BLACKLAND RESEARCH & EXTENSION CENTER

Modeling framework for rice paddy water management and climate impact assessment: Progresses in SWAT+ development

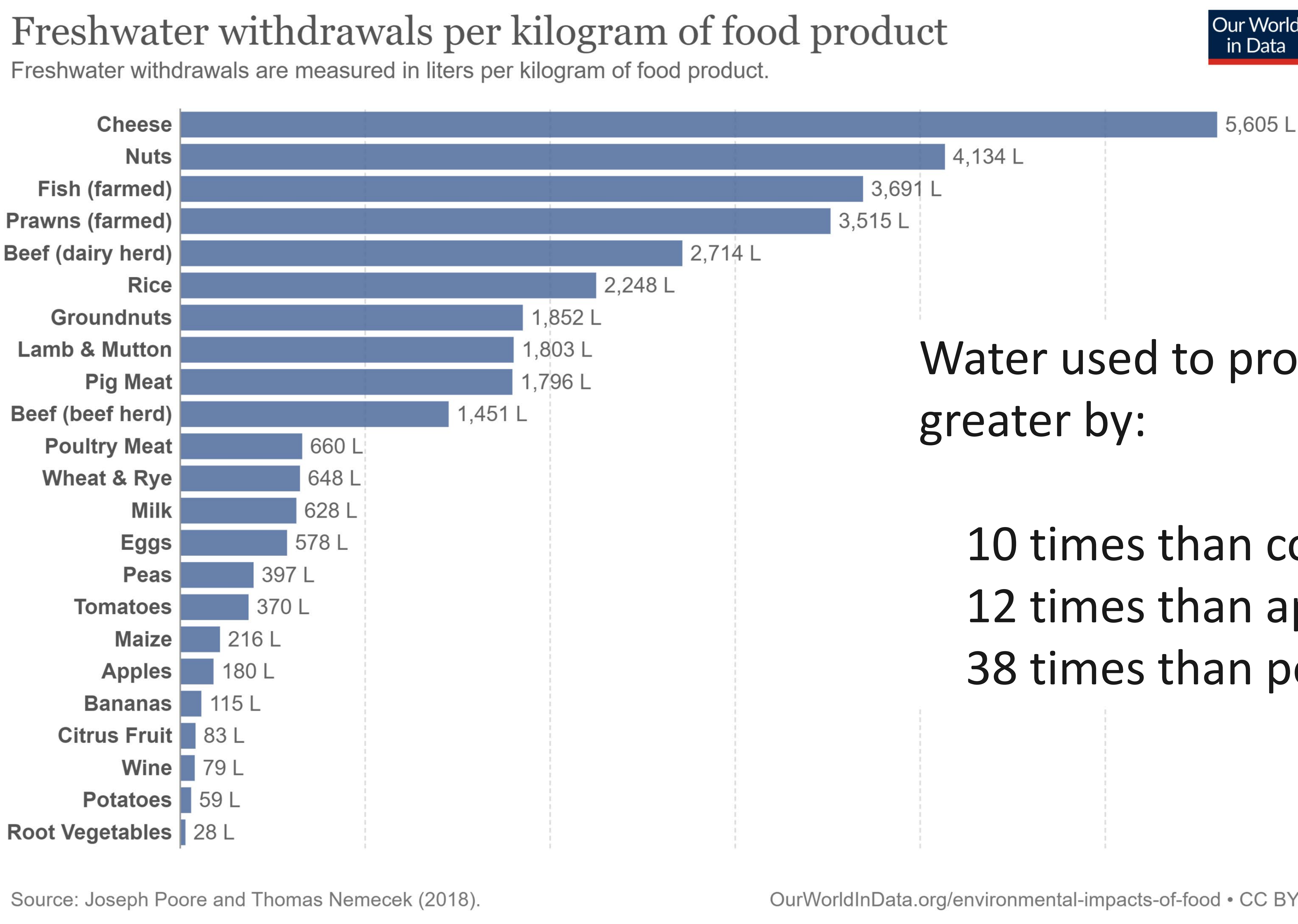
Jaehak Jeong, Jeff Arnold, Soonkun Choi, Seonggyu Park, Kenneth Miller, Ricardo Sorando, Ryan Bailey, Prasad Bandaru

Texas A&M AgriLife Research, Texas, USA; USDA-ARS, Texas, USA; Rural Development Administration, Jeonju, South Korea; Formation Environmental LLC, California, USA; Instituto Cavanilles de Biodiversidad y Biología Evolutiva. University of Valencia, Spain; Colorado State University, Colorado, USA; USDA-ARS, Arizona, USA

Project Goal

Enhance SWAT+ structure and add process modules for agricultural watershed assessment in South Korea and other countries where low-land flooded rice paddies are a significant land use type to evaluate the benefits of conservation practices and assess climate change impact on water use

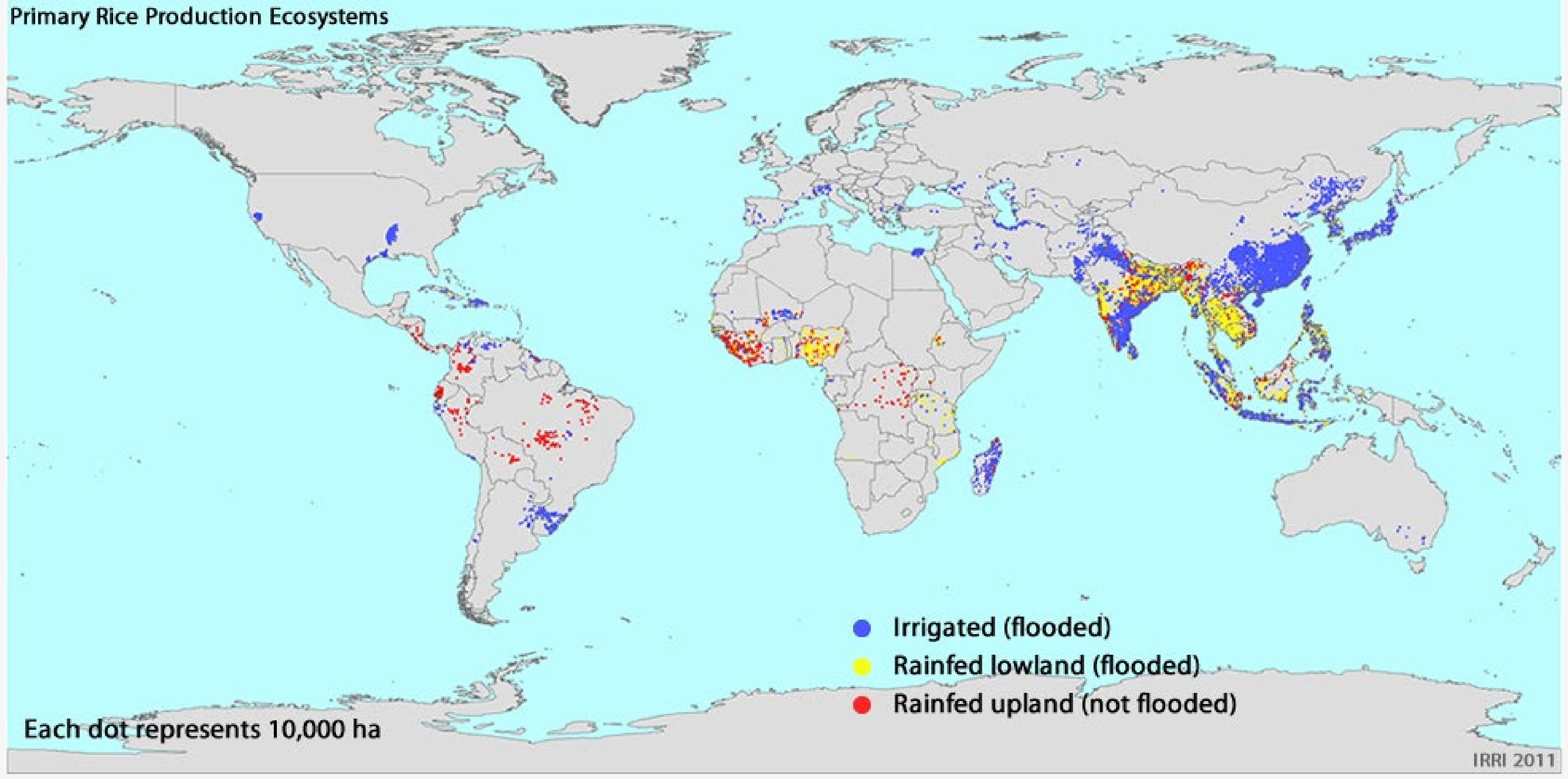
Water used for food production



Water used to produce 1kg rice is greater by:

10 times than corn,
12 times than apple,
38 times than potato

Characteristics of primary global rice production systems



Rice production characteristic	Production System			
	Irrigated lowland	Rainfed lowland	Rainfed upland	Flood prone
Global production area (million ha)	93	52	15	11
Global production area (%)	54.4	30.4	8.8	6.4
Total global production (%)	75	19	4	2
Primary water source	irrigation	rain	rain	rain/flooding
Field type	bunded	bunded	non-bunded	non-bunded
Extent of flooded conditions	continuous	partial	rarely	partial
Level of chemical inputs	**high**	**medium/low**	low	low
Potential total annual rice crops	2-3	1-2	1	1
Average yields (t ha^{-1})	5.3	2.3	1.0	1.5

Global Rice Production from flooded Paddies

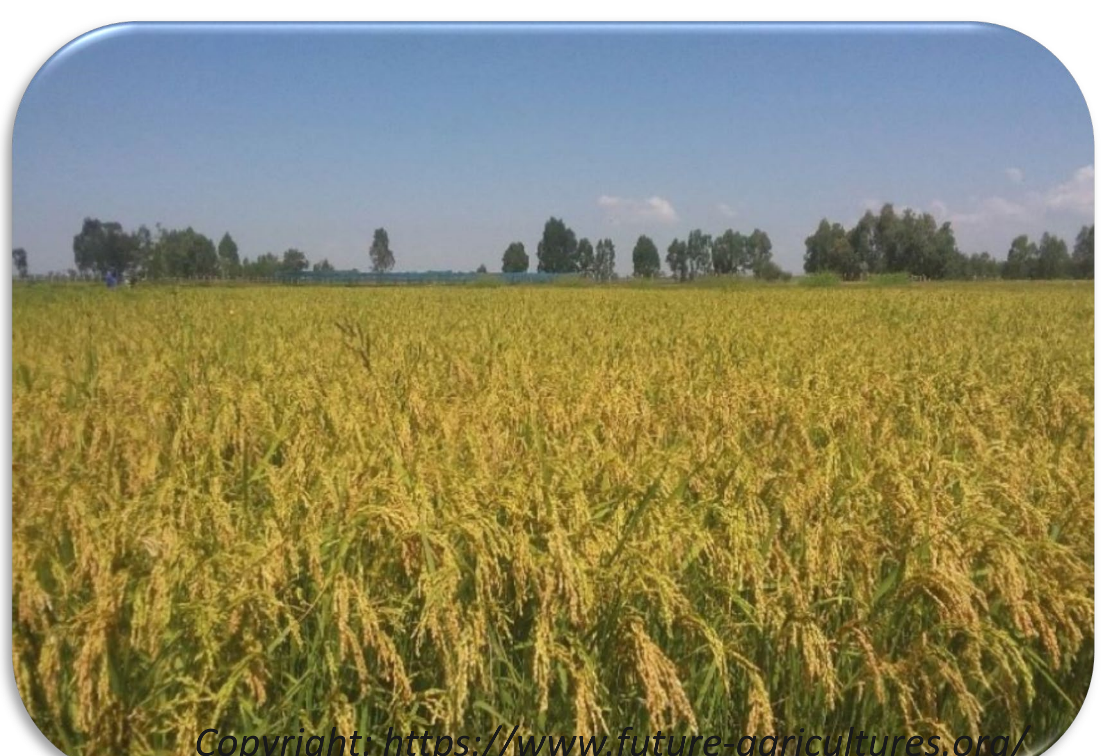
145million ha (85%)

Source: IRRI (2013)

