Supplementary Tables

Table S1 Features of the main rivers in the study area

River	*Basin* (km²)	*Altitude* (m)	*Baseflow* (m³/s)
Enza	430	231	0.90
Parma	111	529	0.38
Crostolo	86	126	0.19
Rio Zolle	5	200	0.01
Masdone	12	200	0.01
Termina	65	200	0.10

Table S2 Hydrogeological parameters obtained from pumping tests in the main well field.

Well field	*T* (m²/s)	*Thickness* (m)	*K* (m/s)	*Aquifer Group*
Bellarosa	3.56E-02	129	2.76E-04	A
S.Ilario	1.70E-02	108	1.57E-04	A
Caprara	2.27E-02	180	1.26E-04	A
Roncocesi	1.91E-02	195	9.81E-05	A
Caneparini	1.00E-02	107	9.35E-05	A
Case Corti	2.20E-02	104	2.12E-04	A
Quercioli (1)	9.00E-03	111	8.14E-05	A
Quercioli (2)	1.00E-04	50	2.00E-06	B
Mangalana	3.90E-03	21	1.86E-04	B
Aiola	6.62E-03	56	1.18E-04	B
Malamassata	5.10E-03	53	9.62E-05	B

Table S3 Irrigation withdrawals (Mm^3/y) in Reggio Emilia Province, from 2002 to 2012

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
RE	21.5	57	27.1	51.4	35.9	34.2	23.7	31.3	18.9	36

Table S4 Withdrawals (Mm^3/y) for different uses from Enza alluvial fan, in 2010

ID	Groundwater body	Civil	Industrial	Irrigation	Zootechnical
IT080090ER-DQ1-CL	Enza phreatic aq.	2.6	1.2	8.6	0.5
IT080370ER-DQ2-CCS	Enza upper confined aq.	8.7	0.4	3.4	0.4
IT082370ER-DQ2-CCI	Enza lower confined aq.	16.7	0.3	4.8	0.1

Table S5 Projections to 2100 of climate indicators for Reggio Emilia (RCP4.5 scenario)

Indicators	RCP4.5
Average annual Tmax	+ 0.2°C/decade
Average annual Tmin	+ 0.2°C/decade
Extreme Tmax	Tmax >30°C (34 more days) Tmax >35°C (32 more days) Tmax >40°C (11 more days)
Extreme Tmin (>20°C)	40 more days
Annual rainfall	-7.9 mm/decade

Table S6 Vertical discretization of the model

Layer	Group	Top layer	Bottom layer
1	A0 + A1	Digital Elevation Model (DEM)	DEM – (Thickness Group A)/2
2	A2	Bottom layer 1	Bottom layer 1 - (Thickness Group A)/4
3	A3 + A4	Bottom layer 2	Bottom layer 2 - (Thickness Group A)/4
4	B	Bottom layer 3	Bottom Group B

Table S7 Summary of stress packages and parameters in groundwater model

Forcers – Stress package	Parameters
Rivers – STREAM (STR)	Conductance (m^2/s), Hydraulic head (m), Baseflow (m^3/s)
"Fontanili" (springs) – DRAIN (DRN)	Conductance per unit length (m^2/s), Hydraulic head (m)
Recharge – RECHARGE (RCH)	Recharge rate (m/s)
Withdrawals – WELL (WEL)	Pumping rate (m^3/s) for each layer

Table S8 Features of STR package

Parameters	Values
Head Stream (m)	Digital Elevation Model (DEM)
Streambed bottom (m)	DEM – 2 m
Streambed top (m)	DEM – 1 m
Outflow segment	Branch into which more tributaries converge
Flow (m^3/s)	Enza river (branch 1) 0.4 m^3/s; Parma river (branch 8) 0.19 m^3/s; Crostolo river (branch 12) 0.10 m^3/s; Rio Zolle (branch 6), Masdone (branch 4), and Quaresimo (branch 10) 0.01 m^3/s; Termina (branch 2) 0.10 m^3/s; Modolena (branch 9) 0.05 m^3/s; Enza Canal: (branch 14) 0.4 m^3/s, (branches 15 and 16) 0 m^3/s
Conductance (m^2/s)	k_{vert} with option "calculated per unit of length or area"

