Dynamic agricultural land use and complex reservoir management for high-resolution SWAT+ simulation

within the Collaborative Research Center RESIST

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Motivation

Purpose

Goal: combine with biological data

- at 20 sampling locations

→ high spatial resolution

Data

High- resolution **data** is available for study area:

1. crop rotation data
2. reservoir management

Model

What is possible in **SWAT+**?

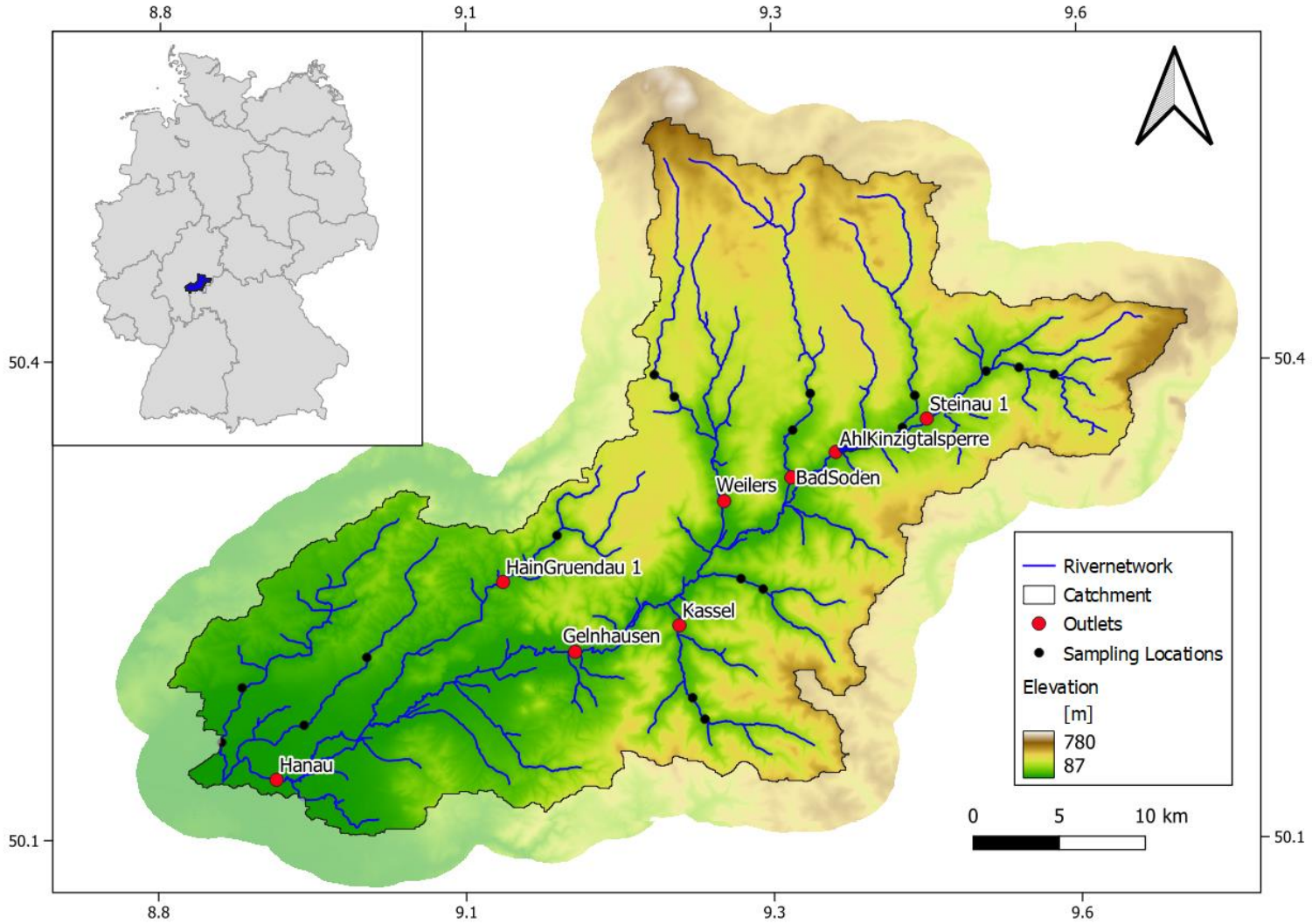
→ New feature:

Decision Tables

Study area

Kinzig

- **German** mid-range mountains
- **catchment area**: 1,057 km²
- main **land use** classes:
  - FRSD 42%
  - AGRL 41%
  - PAST 7%
  - URBN 7%
- complex processes:
  - snow
  - shallow soils and basalt
  - deep alluvial soils - complex flow pathways