TEXAS A&M AGRILIFE

Examples of rice production systems in the world

Vietnam



Ethiopia

Texas, USA

China

South Korea

Lowland Rice Paddy System

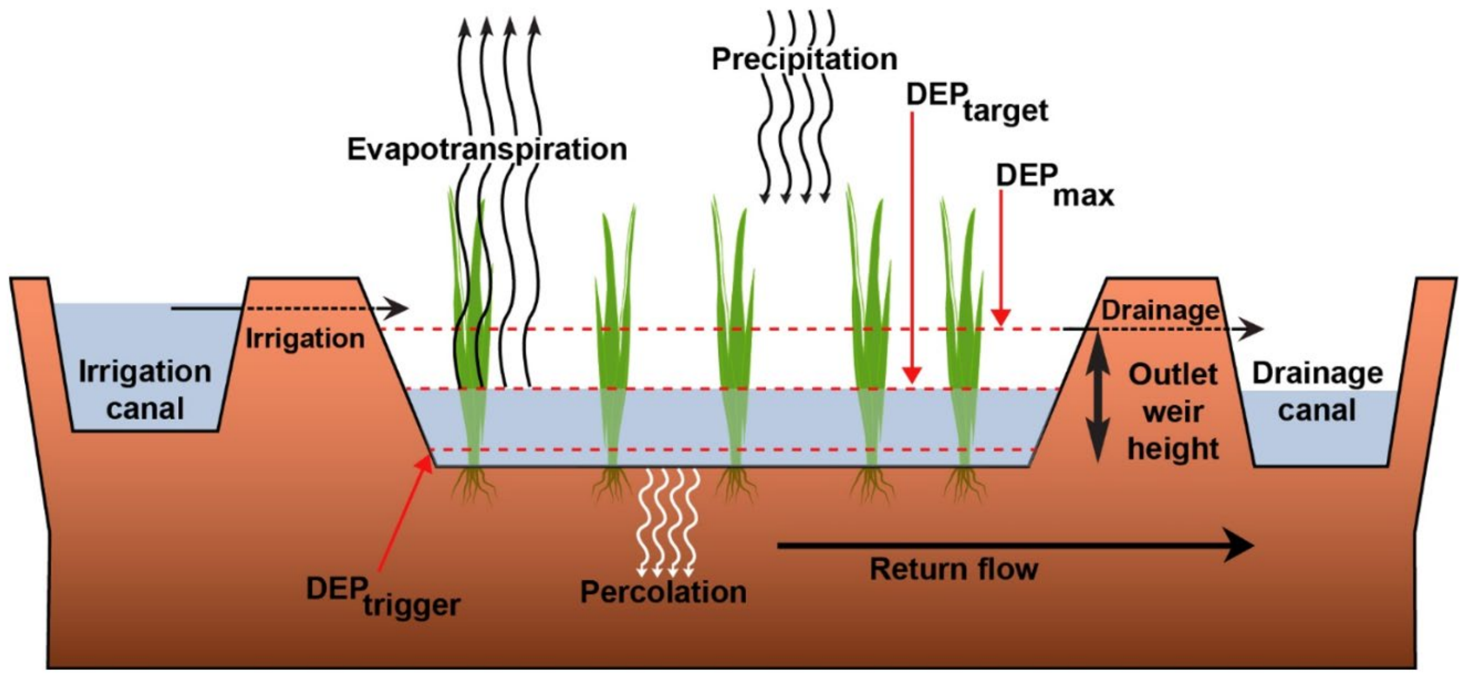
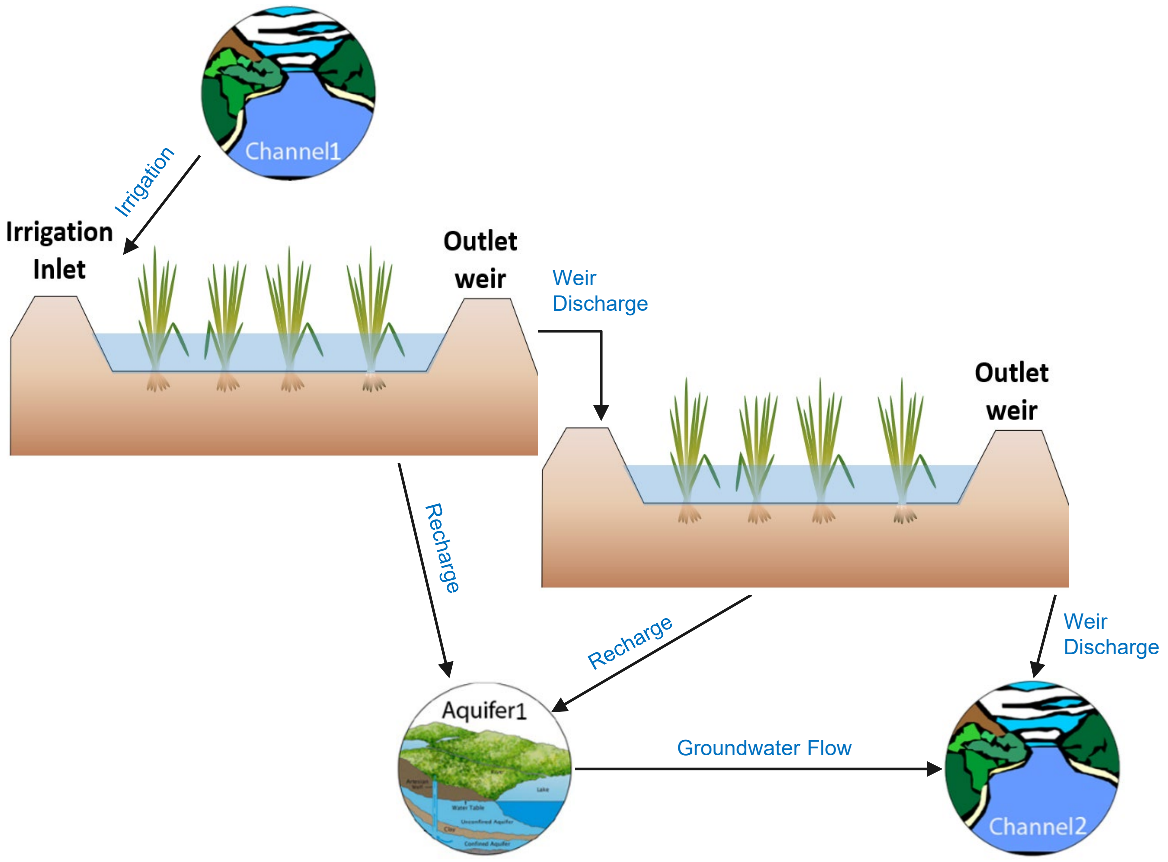
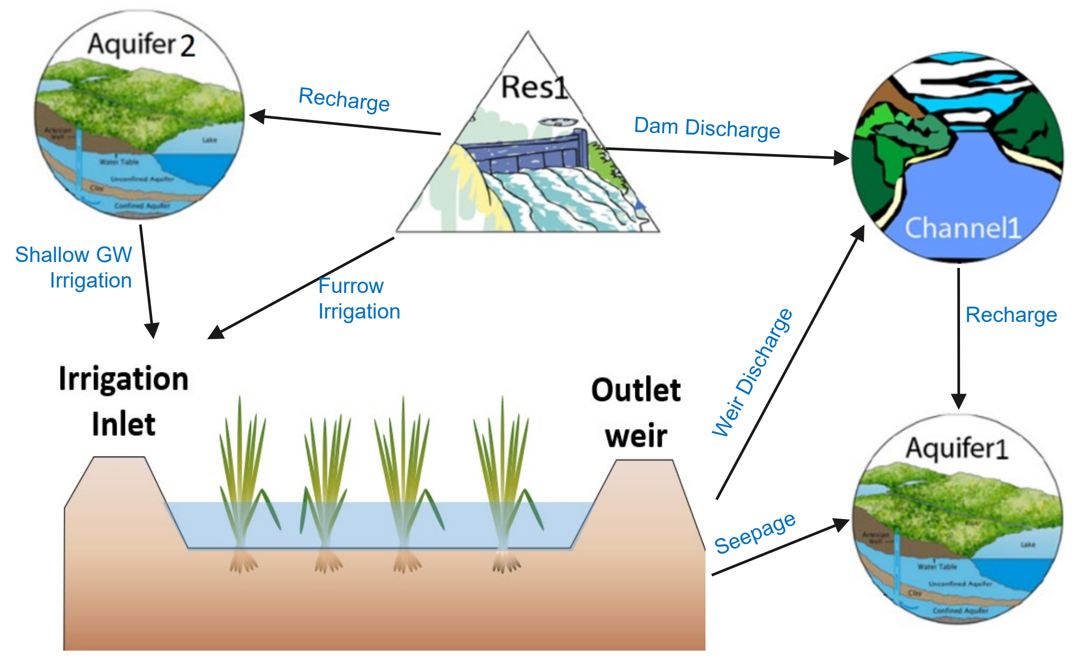


Figure from Gassman et al. (2021)



$$DEP_i = DEP_{i-1} + PCP_i + IRR_i + Q_i + ET_i + VPERC_i + HPERC_i$$

DEP: ponding depth
PCP: precipitation
IRR: irrigation
Q: weir discharge
ET: evapotranspiration
VPERC: vertical percolation
HPERC: horizontal percolation



Needs for research and development

Paddy Hydrology, Water Quality, Rice Production

Representation of unique characteristics of paddy systems differing from other croplands

Management Practices Evaluation

To improve water use efficiency and water quality management

Watershed Impacts

Assess plot-scale to watershed-scale impacts of rice paddy systems

Simulation Model needed for systematic assessment

No process-based model offers to simulate the dynamics of paddy hydrology, water quality, crop growth, and ag management

Application of APEX/SWAT Models

Expand well-established global applications of APEX/SWAT to rice paddy assessment

Science-driven Policy Development

Holistic and systematic modeling approach to provide regionally specific solutions for agricultural policy development

Recommendation by Gassman et al. (2022)

- The paper by 15 coauthors from seven countries entitled "*Simulation of rice paddy systems in SWAT: A review of previous applications and proposed SWAT+ rice paddy module*"

- Recommendations on SWAT+ paddy simulation
  - Inherit and expand APEX-Paddy
  - Hydrologic connectivity through object-oriented structure
  - Crop growth submodel for rice and ET calculation where ET>PET
  - Irrigation source and transfer options
    - Plot-to-plot irrigation-drainage systems
    - Polder paddy systems
    - Irrigation and drainage between paddy plots and spatial objects
    - Water allocation table for defining an irrigation district
  - Vertical/horizontal paddy percolation rates
  - Pollutant cycling and transport processes
  - Pesticide fate and transport

Tasks

- Enhance SWAT+ code for simulating rice paddies
- Add new objects and operations
  - HRUs submerged with paddy irrigation
  - Continuous irrigation with target/threshold depth
  - Transplanting
  - Puddling
  - Fertilizer application and nutrient transport processes
  - Evapotranspiration scheme for wetting and drying periods
  - Weir outlet control vs principal/emergency spillway
- HRU management scheduling
  - Build paddy-related “Conditions” and “Actions” in decision tables for automatic scheduling
  - Paddy operations in manual scheduling
  - Water allocation structure for paddy irrigation based on demand and supply
- New process modules
  - Water balance
  - Fertilizer mass balance
  - Pesticide fate and discharge
  - Salinity mass balance and groundwater recharge
- Update SWAT+ Input/Output structure for paddy simulation

