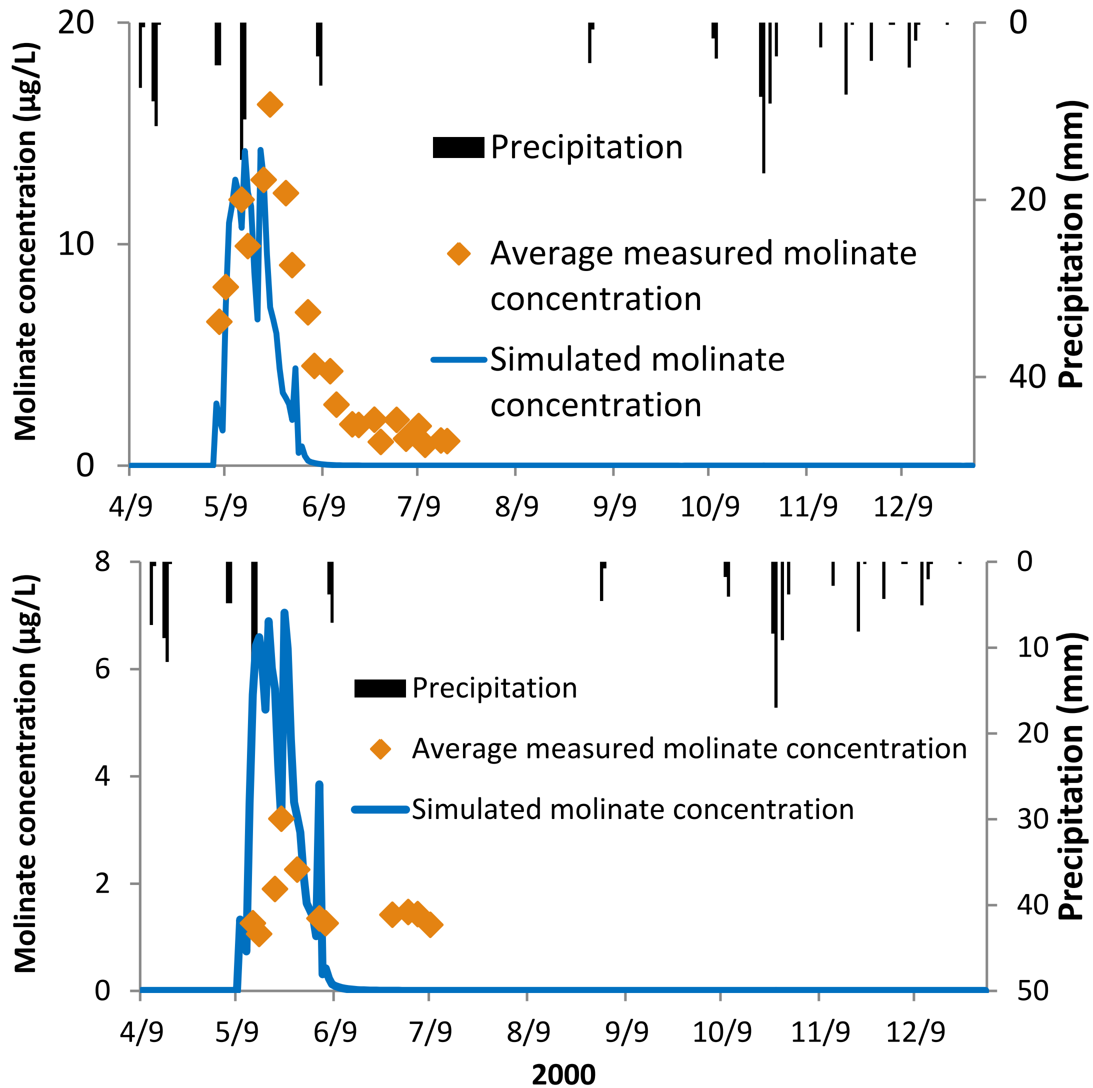


4. Colusa Drain Basin – pesticide concentration

Molinate and thiobencarb concentrations in paddy fields were similar to those reported in literature