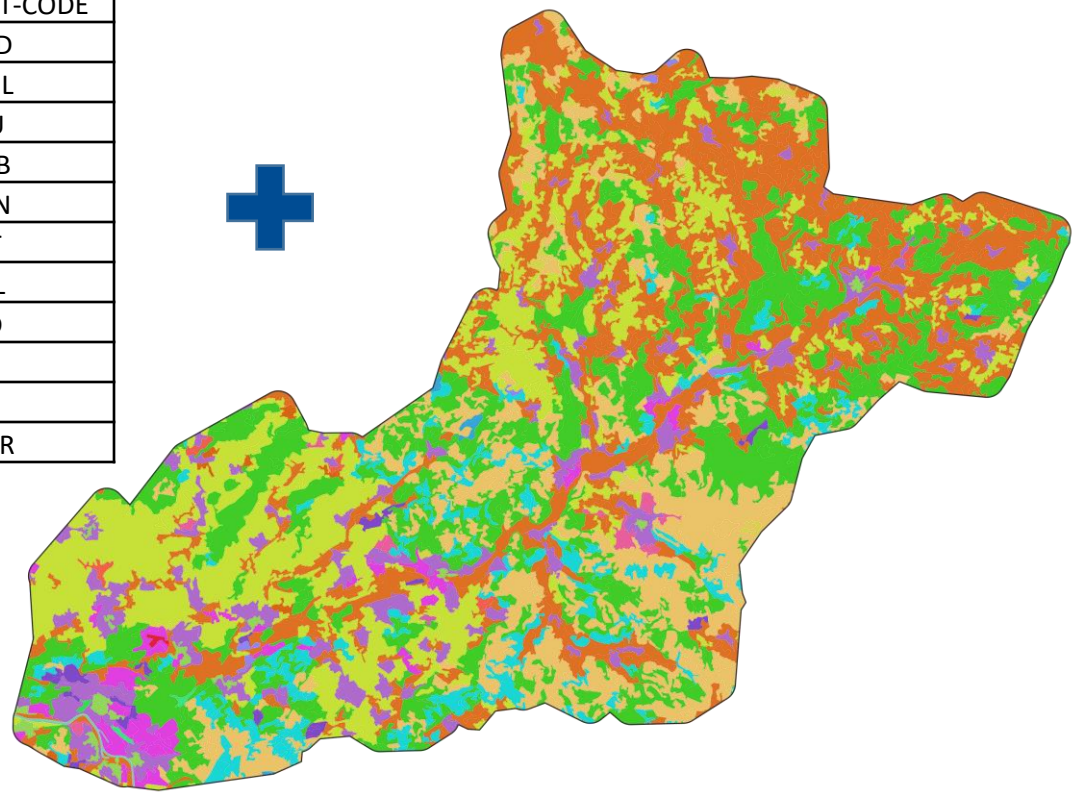
Part 1

Dynamic agricultural land management

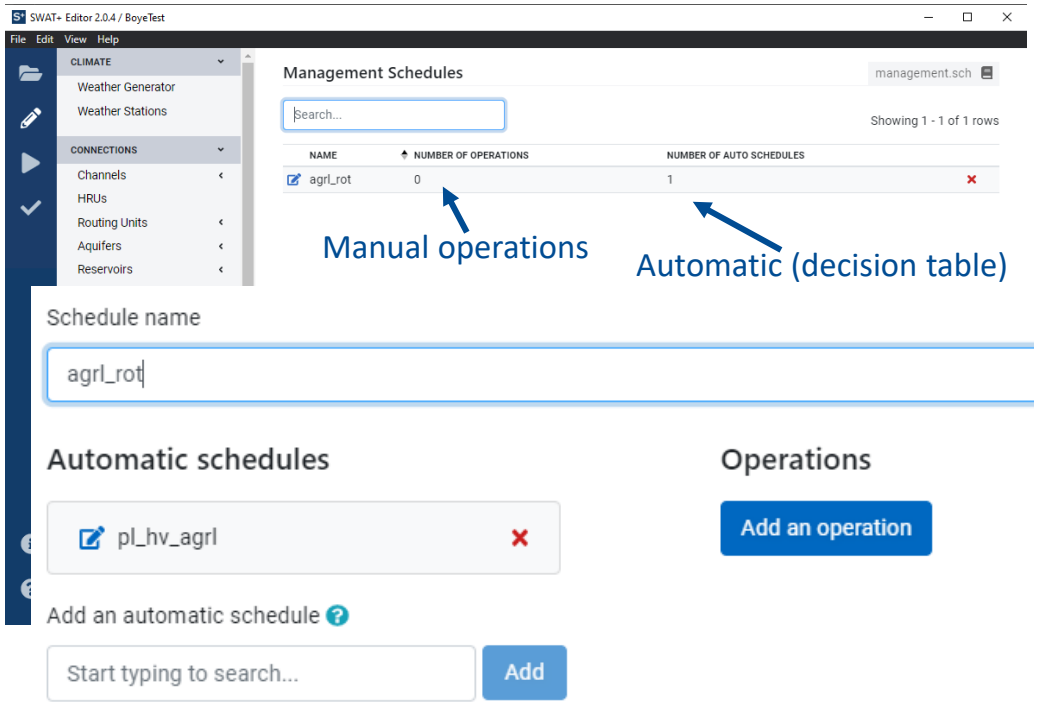
Standard land use and management in SWAT+

Static land use map and lookup table

VALUE	SWAT-CODE
9001	URHD
9002	URML
9003	UIDU
9010	RNGB
9011	URBN
9018	PAST
9020	AGRL
9023	FRSD
9024	FRSE
9025	FRST
9040	WATR

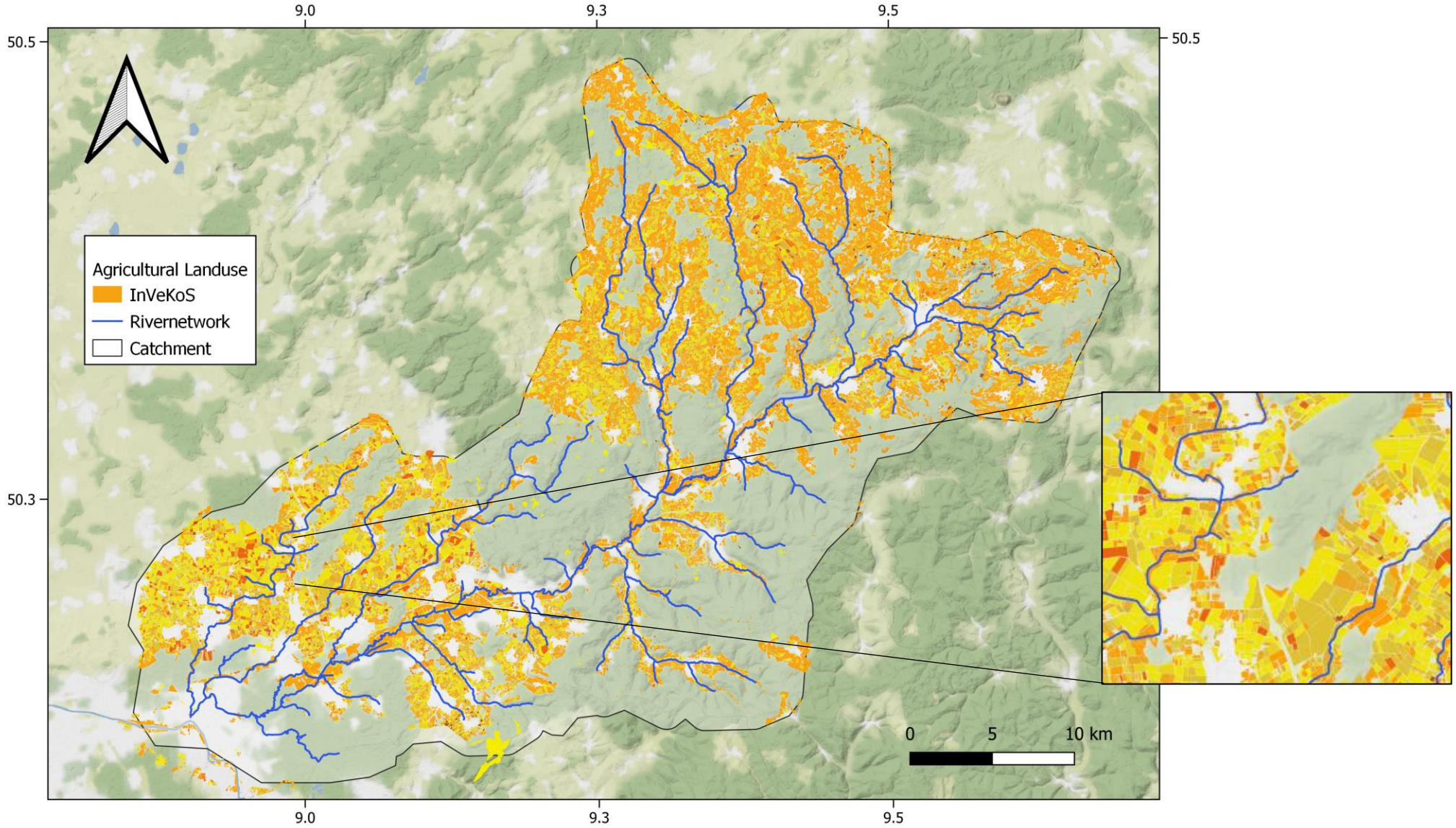


Management schedule (optional)