Paddy Management Scheduling

Management.sch

management.sch: Management schedules									
MGT_NAME	NUMB_OPS	NUMB_AUTO	OP_TYPE	MON	DAY	HU_SCH	OP1	OP2	OP3
paddy	15	0							
			till	3	25	0.000	fallplow	null	0
			weir	4	1	0.000	weir1	null	50
			irrp	4	2	0.000	ponding50	sdc	0
			pudl	4	7	0.000	puddle	med_eff	0
			plnt	5	1	0.000	rice120	tr_rice120	0
			fert	6	27	0.000	elem_p	broadcast	40
			fert	6	27	0.000	urea	broadcast	90
			weir	7	3	0.000	weir1	null	200
			irrp	7	3	0.000	ponding200	sdc	0
			irrp	9	11	0.000	ponding_off	null	0
			weir	9	12	0.000	weir1	null	0
			harv	9	18	0.000	rice120	grain	0
			harv	9	18	0.000	rice120	hay_cut_low	0
			kill	9	18	0.000	rice120	null	0
			till	12	15	0.000	chisplow	null	0
paddy1	26	0							
			irrp	1	31	0.000	ponding_off	res	1
			weir	1	31	0.000	weir1	null	0
			till	3	25	0.000	fallplow	null	0
			weir	4	1	0.000	weir1	null	50
			irrp	4	2	0.000	ponding50	res	1
			pudl	4	7	0.000	puddle	med_eff	0
			fert	4	22	0.000	urea	broadcast	100
			fert	4	22	0.000	28_10_10	broadcast	200
			weir	4	25	0.000	weir1	null	50
			irrp	4	25	0.000	ponding50	res	1
			plnt	5	1	0.000	rice120	tr_rice120	0
			fert	6	27	0.000	elem_p	broadcast	40
			fert	6	27	0.000	urea	broadcast	90
			irrp	9	11	0.000	ponding_off	null	1
			weir	9	12	0.000	weir1	null	0
			harv	9	18	0.000	rice120	grain	0
			harv	9	18	0.000	rice120	hay_cut_low	0
			kill	9	18	0.000	rice120	null	0
			weir	11	1	0.000	weir1	null	600
			irrp	11	2	0.000	ponding600	res	1
paddy2	26	0							
			irrp	1	31	0.000	ponding_off	aqu	0
			weir	1	31	0.000	weir1	null	0
			till	3	25	0.000	fallplow	null	0
			weir	4	1	0.000	weir1	null	50
			irrp	4	2	0.000	ponding50	aqu	0
			pudl	4	7	0.000	puddle	med_eff	0
			irrp	4	20	0.000	ponding_off	null	0
			weir	4	20	0.000	weir1	null	0

management.sch: Management schedules			
MGT_NAME	NUMB_OPS	NUMB_AUTO	OP_TYF
paddy	0	6	
			plow
			weir_adj
			paddy_irr
			puddle
			pl_hv_rice
			fert_paddy
corn	0	3	
			plow
			pl_hv_rice
			fert1

landuse.lum: written by SWAT+ editor v2.2.0 on 2023-03-04 15:16 for SWAT+ rev.60.5.4				
name	cal_group	plnt_com	mgt	cn2
orcd_lum	null	orcd_comm	null	woodgr_g
frse_lum	null	frse_comm	null	wood_f
past_lum	null	past_comm	null	pastg_f
oran_lum	null	oran_comm	null	woodgr_g
rice_paddy_lum	null	rice120_comm	paddy	legr_strow_p
rice_paddy1_lum	null	rice120_comm	paddy1	legr_strow_p
rice_paddy2_lum	null	rice120_comm	paddy2	legr_strow_p

Land management setting

Hru-data.hru

HRU_NUMB	name	topo	hydro	soil	lu_mgt	soil_plant_init	Surf_stor
1	hru0001	topohru0001	hyd0001	aqxe	utrn_lum	soilplant1	null
2	hru0002	topohru0002	hyd0002	aqxe	orcd_lum	soilplant1	null
3	hru0003	topohru0003	hyd0003	aqxe	rice_paddy_lum	soilplant1	paddy001
4	hru0004	topohru0004	hyd0004	aqxe	urbn_lum	soilplant1	null
5	hru0005	topohru0005	hyd0005	aqxe	bsvg_lum	soilplant1	null
6	hru0006	topohru0006	hyd0006	aqxe	orcd_lum	soilplant1	null
7	hru0007	topohru0007	hyd0007	aqxe	rnge_lum	soilplant1	null
8	hru0008	topohru0008	hyd0008	aqxe	oran_lum	soilplant1	null
9	hru0009	topohru0009	hyd0009	aqxe	urbn_lum	soilplant1	null

Paddy/wetland setting

Wetland.wet

wetland.wet: written by SWAT+ editor v2.2.0 on 2023-03-10 10:36 for SWAT+ rev.60.5.4								
NUMB	NAME	INIT	HYD	REL	SED	NUT	PST	WEIR
3	paddy001	high_init	paddy	weir	sedwet1	nutwet1	null	weir1
12	paddy002	high_init	paddy	weir	sedwet1	nutwet1	null	weir1
19	paddy003	high_init	paddy	weir	sedwet1	nutwet1	null	weir1

*New columns

weir.res: Reservoir weir inputs - asdf;lj				
NAME	Linear_C	Exp_K	Width(m)	Depth(m)
weir1	1.83	1.50	5.00	0.0
weir2	1.83	1.50	15.00	1.0

Automatic Operations using Decision Tables

```
management.sch: Management schedules
    MGT_NAME    NUMB_OPS    NUMB_AUTO OP_TYP
     paddy           0           6
              plow
              weir_adj
              paddy_irr
              puddle
              pl_hv_rice
              fert_paddy
     corn            0           3
              plow
              pl_hv_rice
              fert1
```

```
lum.dtl
 16

 NAME        CONDS  ALTS    ACTS
plow           2      2       2
 VAR         OBJ OB_NUM  LIM_VAR    LIM_OP     LIM_CONST     ALT1    ALT2
phu_base0    hru    0      null        -       0.05000        >       -
days_harv    hru    0      null        -      30.00000        -       =
 ACT_TYP     OBJ OBJ_NUM   NAME       OPTION      CONST         CONST2      FP      OUTCOMES
till         hru    0  fieldcultivat  fldcult    0.00000       1.00000     null      y   n
till         hru    0   chisel_plow  chisplow    0.00000       1.00000     null      n   y

 NAME        CONDS        ALTS        ACTS
 weir_adj      2            2           2
 VAR           OBJ    OB_NUM  LIM_VAR  LIM_OP   LIM_CONST        ALT1    ALT2
 month         null     0       evol      -         4             >       >
 month         null     0       evol      -         9             <       >
 ACT_TYP       OBJ     OB_NUM    NAME              OPTION          CONST         CONST2  FILE_POINTER  OUT1   OUT2
 weir_height     hru     0        paddy               wet          100.            1          weir1      y      n
 weir_height     hru     0        paddy               wet          0.0             1          weir1      n      y

 NAME        CONDS  ALTS    ACTS
 paddy_irr     4     2       2
 VAR         OBJ  OB_NUM  LIM_VAR    LIM_OP     LIM_CONST     ALT1   ALT2
 weirh       hru    0       -          -          0            >      -
 wet_depth   hru    0     hwater       -          60.          <      -
 month       null   0      null      -            5            >=     -
 month       null   0      null      -            9            -      >=
 ACT_TYP     OBJ  OB_NUM   NAME                OPTION         CONST          CONST2      FP        OUTCOMES
 irrigate    hru    0      surface             ponding        90.             60.        null       y    n
 irrigate    hru    0      surface             ponding         0.              0.        null       n    y

 NAME        CONDS  ALTS    ACTS
 puddle        3     1       1
 VAR         OBJ OB_NUM  LIM_VAR    LIM_OP     LIM_CONST     ALT1
 month       null   0      evol        -          4            >
 weirh       hru    0       -          -          0.           >
 wet_depth   hru    0     hwater       -          0.           >
 ACT_TYP     OBJ OBJ_NUM   NAME                OPTION         CONST          CONST2      FP        OUTCOMES
 puddle      hru   0       puddle              med_eff         100            1          null       y

 NAME        CONDS  ALTS    ACTS
 pl_hv_rice    3      2       2
 VAR         OBJ OB_NUM  LIM_VAR    LIM_OP  LIM_CONST          ALT1    ALT2
 weirh       hru   0       -           -    0.                  >       -
 phu_base0   hru   0      null         -    0.15                >       -
 phu_plant   hru   0      phu_mat      -    1.15                                -       >
 ACT_TYP     OBJ OBJ_NUM   NAME                 OPTION        CONST          CONST2      FP          OUTCOMES
 plant       hru   0      rice120              rice120         0               1        rice120      y      n
 harvest_kill hru  0      grain_harv           all             0               1        grain        n      y

 NAME        CONDS  ALTS    ACTS
 fert_paddy    3      3       3
```

Conditions

Actions

New conditions

wet_depth	!paddy water depth, mm
weirh	!paddy weir height, mm
vol_wet	!water volume - stored on an hru m3 select case (d_tbl%cond(ic)%lim_var) case ("pvol") !prinicpal storage volume case ("evol") !emergency storage volume

Total numbers:
- 50 conditions
- 38 actions

New Actions

irrigate	Required for paddy irrigation: d_tbl%act(iac)%name=='ponding'
Irr_demand	Required for paddy irrigation: d_tbl%act(iac)%name=='ponding'
Puddle	!puddle
Impound_on	!turn on hru impounded water - rice paddy or wetland
Impound_off	!remove impoundment
weir_height	!adjust weir height – rice paddy/wetland Required: d_tbl%act(iac)%option == "wet"

Water Allocation for Paddy Irrigation

Water_allocation.wro

```
water_allocation.wro
1

NAME    RUL_TYP SRC_OBS DMD_OBS CHA_OB
wallo1  null     2     2    n

NUM OB_TYP   OB_NUM   JAN_MIN FEB_MIN MAR_MIN APR_MIN MAY_MIN JUN_MIN JUL_MIN AUG_MIN SEP_MIN OCT_MIN NOV_MIN DEC_MIN
1   cha      1        0.01    0.01    0.01    0.01    0.01    0.01    0.01    0.01    0.01    0.01    0.01    0.01
2   aqu      2        9999    9999    9999    9999    9999    9999    9999    9999    9999    9999    9999    9999
NUM OB_TYP   OB_NUM   WITHDR           AMOUNT  W_RT    TR_TYP  TREAT   RCV_OB  RCV_NUM   RCV_DTL      SRCS    SRC1    FRAC1   COMP1  SRC2  FRAC2   COMP2
1   hru            1  irr_RIC2_SJV     10      sr      null    null    null    0            null      2       1       0.65    n         2  0.35    y
2   hru            2  irr_RIC2_SJV     10      sr      null    null    null    0            null      2       1       0.65    n         2  0.35    y
```

Lum.dtl

```
NAME            CONDS ALTS     ACTS
 irr_RIC2_SJV       3    2     1
 VAR           OBJ  OB_NUM  LIM_VAR    LIM_OP     LIM_CONST    ALT1   ALT2
 weirh         hru    0        -          -           0           >      -
 month         null   0     null          -           5           >=     -
 month         null   0     null          -           9           -      >=
 ACT_TYP       OBJ  OB_NUM   NAME      OPTION       CONST   CONST2   FP       OUTCOMES
 irr_demand hru  0        ponding    noloss        90      60     null       y     n
```

Management.sch

```
management.sch: Management schedules
MGT_NAME      NUMB_OPS    NUMB_AUTO OP_TYPE    MON      DAY       HU_SCH     OP1
RIC2_SJV             8      3
                            puddle
                         irr_RIC2_SJV
                            weir100
              till     3    30   0.00000 chisplow    null     0.00000
              till     4    15   0.00000 offsethv    null     0.00000
              fert     4    20   0.00000 22-00-00    generic 636
              till     4    25   0.00000 offsetlt    null     0.00000
              fert     5    1    0.00000 15-15-00    generic 133
```

Example water allocation setting

- Two sources (Cha #1 and Aqu #2) available for water allocation
- Two receiving HRUs (#1 and #2) based on the irr_demand in "irr_RIC2_SJV"
- AMOUNT and W_RT are not used
- Water is allocated from the Cha#1 for 65% of the irrigation demand, and then 35% from the Aqu#2.
- If irrigation demand is not met due to limited water availability in the channel Aqu#2 is used as a compensating irrigation source

New Manual Operations in management.sch

OP Name	Description
weir	!change weir height !OP1 – weir name in weir.res !OP3 – new weir height for overflow, mm
irrp	!change paddy irrigation !OP1 – irrigation type name in irr.ops !OP2 – irrigation source (cha/sdc/res/aqu/null) !OP3 – object ID of the irrigation source (0 for nearby one)
pudl	!puddling operation !OP2 – Puddle type name in puddle.ops
Plnt	!planting (or transplanting) !OP1 – plant name in plants.plt !OP2 – transplanting type name in transplant.plt (OP3=1) !OP3 – 0 (seeding) or 1 (transplanting)