Same order of magnitude as the measured molinate concentrations

Best simulation scored a 0.79 and 0.24 for R^2 and E_{NS}



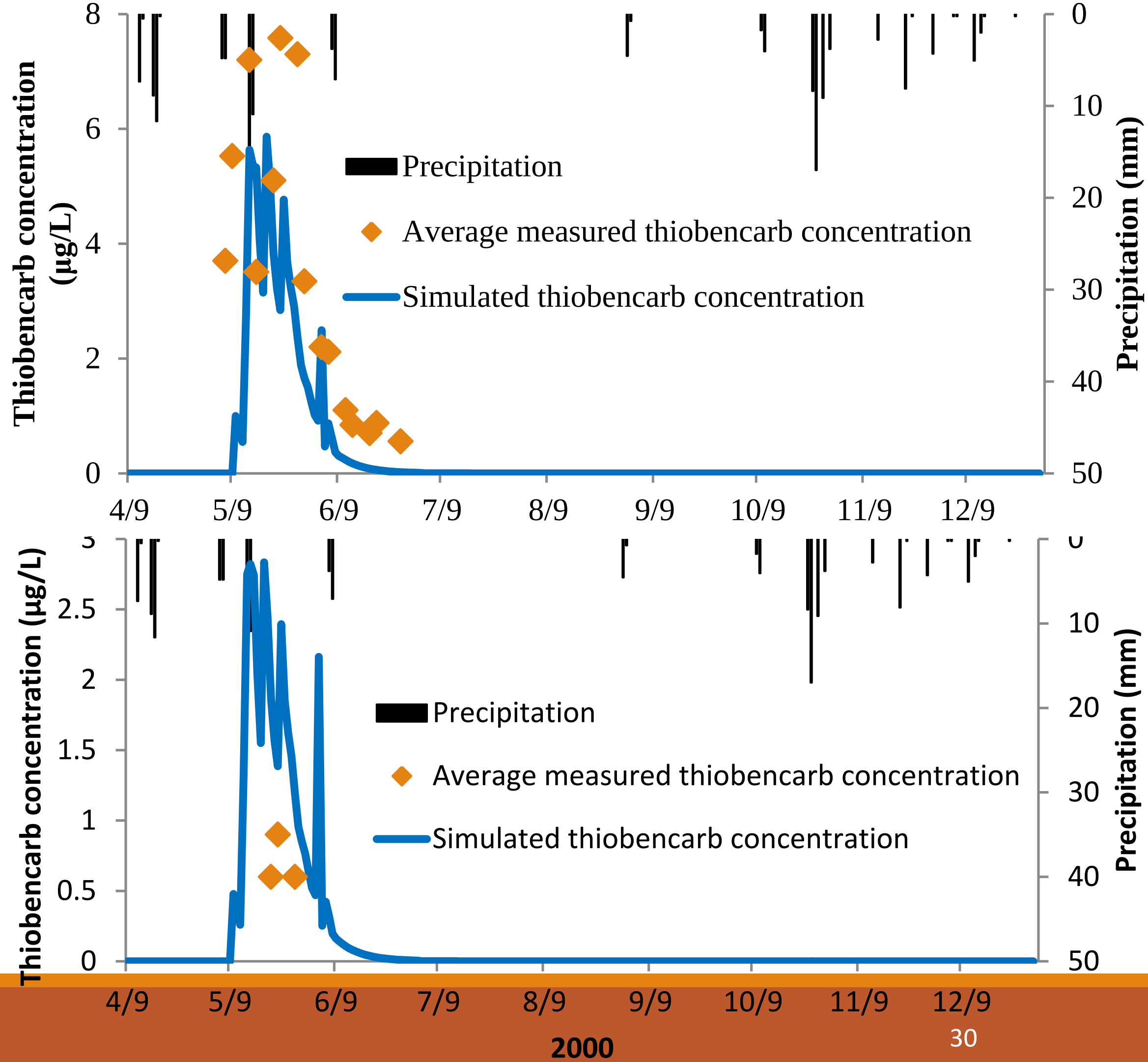
Molinate concentration in location 1 (above) and 2 (below) using a seepage of 0.1 cm/day

4. Colusa Drain Basin – pesticide concentration

Predicted thiobencarb simulations were in the same order of magnitude as observations

R^2 of 0.72

But E_{NS} were always negative



Thiobencarb concentration in location 1 (above) and 2 (below) using a seepage of 0.1 cm/day

4. Colusa Drain Basin – Conclusion

Watershed hydrology was poorly simulated

- Artificial river network
- Subbasin discretization
- Water exchange within and between the watershed

Successfully predicted the fate and transport of two liquid formulations in rice paddies

- Small daily paddy water discharge greatly improved the simulations
- Molinate was better approximated

General conclusion

In this research, a model than can simulate simultaneously pesticide fate and transport in paddy field and upland field was validated

Development of the model:

- By modifying the behavior of the SWAT model when simulating paddy fields hydrology
- By implementing the PCPF-1 model into SWAT

The PCPF-1@SWAT model behave greatly when the hydrology of watersheds were naturally driven

Accurate data regarding pesticide application amount and timing greatly improve predictions of pesticide concentrations in rivers

Rice Paddy Module Development in SWAT

Discussion about Rice Paddies in SWAT at the SWAT SEEA III conference (Indonesia)

From the audience discussion and comments:

- Rice was grown in lots of watersheds in Asia
  - Rice was often merge with other agricultural land use
  - Or treated as non-ponding
  - Use of the pothole function was minor

Agreed on developing rice paddy module

Discussion on rice cultivations practices across Asia

Technical issue of the current SWAT model regarding rice cultivation

Team management, fund…

Possible future meeting and collaboration

Rice Paddy Module Development in SWAT

- Few rice paddy applications in SWAT were already published
  - Applying SWAT for TMDL programs to a small watershed containing rice paddy fields, M.S. Kang, S. W. Park, J. J. Lee, K. H. Yoo (2006)
  - Development and test of SWAT for modeling hydrological processes in irrigation districts with paddy rice, Xianhong Xie, Yuanlai Cui (2011)
  - Integrated modeling of conjunctive water use in a canal-well irrigation district in the lower Yellow River Basin, China, Luguang Liu, Yuanlai Cui, Yufeng Luo (2013)

- Will be published soon
  - Development and validation of a basin scale model PCPF-1@SWAT for simulating fate and transport of rice pesticide, Julien Boulange, Hirozumi Watanabe, Keiya Inao, Takashi Iwafune, Minghua Zhang, Yuzhou Luo, and Jeff ArnoldMethodology for implementation of a rice module in SWAT
  - Examination of the water balance of irrigated paddy fields in SWAT 2009 using the curve number procedure and the pothole function, A. Sakaguchi, S. Eguchi, M. Kasuya (Transactions of the ASABE, Submitted)
  - Development and test of paddy module for SWAT to model hydrological processes, A. Sakaguchi, S. Eguchi, T. Kato, M. Kasuya (Agricultural Water Management, Revising)