InVeKoS* Data

- only agricultural areas
- unique crops for each field: ~70,000 fields
- each year new crops: 2005-2022



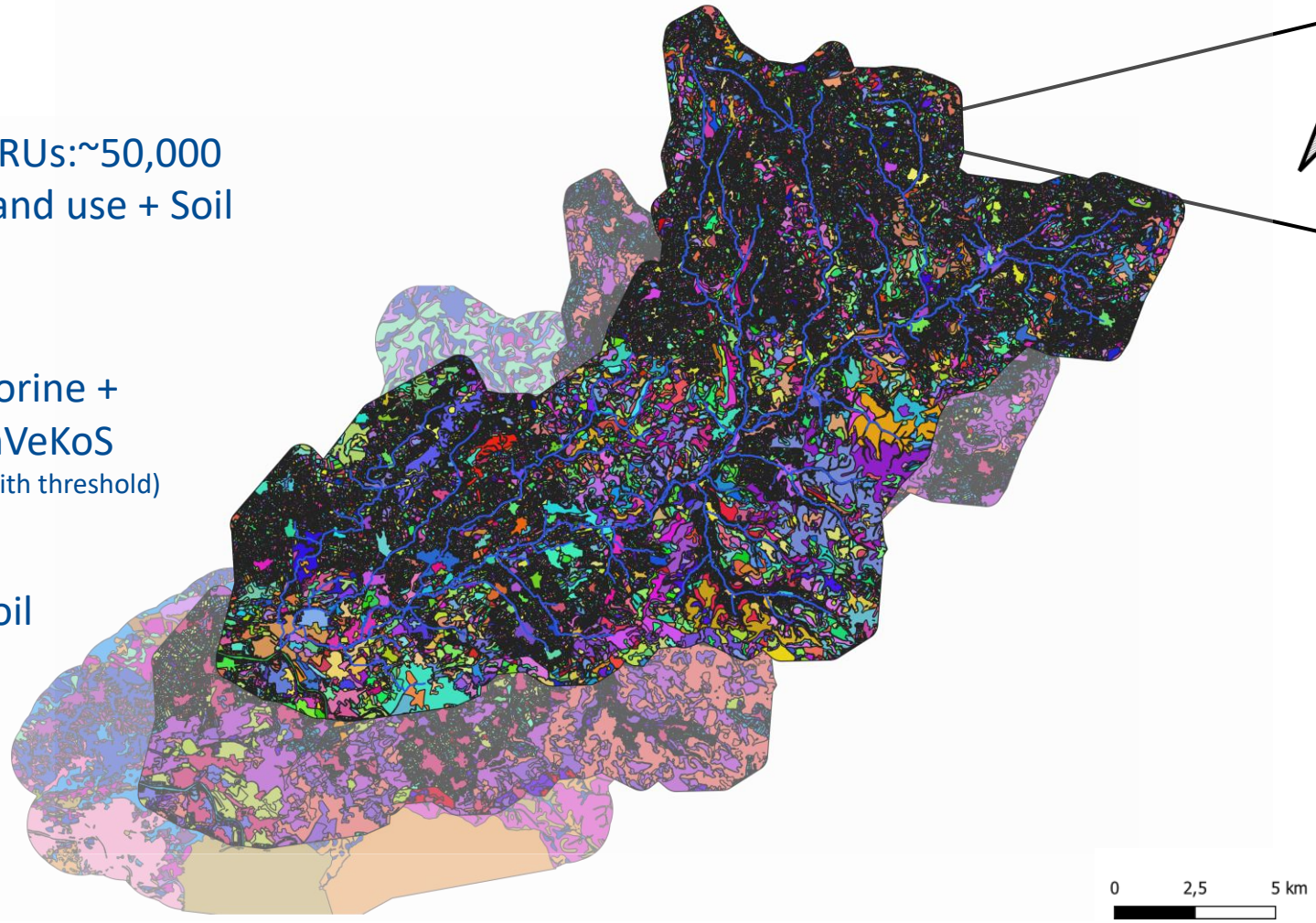
*InVeKoS. 2023. Crop data based on the German agricultural subsidies program. WI-Bank Hessen.

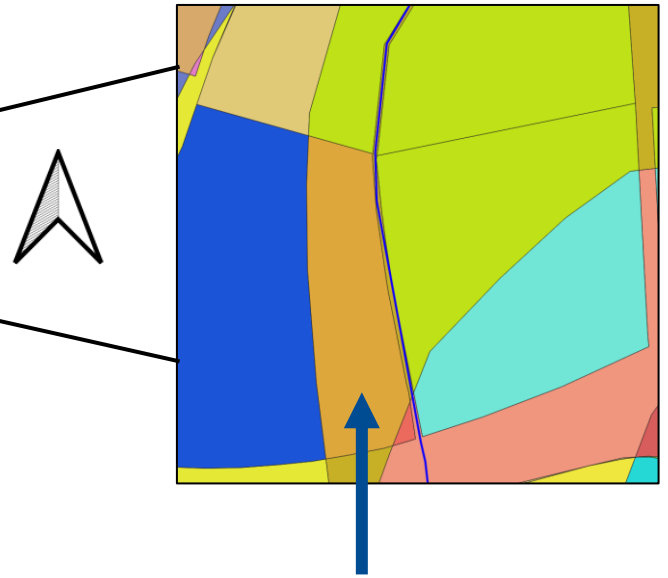
Data preparation – merge maps

HRUs:~50,000
Land use + Soil

Corine +
InVeKoS
(with threshold)

Soil





5004-131-411-131-411-131-411-...

5004 - Soil: BB4_K
131 - Land Use: Winter Barley (2005,2007,2009)
411 - Land Use: Silage corn (2006,2008,2010)