Management.sch

management.sch: Management schedules

MGT_NAME	NUMB_OPS	NUMB_AUTO	OP_TYPE	MON	DAY	HU_SCH	OP1	OP2	OP3
paddy	15	0							
			till	3	25	0.000	fallplow	null	0
			weir	4	1	0.000	weir1	null	50
			irrp	4	2	0.000	ponding50	sdc	0
			pudl	4	7	0.000	puddle	med_eff	0
			plnt	5	1	0.000	rice120	tr_rice120	0
			fert	6	27	0.000	elem_p	broadcast	40
			fert	6	27	0.000	urea	broadcast	90
			weir	7	3	0.000	weir1	null	200
			irrp	7	3	0.000	ponding200	sdc	0
			irrp	9	11	0.000	ponding_off	null	0
			weir	9	12	0.000	weir1	null	0
			harv	9	18	0.000	rice120	grain	0
			harv	9	18	0.000	rice120	hay_cut_low	0
			kill	9	18	0.000	rice120	null	0
			till	12	15	0.000	chisplow	null	0
paddy1	26	0							
			irrp	1	31	0.000	ponding_off	res	1
			weir	1	31	0.000	weir1	null	0
			till	3	25	0.000	fallplow	null	0
			weir	4	1	0.000	weir1	null	50
			irrp	4	2	0.000	ponding50	res	1
			pudl	4	7	0.000	puddle	med_eff	0
			fert	4	22	0.000	urea	broadcast	100
			fert	4	22	0.000	28_10_10	broadcast	200
			weir	4	25	0.000	weir1	null	50
			irrp	4	25	0.000	ponding50	res	1
			plnt	5	1	0.000	rice120	tr_rice120	0
			fert	6	27	0.000	elem_p	broadcast	40
			fert	6	27	0.000	urea	broadcast	90
			irrp	9	11	0.000	ponding_off	null	1
			weir	9	12	0.000	weir1	null	0
			harv	9	18	0.000	rice120	grain	0
			harv	9	18	0.000	rice120	hay_cut_low	0
			kill	9	18	0.000	rice120	null	0
			weir	11	1	0.000	weir1	null	600
			irrp	11	2	0.000	ponding600	res	1
paddy2	26	0							
			irrp	1	31	0.000	ponding_off	aqu	0
			weir	1	31	0.000	weir1	null	0
			till	3	25	0.000	fallplow	null	0
			weir	4	1	0.000	weir1	null	50
			irrp	4	2	0.000	ponding50	aqu	0
			pudl	4	7	0.000	puddle	med_eff	0
			irrp	4	20	0.000	ponding_off	null	0
			weir	4	20	0.000	weir1	null	0

Irr.ops

irr.ops: written by SWAT+ editor v2.2.0 on 2023-03-04 15:16 for SWAT+ re

NAME	IRR_AMT	IRR_EFF	SURQ_RTO	IRR_DEP	IRR_SALT	IRR_NO3N	IRR_PO4
drip	50	0.9	0	0	0	0	0
sprinkler	50	0.7	0.1	0	0	0	0
subsurface	50	1	0	150	0	0	0
surface	50	0.9	0.1	0	0	0	0
ponding50	50	1	0.0	60	0	0	0
ponding200	200	1	0.0	180	0	0	0
ponding600	600	1	0.0	600	0	0	0
ponding_off	0	1	0.1	0	0	0	0

Puddle.ops

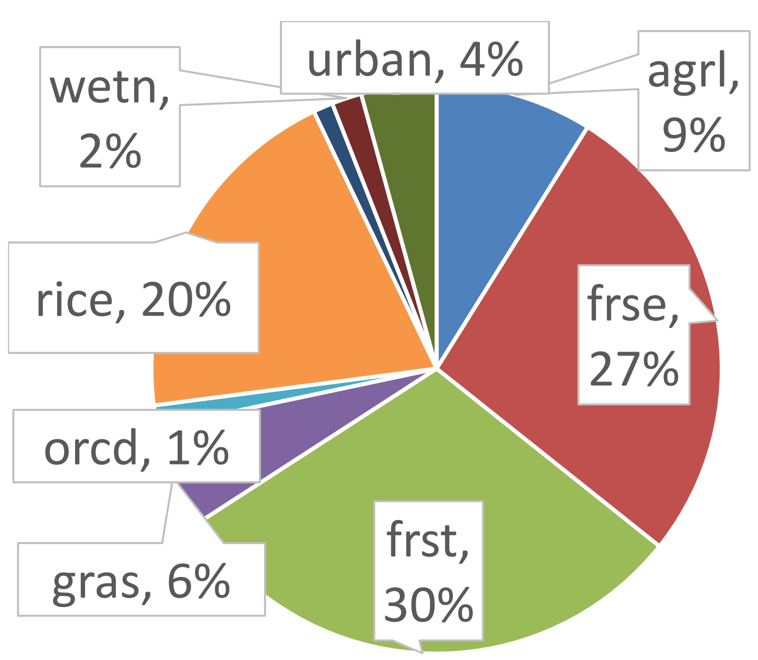
name	hydcon_mm/h	sed_ppm	orgn_ppm	sedp_ppm	no3_ppm	solp_ppm	nh3_ppm	no2_ppm
high_eff	0.01000	10000	0.00000	800.00000	10.00000	20.00000	1.00000	1.00000
med_eff	0.00000	10000	0.00000	500.00000	10.00000	20.00000	1.00000	1.00000
low_eff	0.15000	10000	0.00000	100.00000	10.00000	20.00000	1.00000	1.00000

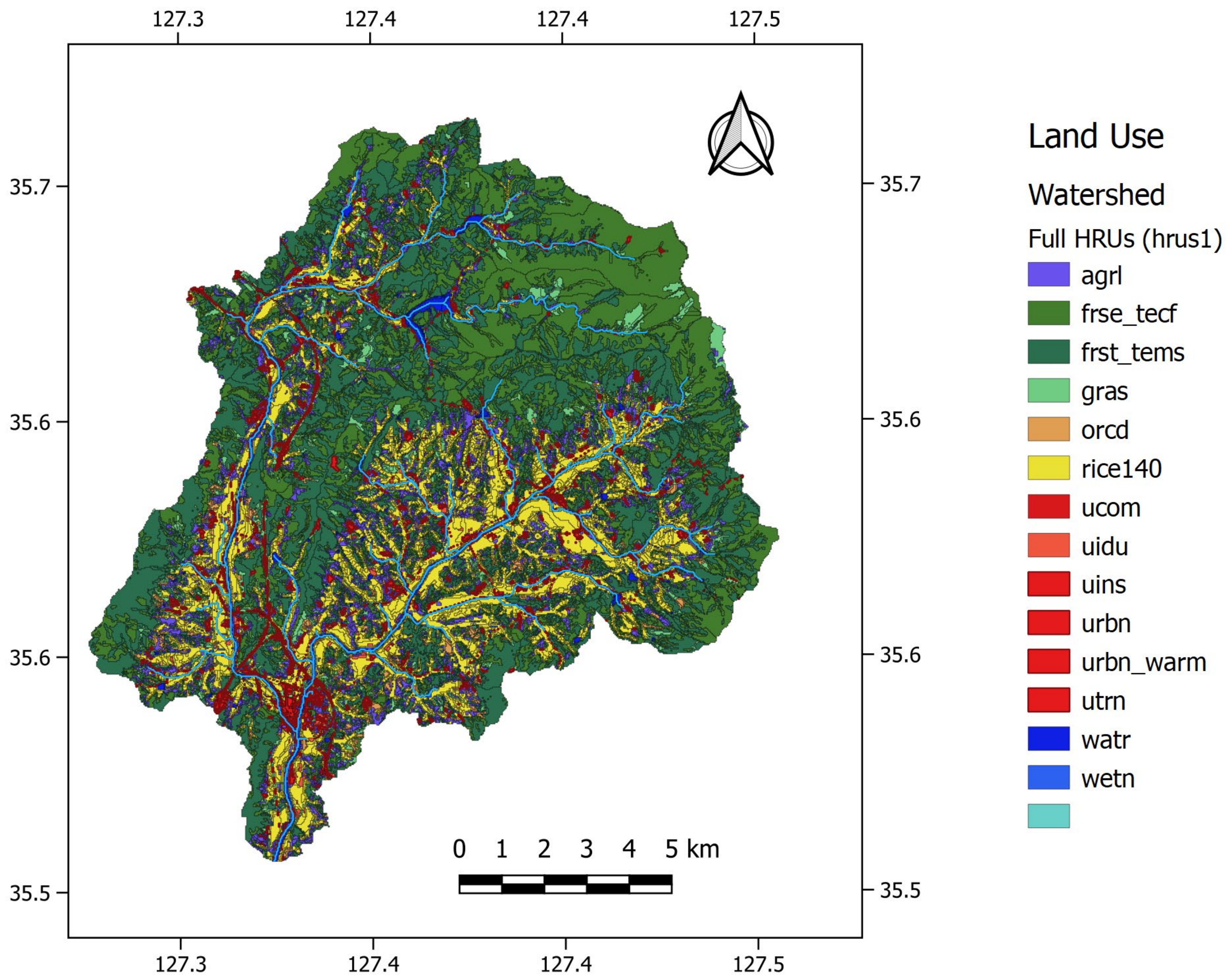
Case Studies

- Sin-Gi watershed, South Korea
- Albufera watershed, Spain
- San Juaquin watershed, California, USA

Sin-Gi Watershed

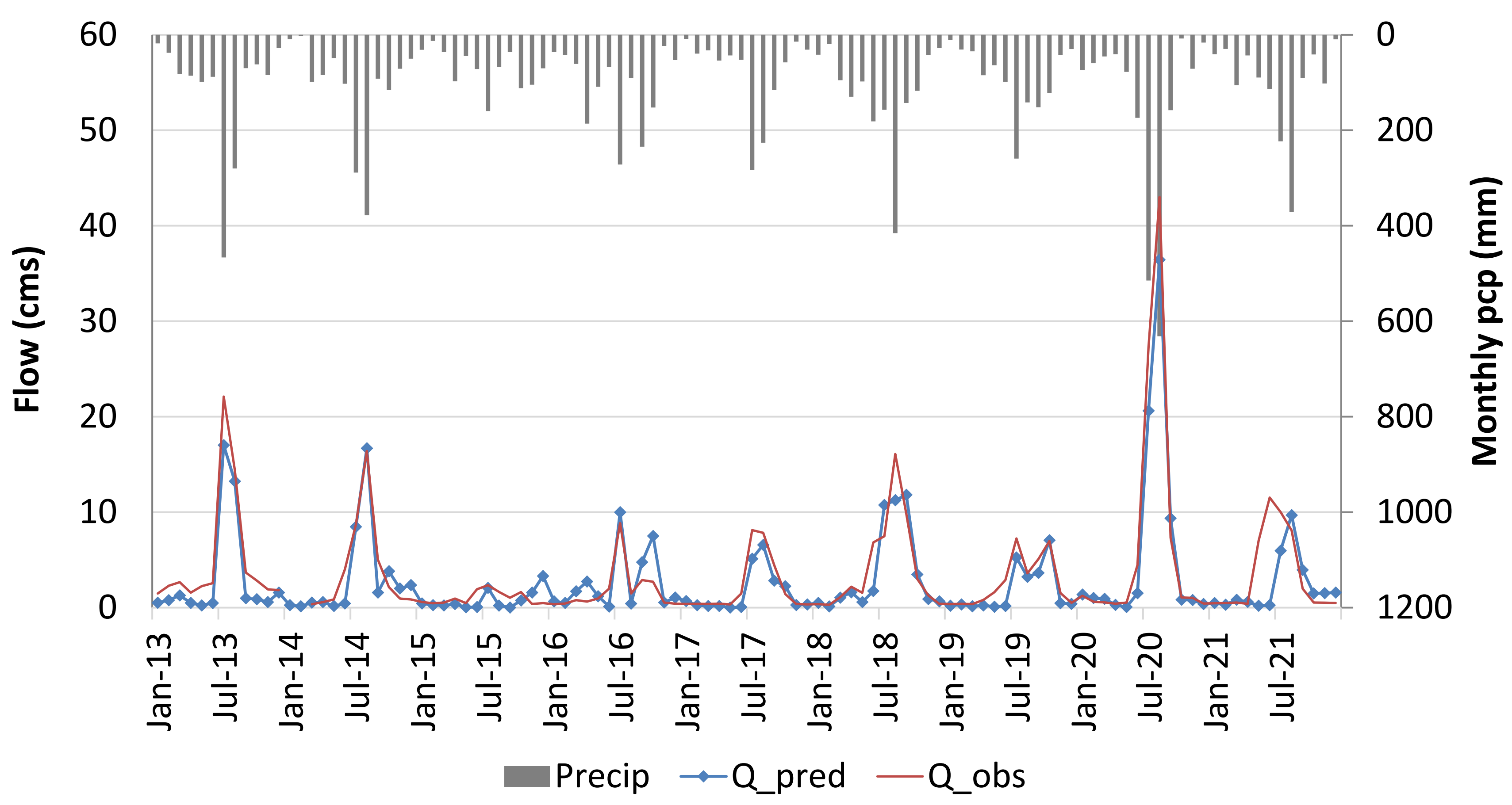
- Forests on high elevation and rice paddies in the valley area (191 km^2 area)
- Precipitation is influenced by monsoonal climate in June-September (annual rainfall is 1,268mm)
- Average high/low temperature is 29°C and 21°C
- Mean slope is 30%
- Mean elevation is 271m, outlet is at 110m, and mountain top is at 800m





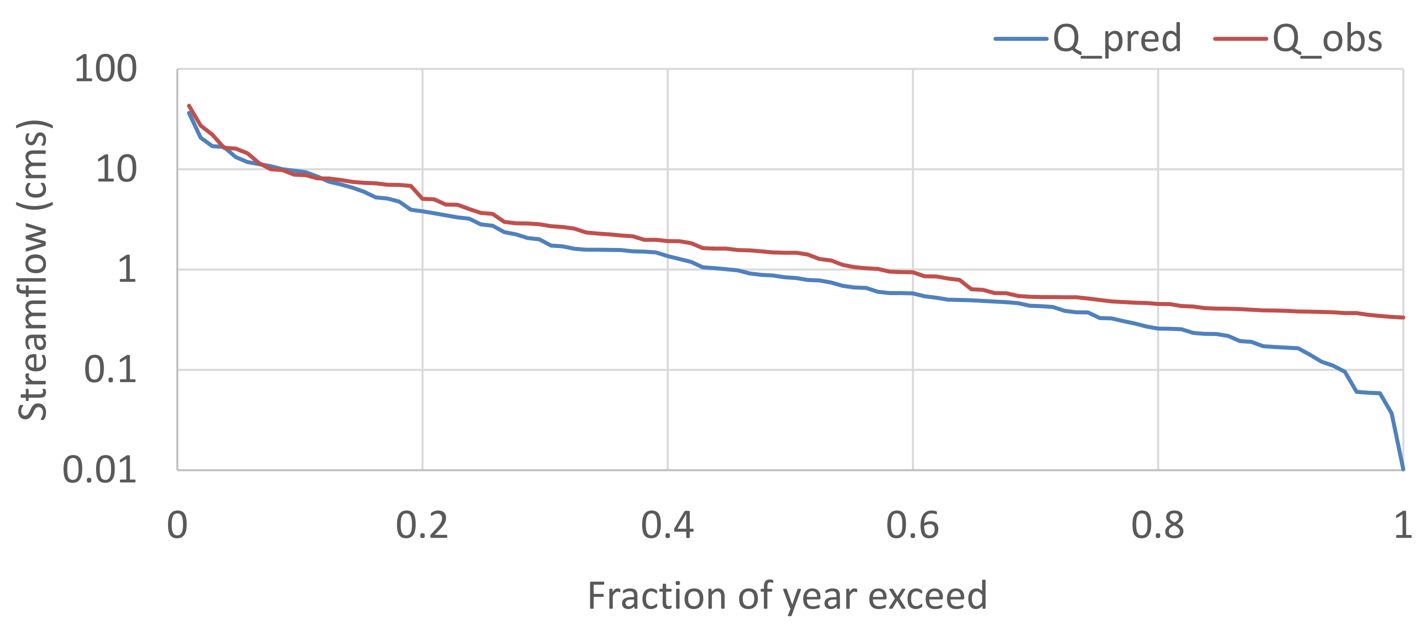
Results – streamflow

- Streamflow at the watershed outlet



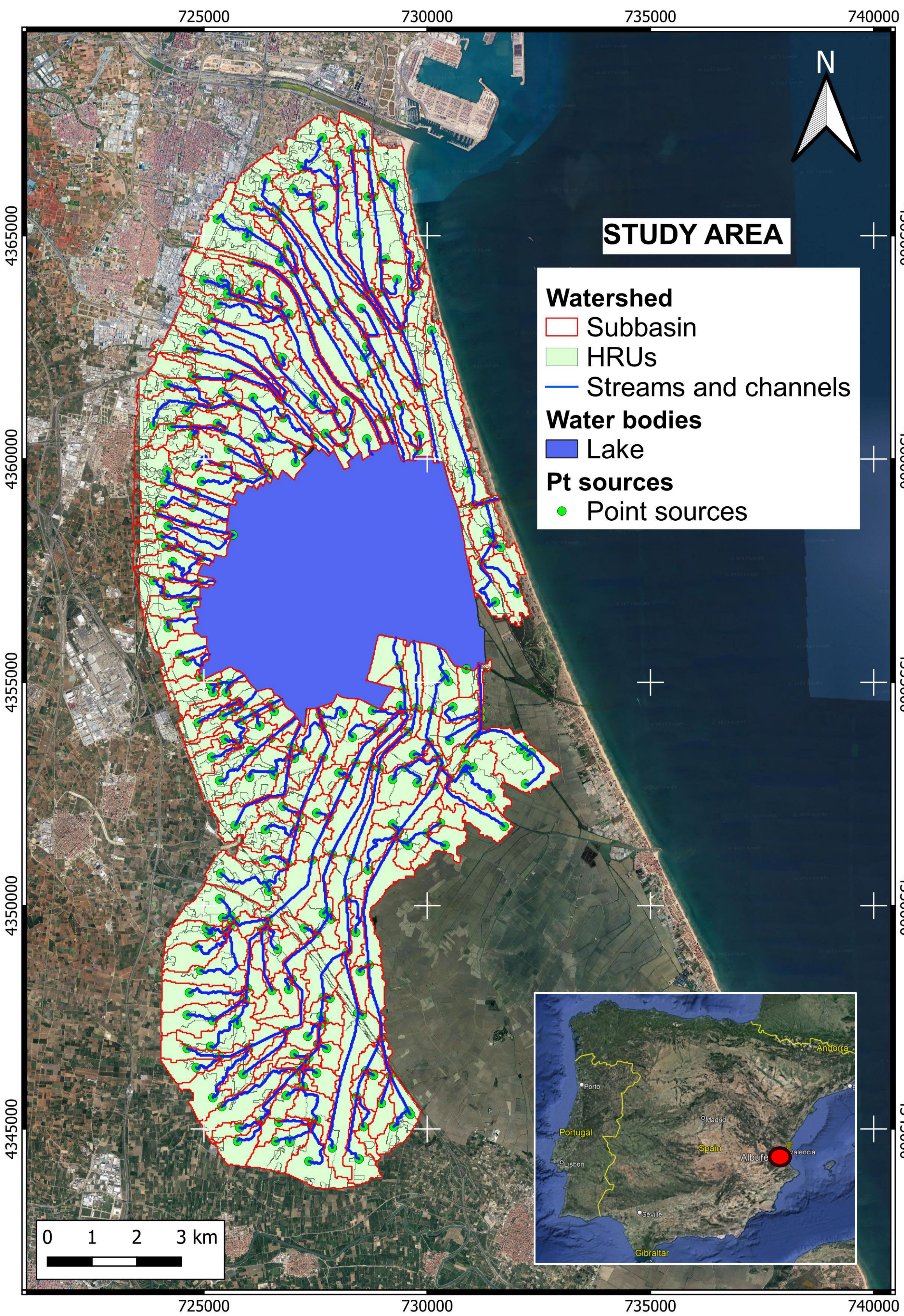
Performance metric	Paddy module	SCS-CN method
PBIAS	19.30	33.56
N&S efficiency	0.89	0.75
RSR	0.33	0.50
R^2	0.87	0.84

- Flow duration curve



Of the entire flow regimes, the top 20% flow accounts for 75% of the flow volume in the Singi stream.

Albufera Watershed, Spain



THE CASE OF THE ALBUFERA OF VALENCIA LAGOON (SPAIN)

- Objective: Evaluate water and nutrients balance

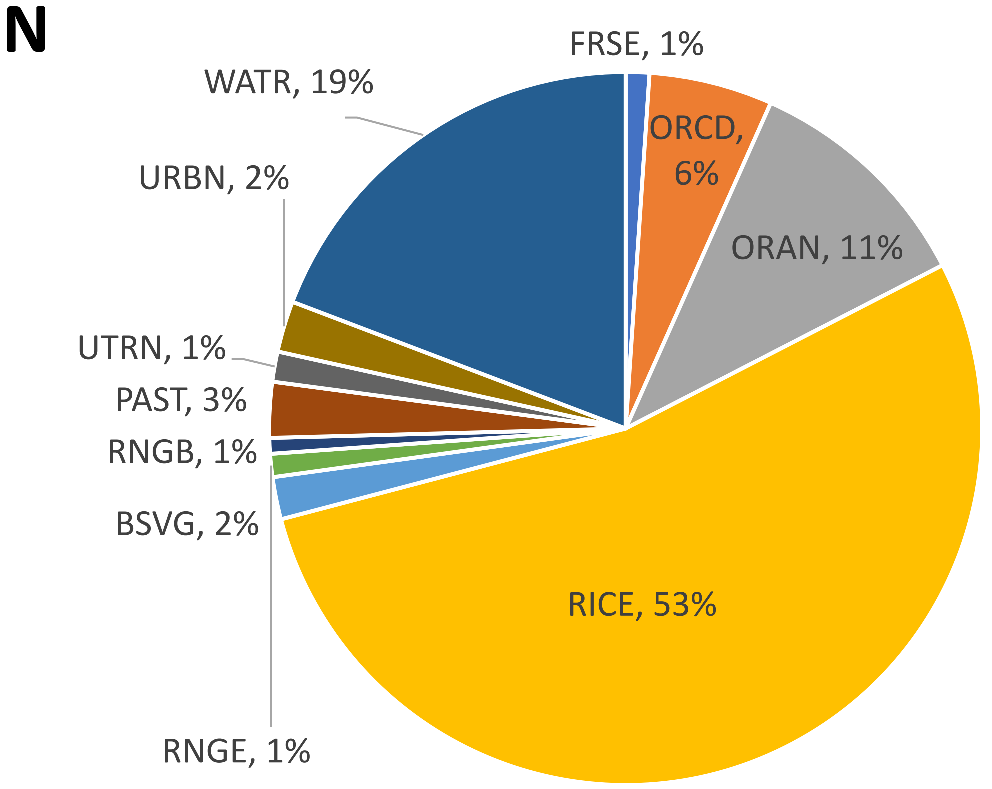
- STUDY AREA
  - **HUMAN PRESSURES**
    - URBANIZATION
    - INDUSTRIAL PRODUCTION
    - INTENSIVE AGRICULTURAL INPUTS (RICE, IRRIGATED CROPS, CITRUS PRODUCTION)
    - HIDROLOGICAL COMPLEXITY (TWO PRINCIPAL RIVERS, DENSE AGRICULTURAL DRAINAGE NETWORK, RAMSAR WETLAND, HUMAN EXPLOITATION AQUIFER, ETC…)
    - SOCIAL/ENVIRONMENTAL CONFLICTS (CONSERVATIONS VS LANDUSE INTENSIFICATION)