Decision Tables

Decision Tables – Example fodder grass for 18 years

name	conds	alts	acts
pl_hv_wpas_yr_1	17	16	10

var	obj	obj_num	lim_var	lim_op	lim_const	alt1	alt2	alt3	alt4	alt5	alt6	alt7	alt8	alt9	alt10	alt11	alt12	alt13	alt14	alt15	alt16
year_rot	hru	0	null	-	1	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	-
year_rot	hru	0	null	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	=
soil_water	hru	0	fc	*	0.95	-	<	-	<	-	<	-	<	-	<	-	<	-	<	-	-
jday	hru	0	null	-	1	=	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
jday	hru	0	null	-	60	-	>	-	-	-	-	-	-	-	-	-	-	-	-	-	-
jday	hru	0	null	-	74	-	<	=	-	-	-	-	-	-	-	-	-	-	-	-	-
jday	hru	0	null	-	135	-	-	-	>	-	-	-	-	-	-	-	-	-	-	-	-
jday	hru	0	null	-	151	-	-	-	<	=	-	-	-	-	-	-	-	-	-	-	-
jday	hru	0	null	-	152	-	-	-	-	-	>	-	-	-	-	-	-	-	-	-	-
jday	hru	0	null	-	166	-	-	-	-	-	<	=	-	-	-	-	-	-	-	-	-
jday	hru	0	null	-	182	-	-	-	-	-	-	-	>	-	-	-	-	-	-	-	-
jday	hru	0	null	-	196	-	-	-	-	-	-	-	<	=	-	-	-	-	-	-	-
jday	hru	0	null	-	213	-	-	-	-	-	-	-	-	-	>	-	-	-	-	-	-
jday	hru	0	null	-	227	-	-	-	-	-	-	-	-	-	<	=	>	-	-	-	-
jday	hru	0	null	-	243	-	-	-	-	-	-	-	-	-	-	-	<	=	-	-	-
jday	hru	0	null	-	274	-	-	-	-	-	-	-	-	-	-	-	-	-	>	-	-
jday	hru	0	null	-	288	-	-	-	-	-	-	-	-	-	-	-	-	-	<	=	-

act_typ	obj	obj_num	name	option	const	const2	fp	outcome														
plant	hru	0	plant_agrl	wpas	0	1	null	y	n	n	n	n	n	n	n	n	n	n	n	n	n	n
fertilize	hru	0	fert1	28_10_10	250	1	broadcast	n	y	y	n	n	n	n	n	n	n	n	n	n	n	n
harvest	hru	0	cut_harv1	wpas	0	1	hay_cut_high	n	n	n	y	y	n	n	n	n	n	n	n	n	n	n
fertilize	hru	0	fert2	28_10_10	250	1	broadcast	n	n	n	n	n	y	y	n	n	n	n	n	n	n	n
harvest	hru	0	cut_harv2	wpas	0	1	hay_cut_high	n	n	n	n	n	n	n	y	y	n	n	n	n	n	n
fertilize	hru	0	fert3	28_10_10	250	1	broadcast	n	n	n	n	n	n	n	y	y	n	n	n	n	n	n
harvest	hru	0	cut_harv3	wpas	0	1	hay_cut_high	n	n	n	n	n	n	n	n	n	y	y	n	n	n	n
fertilize	hru	0	fert4	28_10_10	250	1	broadcast	n	n	n	n	n	n	n	n	n	n	n	y	y	n	n
harvest_kill	hru	0	cut_harv4	wpas	0	1	hay_cut_high	n	n	n	n	n	n	n	n	n	n	n	n	n	y	y
rot_reset	hru	0	reset_1	null	1	0	null	n	n	n	n	n	n	n	n	n	n	n	n	n	n	y

Conditions | Alternatives | Outcomes | Actions

Results

Management table for one rotation

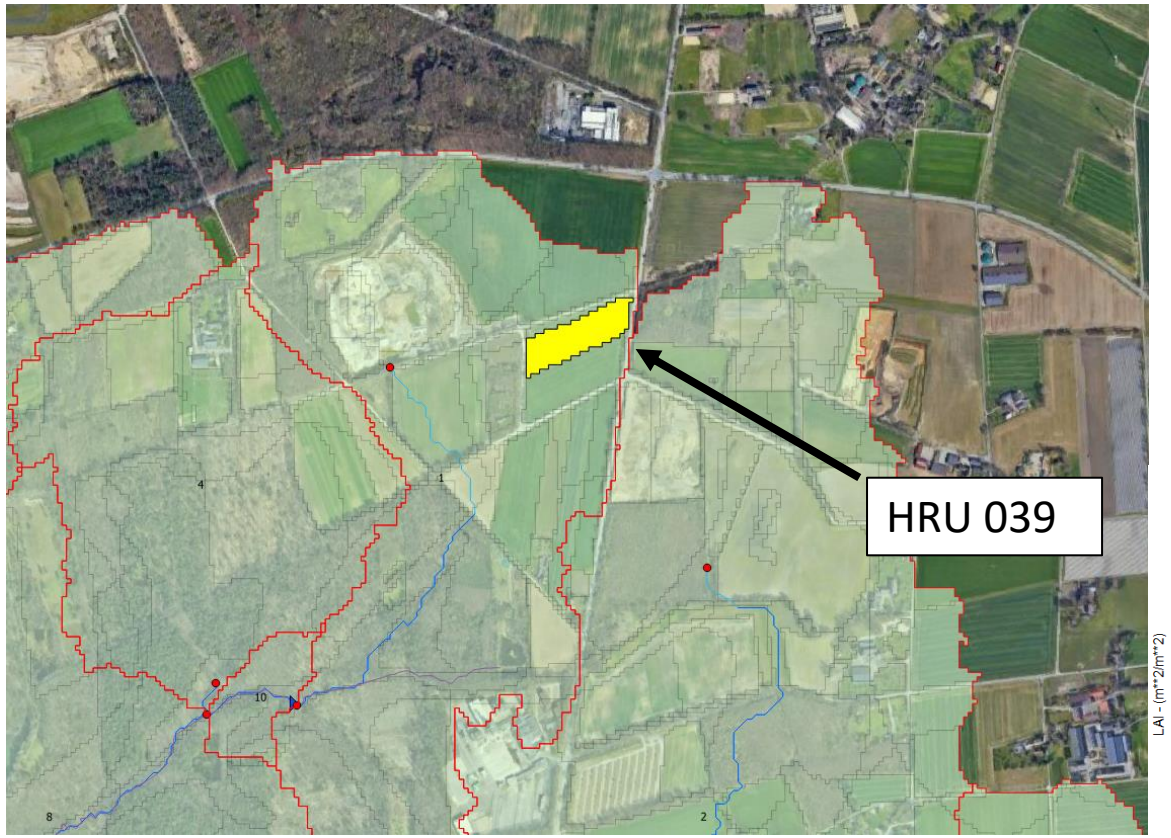
management.sch - Editor

Datei Bearbeiten Format Ansicht Hilfe

```
8477_rot                        0        18
                                          pl_hv_wwht_yr1
                                          pl_hv_barl_yr2
                                          pl_hv_barl_yr3
                                          pl_hv_rape_yr4
                                          pl_hv_swht_yr5
                                          pl_hv_csil_yr6
                                          pl_hv_wwht_yr7
                                          pl_hv_rape_yr8
                                          pl_hv_agrl_yr9
                                         pl_hv_agrl_yr10
                                         pl_hv_agrl_yr11
                                         pl_hv_wwht_yr12
                                         pl_hv_wwht_yr13
                                         pl_hv_csil_yr14
                                         pl_hv_wwht_yr15
                                         pl_hv_rape_yr16
                                         pl_hv_rape_yr17
                                         pl_hv_rape_yr18
```

- for simulation periods >18 years the rotations are repeated accordingly

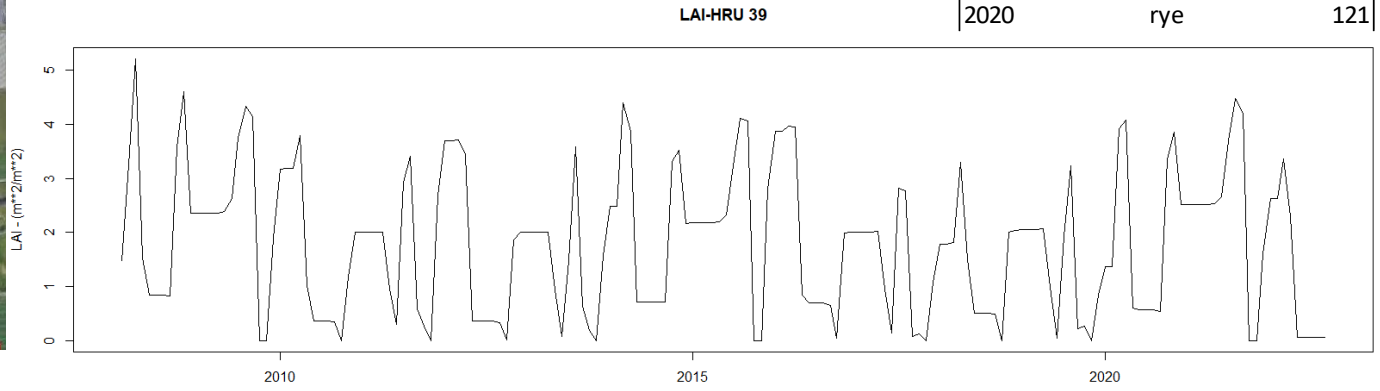
Example of one HRU-based time series: Leaf Area Index (LAI)



- LAI = green leaf area / ground area [m^2/m^2]
- crop code from InVeKoS + fodder grass as cover crop

→ time – dependent management: simulated LAI and input of nutrients

HRU 39		
year	crop	code
2008	csil	411
2009	rye	121
2010	wbar	131
2011	rye	121
2012	csil	411
2013	rye	121
2014	csil	411
2015	rye	121
2016	wbar	131
2017	rye	121
2018	csil	411
2019	csil	411
2020	rye	121



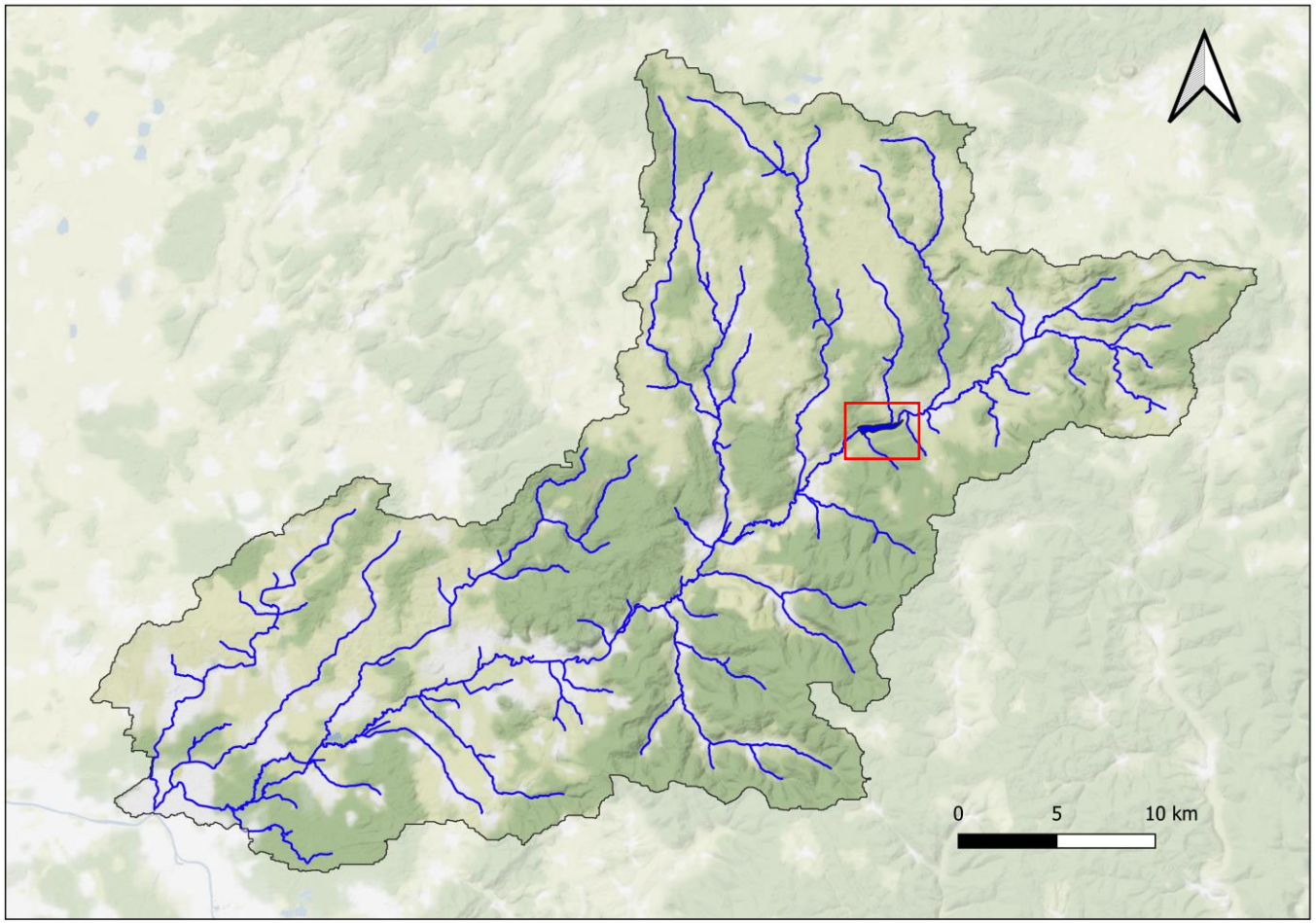
Summary: We only need...