  - **NATURAL PARK AND INTERNATIONAL WETLAND PROTECTED AREA (ENDEMIC AQUATIC SPECIES AND BIRDS PROTECTION AREA)**

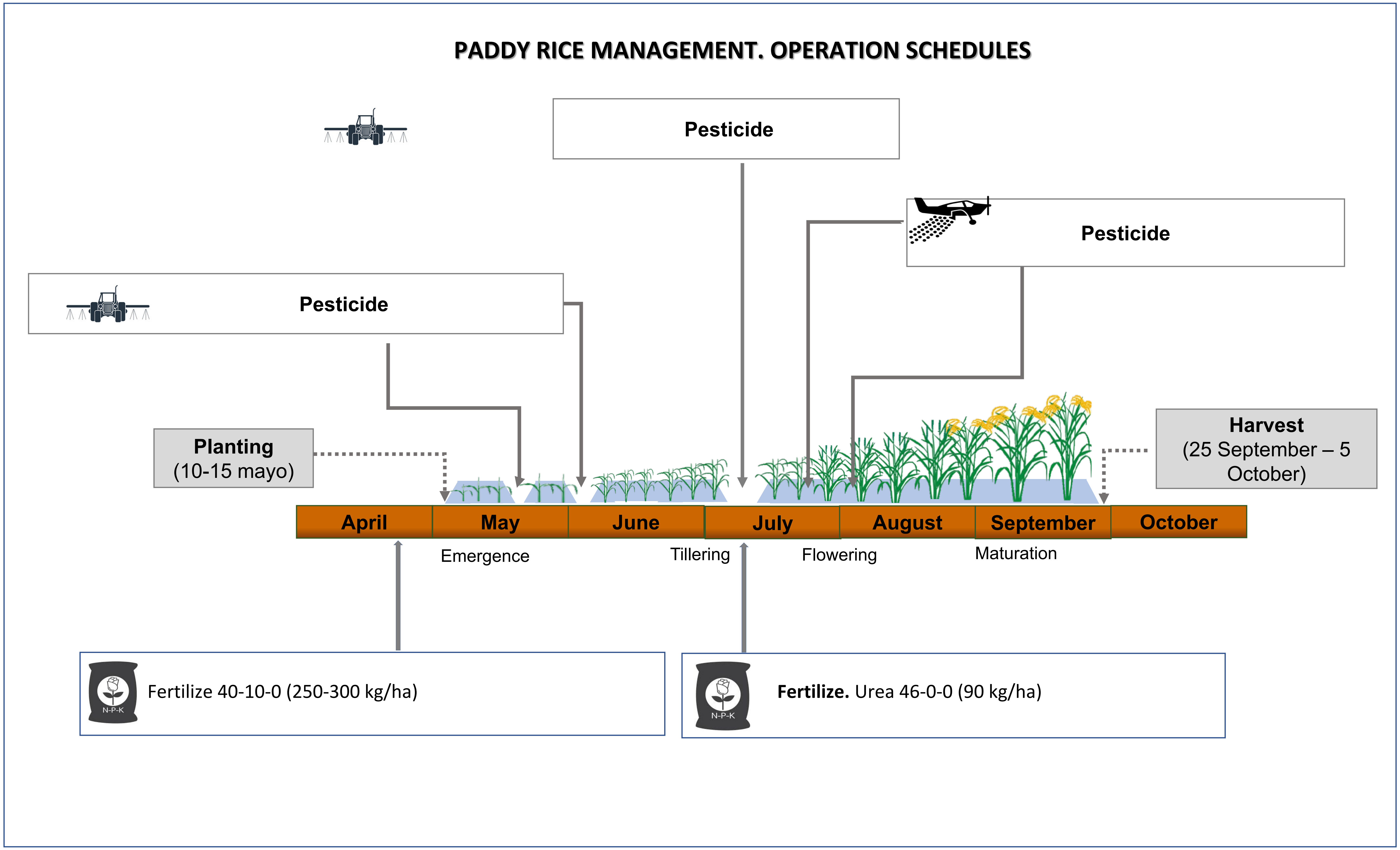
SWAT+ PROJECT INFORMATION

Object totals

270	Subbasins
1136	HRUs
352	Channels
272	Aquifers
1	Reservoirs
373	Routing Units
373	Landscape Units
116	Recall (point source/inlet data)
0	Export Coefficients
0	Delivery Ratio



Albufera Watershed, Spain

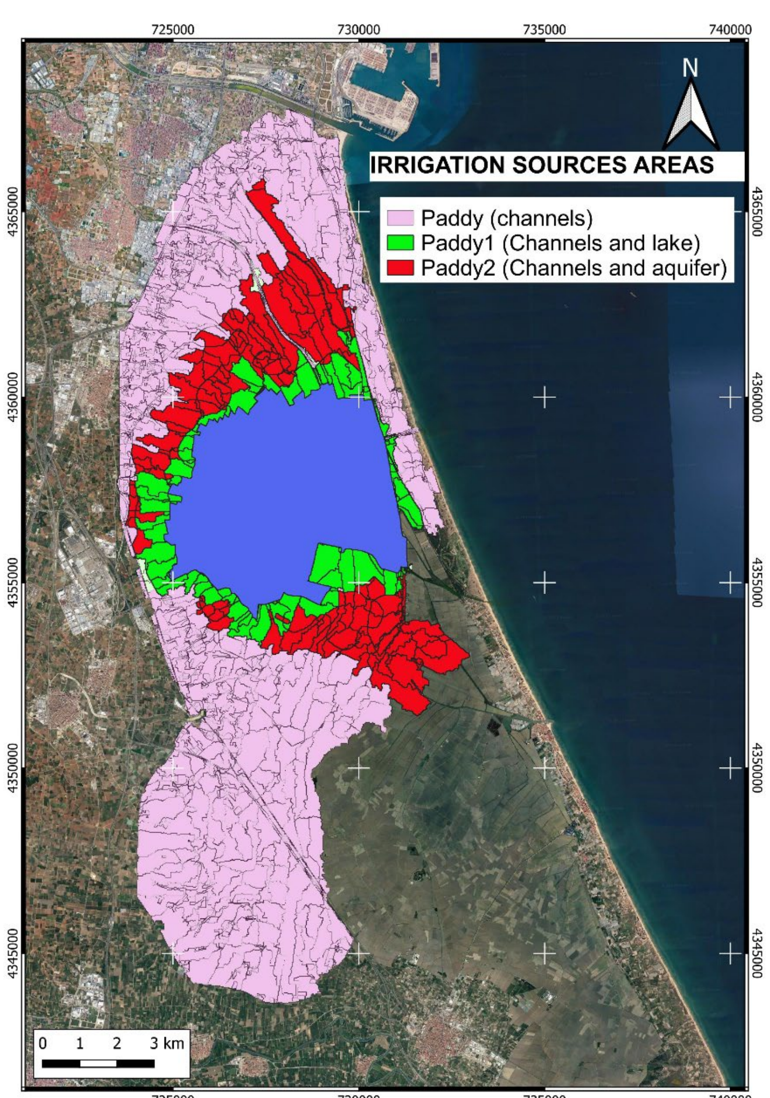


Water Balance and Management Operations

- PADDIES RICE IRRIGATION FROM WATER CHANNEL ALLOCATION. FROM MAY TO SEPTEMBER. 120 – 180 mm depth

Periodo	t	P_{ef}	ET_c	I	Dr	ΔH	
	d	mm				Mm	mm/d
12/05-14/05	3	0,0	18,5		7,8		
15/05-05/06	22	11,4	105,2		91,2		
12/05-05/06	**25**	**11,4**	**123,7**	**366,3**	**99,0**	**155,0**	**6,2**
06/06-10/06	**5**	**0,0**	**29,4**	**0,0**	**20,7**	**-50,1**	**-10,0**
11/06-14/06	4	0,0	26,5	46,0	16,6		
15/06-06/07	22	0,6	143,7	351,6	103,0		
11/06-06/07	**26**	**0,6**	**170,3**	**397,6**	**119,6**	**87,6**	**3,4**
07/07-11/07	**5**	**0,0**	**30,2**	**0,0**	**19,1**	**-49,3**	**-9,9**
12/07-27/07	16	21,9	96,7	287,5	118,9	93,9	5,9
28/07-18/08	22	0,0	120,6	395,4	262,3	12,4	0,6
12/07-18/08	**38**	**21,9**	**217,3**	**682,9**	**381,2**	**106,3**	
19/08-31/08	13	9,6	54,2	176,3	155,0	-23,3	-1,8
01/0-14/09	14	2,1	55,4	128,2	166,9	-92,0	-6,6
19/08-14/09	**27**	**11,7**	**109,6**	**304,5**	**321,9**	**-115,3**	
12/05-14/09	**126**	**45,5**	**680,5**	**1.751,4**	**982,3**	**134,2**	

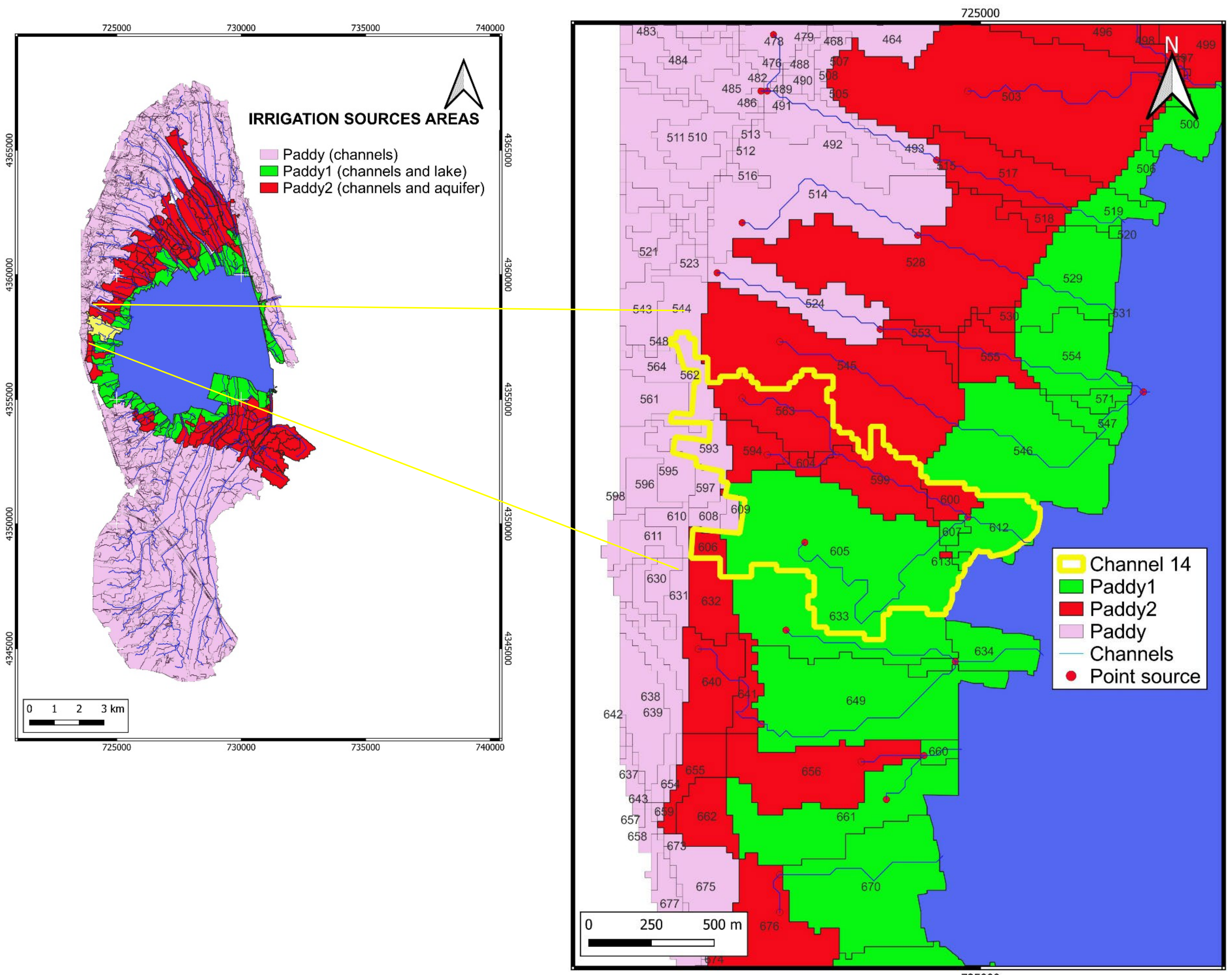
- Td: total days
- Pef: efective precipitation
- Etc: rice water consumption
- I: irragation
- Dr: drainage
- ΔH: water depth variation

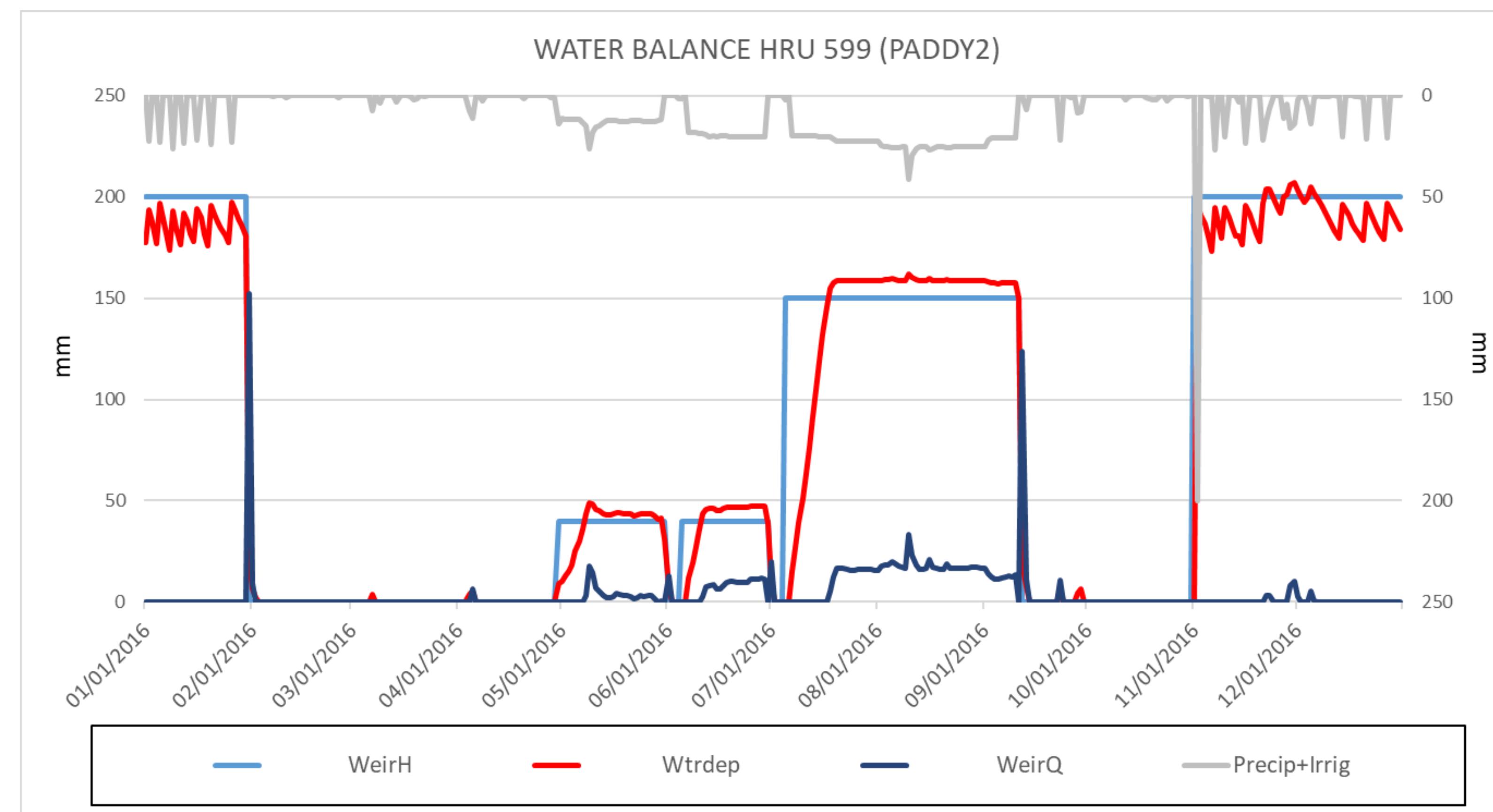


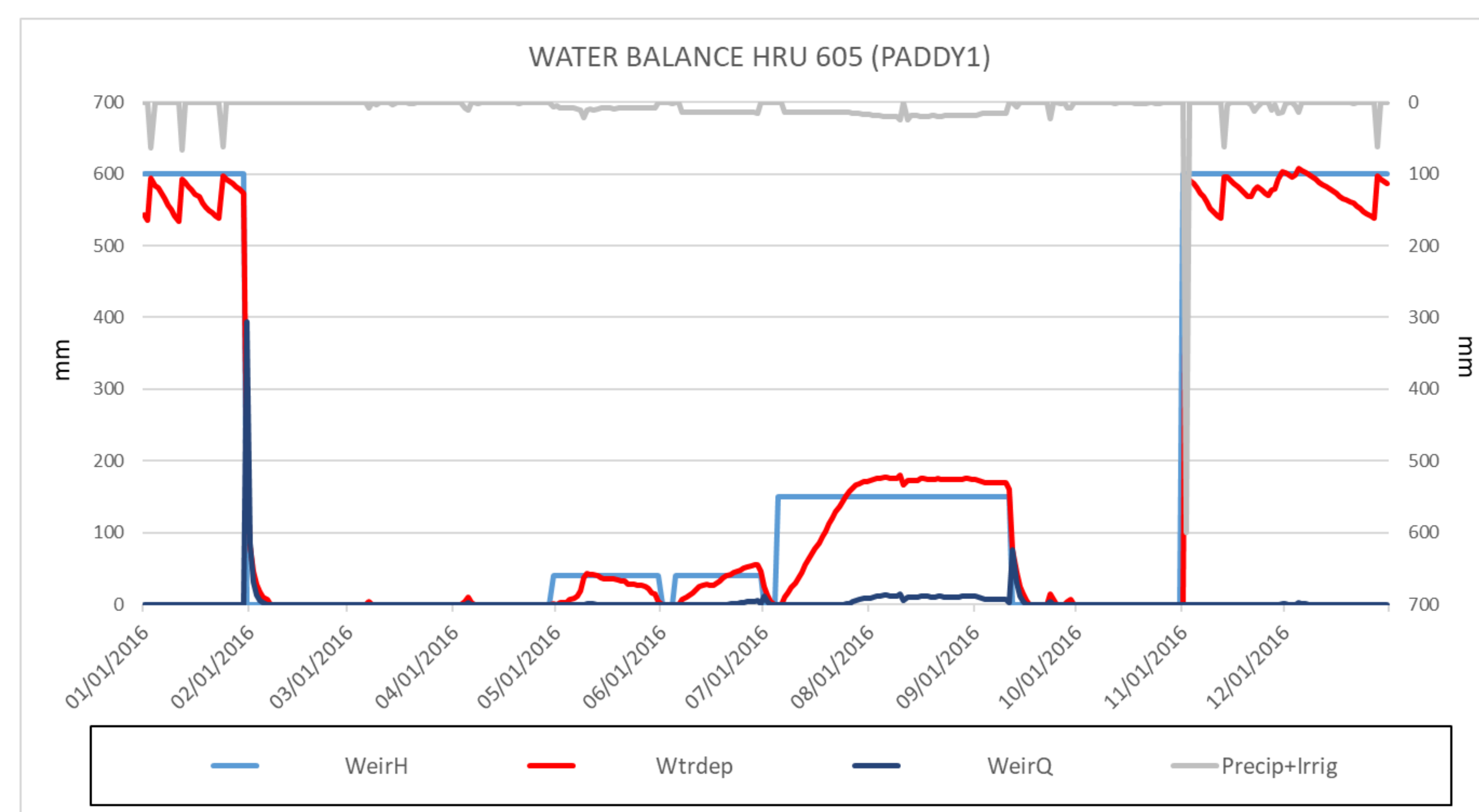

```
management.sch: Management schedules
    MGT_NAME    NUMB_OPS   NUMB_AUTO OP_TYPE   MON     DAY    HU_SCH   OP1        OP2        OP3
     paddy          20          0
                                     till       3      25     0.000   fallplow   null        0
                                     fert       4      22     0.000   urea       broadcast   100
                                     fert       4      22     0.000   28_10_10   broadcast   200
                                     weir       4      25     0.000   weir1      null        50
                                     irrp       4      25     0.000   ponding50   sdc        0
                                     pudl       4      28     0.000   puddle     med_eff     0
                                     plnt       5       1     0.000   rice120    tr_rice120  0
                                     irrp       6      25     0.000   ponding_off null       0
                                     weir       6      25     0.000   weir1      null        0
                                     fert       6      27     0.000   elem_p     broadcast   40
                                     fert       6      27     0.000   urea       broadcast   90
                                     weir       7       3     0.000   weir1      null        200
                                     irrp       7       3     0.000   ponding200  sdc        0
                                     irrp       9      11     0.000   ponding_off null       0
                                     weir       9      12     0.000   weir1      null        0
                                     harv       9      18     0.000   rice120    grain       0
                                     harv       9      18     0.000   rice120    hay_cut_low 0
                                     kill       9      18     0.000   rice120    null        0
                                     till      12      15     0.000   chisplow   null        0
                                     skip       0       0     0.000   null       null        0

     paddy1         22          0
                                     irrp       1      31     0.000   ponding_off res        1
                                     weir       1      31     0.000   weir1      null        0
                                     till       3      25     0.000   fallplow   null        0
                                     fert       4      22     0.000   urea       broadcast   100
                                     fert       4      22     0.000   28_10_10   broadcast   200
                                     weir       4      25     0.000   weir1      null        50
                                     irrp       4      25     0.000   ponding50   sdc        0
                                     pudl       4      28     0.000   puddle     med_eff     0
                                     plnt       5       1     0.000   rice120    tr_rice120  0
                                     irrp       6      25     0.000   ponding_off null       0
                                     weir       6      26     0.000   weir1      null        0
                                     fert       6      27     0.000   elem_p     broadcast   40
                                     fert       6      27     0.000   urea       broadcast   90
                                     weir       7       3     0.000   weir1      null        200
                                     irrp       7       3     0.000   ponding200  sdc        0
                                     irrp       9      11     0.000   ponding_off null       1
                                     weir       9      12     0.000   weir1      null        0
                                     harv       9      18     0.000   rice120    grain       0
                                     harv       9      18     0.000   rice120    hay_cut_low 0
                                     kill       9      18     0.000   rice120    null        0
                                     weir      11       1     0.000   weir1      null        600
                                     irrp      11       2     0.000   ponding600 res         1

     paddy2         22          0
                                     irrp       1      31     0.000   ponding_off null       0
                                     weir       1      31     0.000   weir1      null        0
                                     till       3      25     0.000   fallplow   null        0
                                     fert       4      22     0.000   urea       broadcast   100
                                     fert       4      22     0.000   28_10_10   broadcast   200
                                     weir       4      25     0.000   weir1      null        50
                                     irrp       4      25     0.000   ponding50   sdc        0
                                     pudl       4      28     0.000   puddle     med_eff     0
                                     plnt       5       1     0.000   rice120    tr_rice120  0
                                     irrp       6      24     0.000   ponding_off null       0
                                     weir       6      25     0.000   weir1      null        0
                                     fert       6      27     0.000   elem_p     broadcast   40
                                     fert       6      27     0.000   urea       broadcast   90
                                     weir       7       3     0.000   weir1      null        200
                                     irrp       7       3     0.000   ponding200  sdc        0
                                     irrp       9      11     0.000   ponding_off null       0
                                     weir       9      12     0.000   weir1      null        0
                                     harv       9      18     0.000   rice120    grain       0
                                     harv       9      18     0.000   rice120    hay_cut_low 0
                                     kill       9      18     0.000   rice120    null        0
                                     weir      11       1     0.000   weir1      null        200
                                     irrp      11       2     0.000   ponding200  null       0
```

- PADDIES RICE IMPOUND FOR ENVIRONMENTAL MESURES FROM WATER AQUIFER AND LAKE ALLOCATION. FROM NOVEMBER TO JANUARY. 400-800 mm around the lake (paddy1) and 200 mm (paddy2).