1. **Data:** InVeKoS, Corine (or other non-agricultural land use), Soil
2. Lookup table SWAT-Code / Land use code
3. Management rules
4. Modification of 4 files (scripted):
   - landuse.lum
   - management.sch
   - plant.ini
   - hru-data.hru

Part 2

Kinzig reservoir managed with decision tables

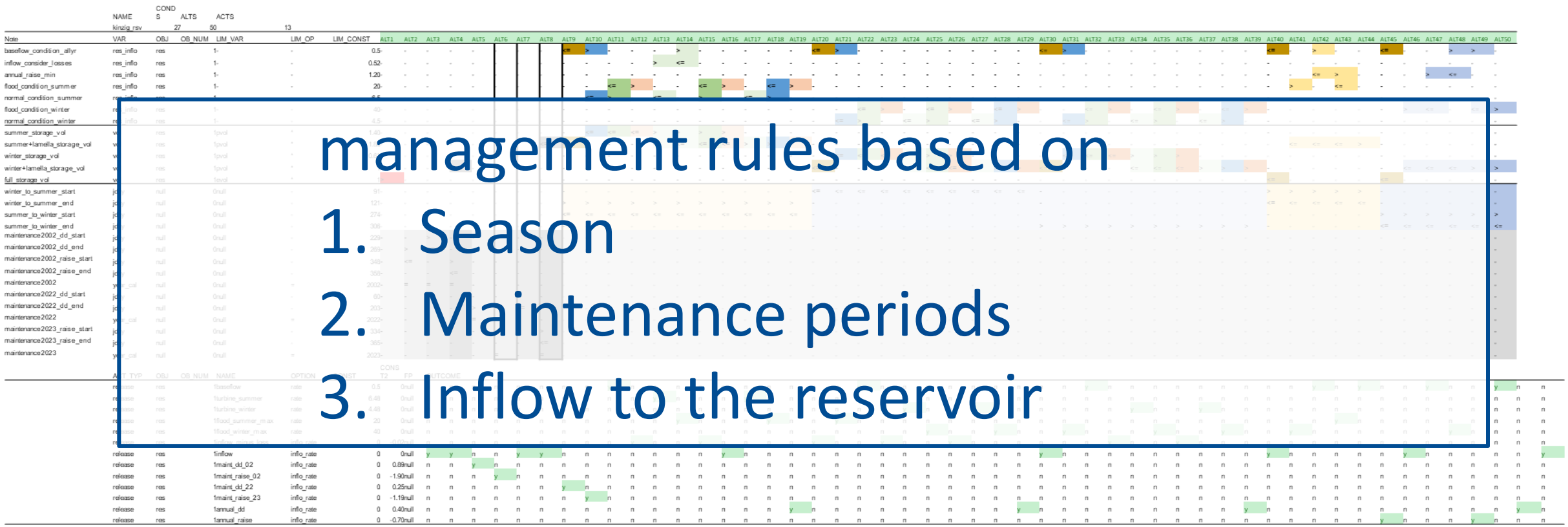
Kinzig Reservoir



Multi-purpose reservoir:

- raising low-flows
- flood protection
- energy production

Highly complex decision table



management rules based on

1. Season
2. Maintenance periods
3. Inflow to the reservoir

Necessary changes in the source code (conditions.f90)

1. changed ob_num to get the correct channel number and not the reservoir number

```
        !channel flow
        case ("channel_flo")
+         ob_num = d_tbl%cond(ic)%ob_num
+         !ob_num = ob_cur   !the dtbl ob_n
          if (ob_num == 0) ob_num = ob_cur
```

2. added condition "res_inflo" to conditions of decision tables. Reservoir inflow can be used to decide on outflow.

```
+       !reservoir inflow: JK added 28/02/2023
+       case ("res_inflo")
+         !determine target variable
+         ob_num = d_tbl%cond(ic)%ob_num   !kp: before ob_num = ob_cur
+         if (ob_num == 0) ob_num = ob_cur
+         iob = sp_ob1%res + ob_num - 1
+         flo_m3 = ob(iob)%hin%flo / 86400.
+         call cond_real (ic, flo_m3, d_tbl%cond(ic)%lim_const, idtbl)
+
```

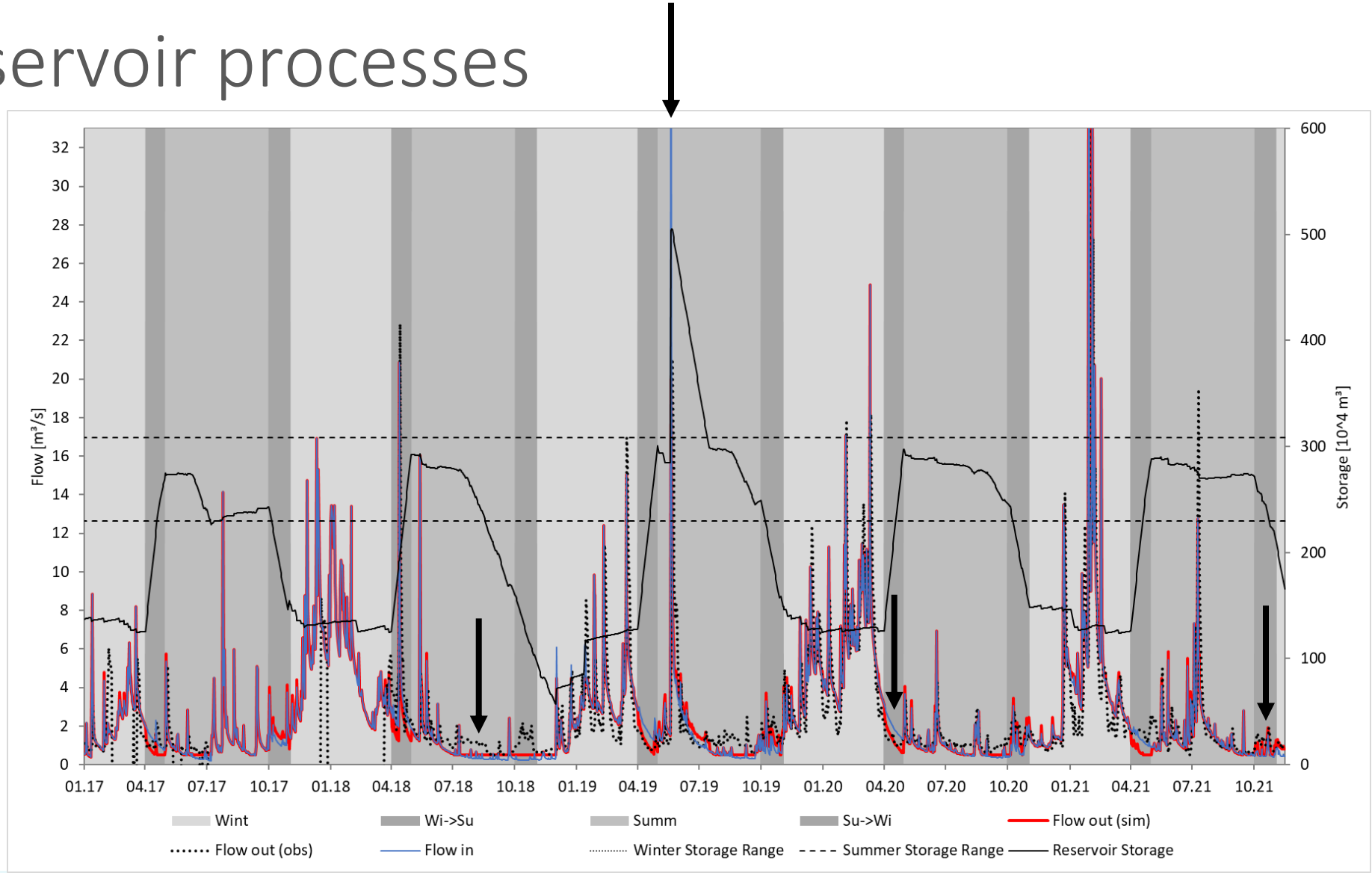
3. added functionality to use const2 in res_rel.dtl action for "inflo_rate" to reduce or increase the outflow

```
        case ("inflo_rate")
+         !ht2%flo = amax1 (ht1%flo, dtbl_res(id)%act(iac)%const * 86400.)
+         !!JK: added functionality to use const2 to reduce/increase inflow variable
+         ht2%flo = amax1 (ht1%flo + dtbl_res(id)%act(iac)%const2 * 86400., dtbl_res(id)%act(iac)%const * 86400.)
```

Results

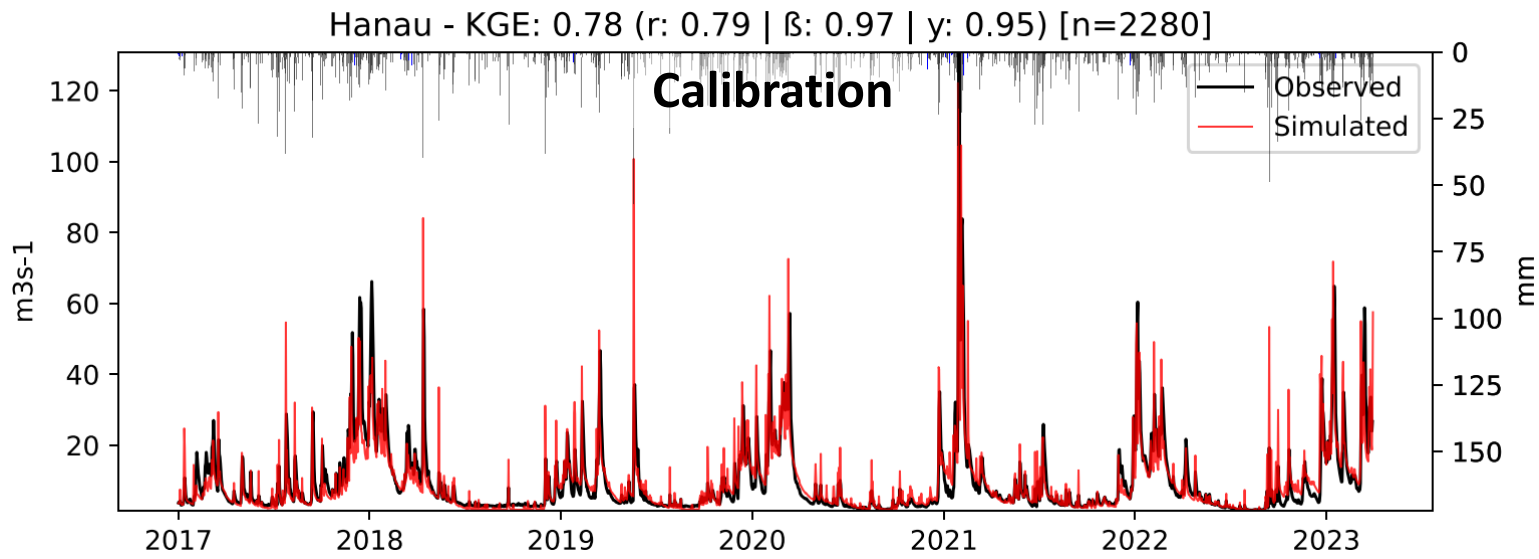
Multi-year reservoir processes

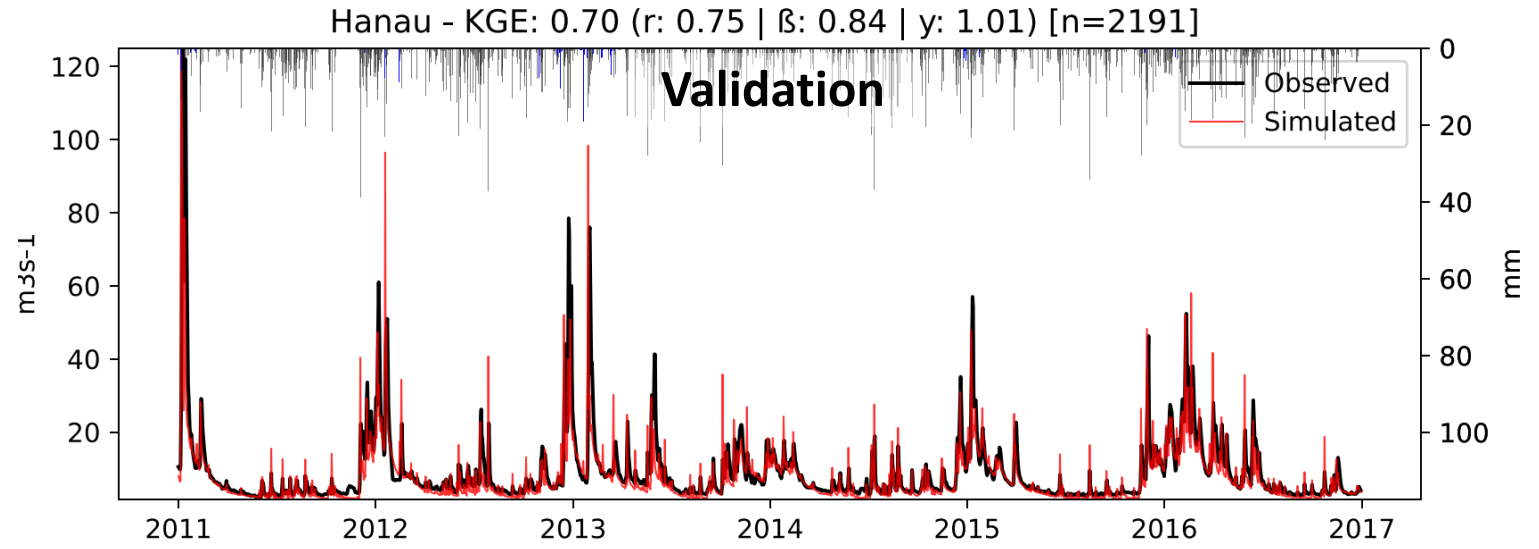
- Reservoir operation close to the natural flow regime
- Improvements to peak discharges and some low flow periods (black arrows)



Calibration and Validation

- Manual calibration necessary due to long run time
  - 9s per day with land management
  - 3s per day without land management
- Good calibration and validation results (average KGE at eight gauges):
  - 0.70 calibration
  - 0.79 validation
- Main calibration issues:
  - SWAT+ has a tendency to respond too fast (1-2 days)
  - Baseflow too low despite introducing fast, slow and deep aquifers