Preliminary Results: HRUs 599 and 605







- Paddy rice module faithfully represents the levels that define a rice field
- The balance between weir height (management.sch) and the parameters defining irrigation (IRR_AT and IRR_DEP in irr.ops) is key to properly simulate the water depth
- The surface area of the HRUs must be taken into account in the process of paddy fields impound time

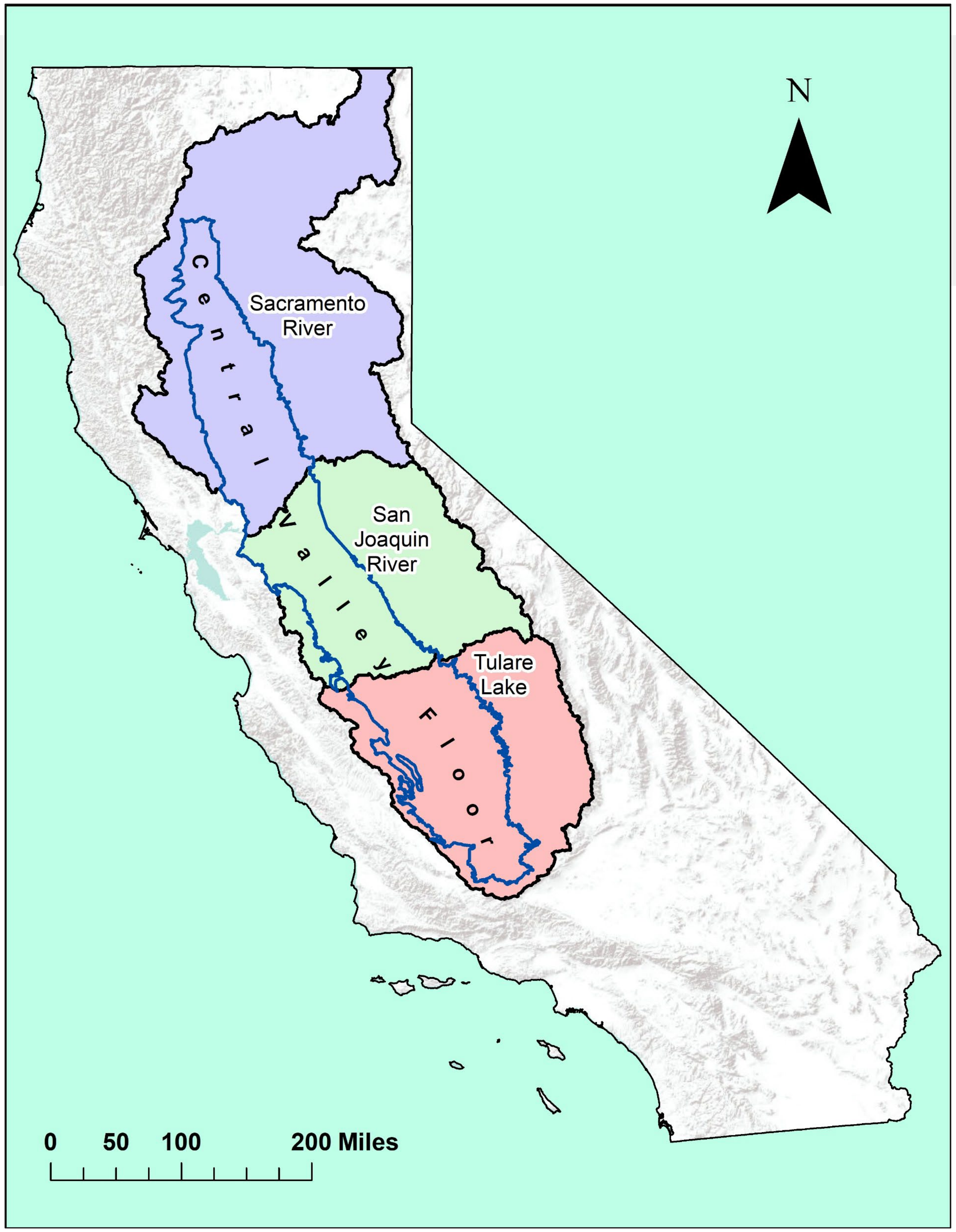
Overview of Central Valley Agriculture

More than 300 crops grown

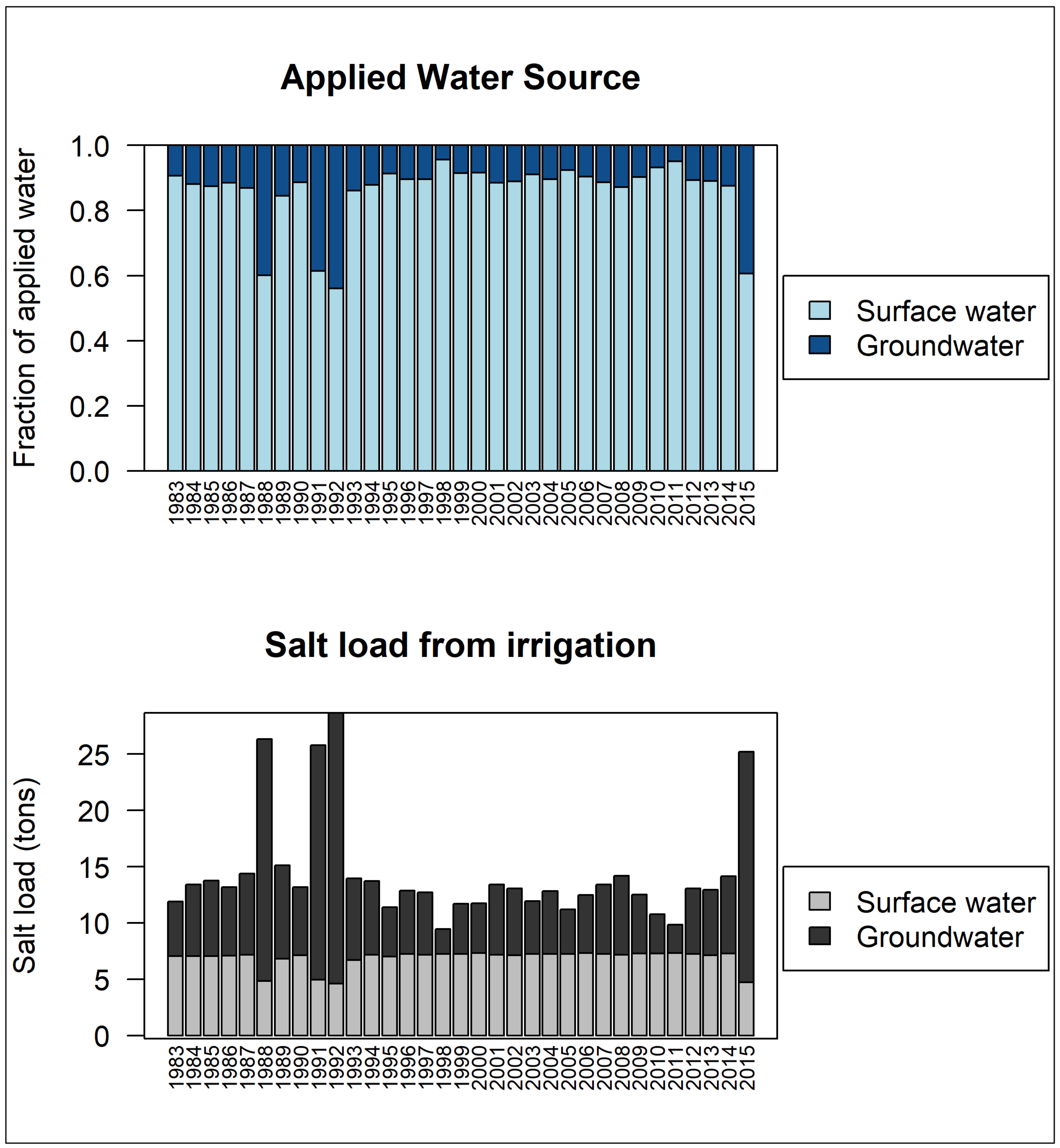
$38 billion in production value in 2021

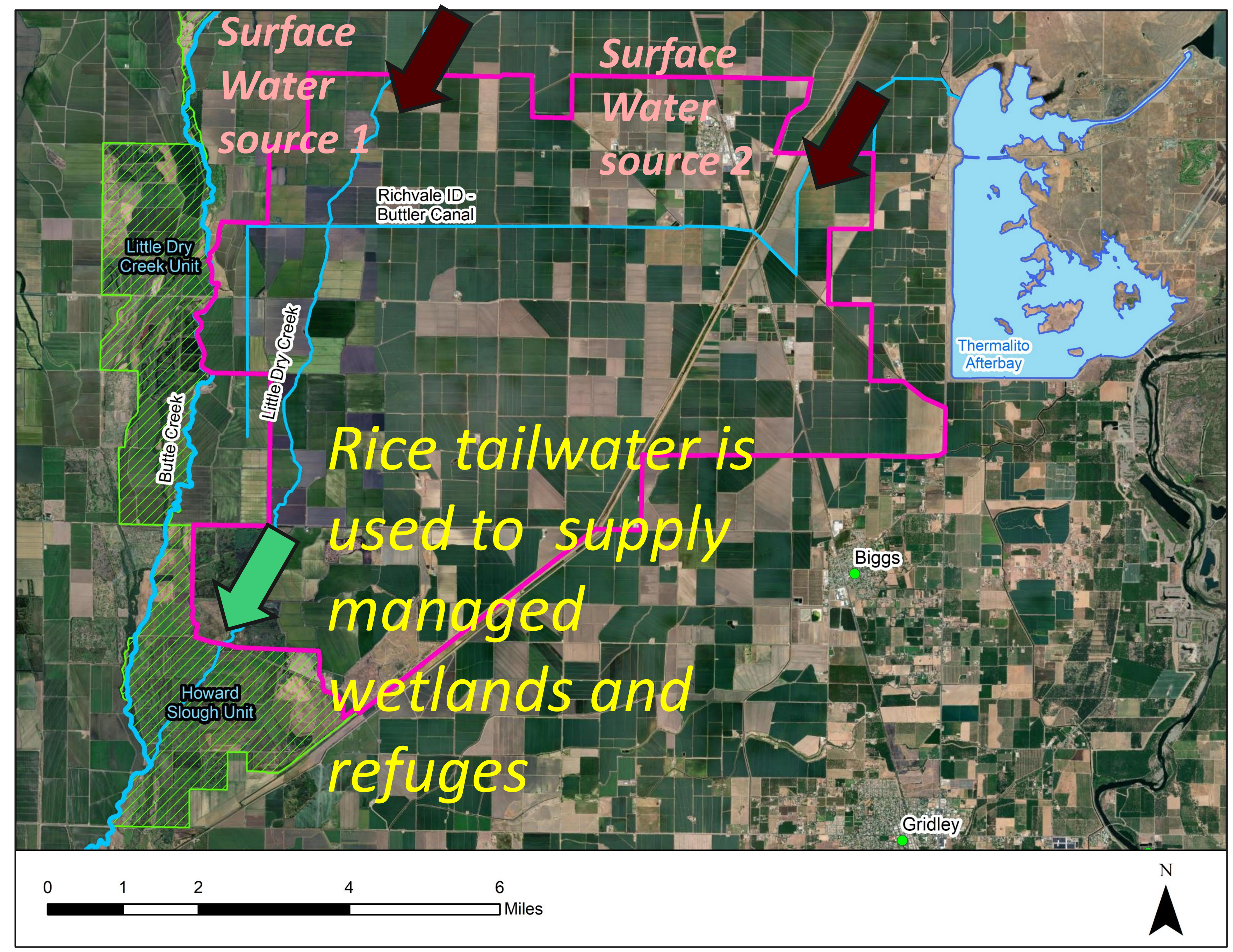
Approximately 75% of the irrigated land in California

17% of the Nation's irrigated land is in the Central Valley



Irrigation Salt Loading Example





Total applied water in irrigation district: ~ 185 – 204 TAF

Surface water TDS = 60 mg/L

Groundwater TDS = 400 mg/L

Summary

Paddy module in SWAT+

Water balances at the field-scale and watershed-scale improved substantially with the paddy module implementation

Large scale application

Representation of complex paddy systems at the watershed scale is still a challenge

Tasks to do with SWAT+

Expand decision tables, calibrate Sin-Gi, Albufera, and San Joaquin, conservation practices, enhance GHGs