Performance statistics: Incorporating complex catchment management

- Slight performance improvements during validation
- Reservoir implementation always leads to improvements
- Management implementation mostly leads to improvements (not for Ahl during calibration)

	Gauge	Management	KGE
Calibration	Ahl (reservoir)	Res + Mgt	0.63
		No Res + Mgt	0.63
		Res + No Mgt	0.66
	Hanau (outlet)	Res + Mgt	0.78
		No Res + Mgt	0.78
		Res + No Mgt	0.78
Validation	Ahl (reservoir)	Res + Mgt	0.76
		No Res + Mgt	0.75
		Res + No Mgt	0.73
	Hanau (outlet)	Res + Mgt	0.70
		No Res + Mgt	0.70
		Res + No Mgt	0.69

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German Research Foundation

Thank you for your attention

(c) Carsten Pauls

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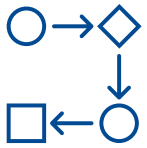
Approach in SWAT+

- landuse.lum file is populated automatically, if the plant name can be found in the plants.plt database
- not possible to load a crop rotation as a plant name

Crop rotations for every field in HRU-definition:

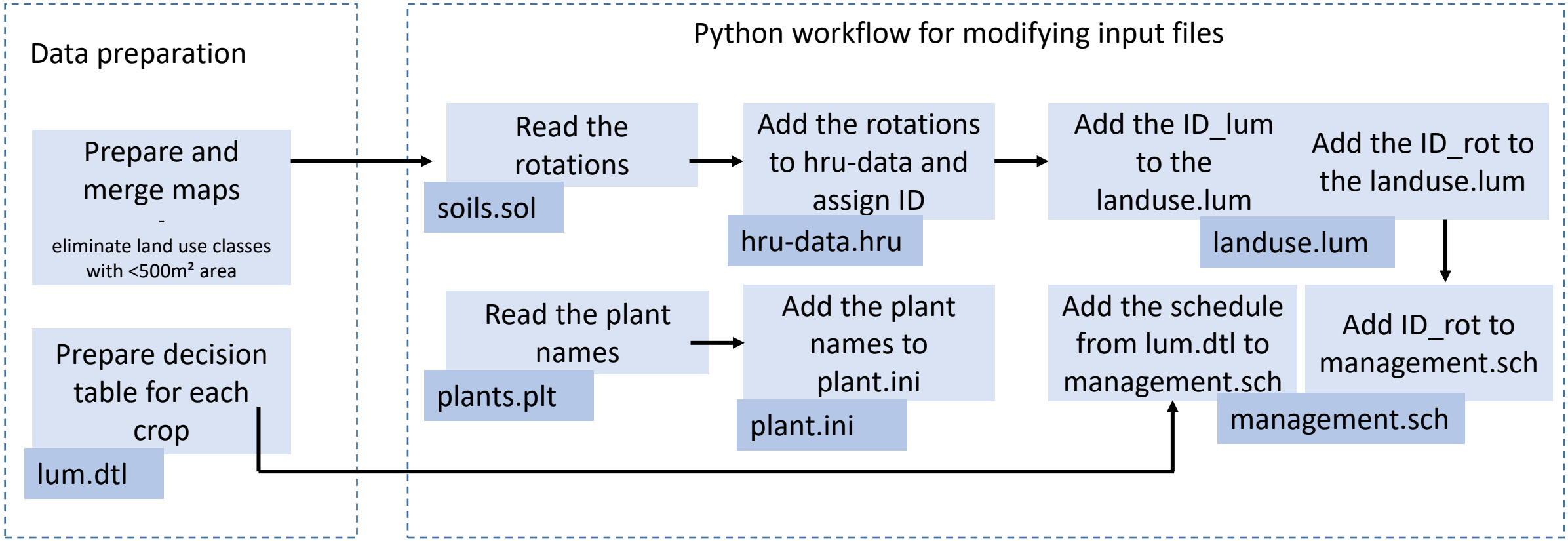
- land use map: CORINE (URBN, WATR, FRST, ... AGRL)
- soil map: InVeKoS, rotation – code – strings as soil names

→ **68551 fields - 25848 rotations**
Combined with soil: 51928 HRUs



Workflow

Implementation of crop rotation for each HRU in SWAT+



Decision Tables

name	conds	alts	acts								
pl_hv_wbar_yr1		5	3	2							
var	obj	obj_num	lim_var	lim_op	lim_const		alt1	alt2	alt3		
year_rot		hru	0	null	-	1	=	=	=		
jday	null	0	null	-	121	=	-	-			
jday	null	0	null	-	250	-	>	-			
jday	null	0	null	-	266	-	<	-			
jday	null	0	null	-	265	-	-	=			
act_typ	obj	obj_num	name	option	const	const2	fp	outcome			
plant	hru	0	plant_wbar		wbar	0	1	null	y	n	n
harvest_kill	hru	0	grain_harv		wbar	0	1	grain	n	y	y

name	conds	alts	acts								
pl_hv_wbar_yr2		5	3	2							
var	obj	obj_num	lim_var	lim_op	lim_const		alt1	alt2	alt3		
year_rot		hru	0	null	-	2	=	=	=		
jday	null	0	null	-	121	=	-	-			
jday	null	0	null	-	250	-	>	-			
jday	null	0	null	-	266	-	<	-			
jday	null	0	null	-	265	-	-	=			
act_typ	obj	obj_num	name	option	const	const2	fp	outcome			
plant	hru	0	plant_wbar		wbar	0	1	null	y	n	n
harvest_kill	hru	0	grain_harv		wbar	0	1	grain	n	y	y

- general schedules like pl_hv_agrl always reset the rotation year

BUT:

- setting all operations in the management schedule for each year is too complicated

SO:

- one DTL needed for each crop and each year

Too fast response seems to be due to routing?

- Upstream gauge 0-1 day shift with best performance
- Central gauge 1-2 days shift best performance
- Downstream gauge 2 days shift best performance

Calibration period (2017-2023)				Validation period (2011-2016)			
RunDesc	Gauge	KGE	r	RunDesc	Gauge	KGE	r
0 dShift	Steinau	0.65	0.746	0 dShift	Steinau	0.73	0.781
1 dShift	Steinau	0.74	0.875	1 dShift	Steinau	0.82	0.892
2 dShift	Steinau	0.52	0.585	2 dShift	Steinau	0.64	0.671
0 dShift	Gelnhausen	0.70	0.712	0 dShift	Gelnhausen	0.65	0.696
1 dShift	Gelnhausen	0.86	0.886	1 dShift	Gelnhausen	0.78	0.869
2 dShift	Gelnhausen	0.84	0.863	2 dShift	Gelnhausen	0.79	0.879
0 dShift	Hanau	0.66	0.666	0 dShift	Hanau	0.58	0.619
1 dShift	Hanau	0.78	0.787	1 dShift	Hanau	0.70	0.747
2 dShift	Hanau	0.85	0.869	2 dShift	Hanau	0.78	0.851