Table S9 Average withdrawals (m^3/s) of the well fields in Reggio Emilia Province

Well field	Layer	Row	Column	Q_i (m^3/s)	Q_{tot} (m^3/s)
Bellarosa	1	55	65	1.15E-02	0.0230
	2	55	65	5.75E-03	
	3	55	65	5.75E-03	
Gazzaro	1	57	54	4.17E-03	0.009
	2	57	54	2.09E-03	
	3	57	54	2.09E-03	
	4	57	54	6.53E-04	
Cabina Gas	1	54	54	2.30E-04	0.0005
	2	54	54	1.15E-04	
	3	54	54	1.15E-04	
Pensile	4	52	55	6.00E-03	0.006
Caprara	1	47	70	5.00E-02	0.1
	2	47	70	2.50E-02	
	3	47	70	2.50E-02	
Roncocesi	1	61	93	1.08E-01	0.2160
	2	61	93	5.40E-02	
	3	61	93	5.40E-02	

Well field	Layer	Row	Column	Q_i (m³/s)	Q_{tot} (m³/s)
Quercioli	1	69	77	1.19E-01	0.2720
	2	69	77	5.95E-02	
	3	69	77	5.95E-02	
	4	69	77	3.42E-02	
Case Corti	1	75	88	2.97E-02	0.068
	2	75	88	1.49E-02	
	3	75	88	1.49E-02	
	4	75	88	8.55E-03	
S.Ilario nuovo	1	57	59	6.25E-02	0.125
	2	57	59	3.13E-02	
	3	57	59	3.13E-02	
Caneparini	1	76	85	1.75E-02	0.04
	2	76	85	8.74E-03	
	3	76	85	8.74E-03	
	4	76	85	5.03E-03	
Aiola	4	71	65	3.60E-02	0.036
Malamassata	4	90	61	2.00E-03	0.02
Mangalana	4	101	73	1.40E-02	0.014
Rubbianino	4	102	82	8.00E-03	0.008

Table S10 Average irrigation and industrial withdrawals Q_{irr_ind} (m^3/s) in the active area, by layer and cells

Layer	$Q_{irr\_ind,i}$ (m³/s)	Cells (n°)	$Q_{cell,i}$ (m³/s)
1	0.2	3,990	5.02E-05
2	0.2	3,990	5.02E-05
3	0.2	1,900	1.05E-04
4	0.2	2,142	9.34E-05

Table S11 Average baseflows in ST1 over the 30-year time horizon (2020-2050)

Rivers	Baseflow RCP4.5 (m³/s)
Parma	0.360
Enza	0.383
Crostolo	0.176
Termina	0.095
Masdone	0.010
Rio Zolle	0.010
Modolena	0.048
Quaresimo	0.010
Canale Enza	0.383

Table S12 Flow max amount (Ml/day) extracted from well fields

Well fields	Flow Max Amount (Ml/day)
Pump_Bellarosa	3.36
Pump_Gazzaro	1.04
Pump_CabinaGas	0.14

Well fields	Flow Max Amount (Ml/day)
Pump_Pensile	1.90
Pump_Caprara	9.57
Pump_Roncocesi	23.84
Pump_ Quercioli	31.91
Pump_Case Corti	10.76
Pump_S. Ilario Nuovo	15.13
Pump_ Caneparini	5.15
Pump_Aiola	3.75
Pump_Malamassata	1.23
Pump_Mangalana	3.40
Pump_ Rubbianino	1.81
Pump_Parma	35.22

Table S13 Water deficit (Mm^3) as a function of Surplus demand for different RV2 volumes and BAU_{RV2} and ST2 scenarios

RV2 Volume (Mm^3)	Deficit (Mm^3)							
	Surplus		Surplus + 25%		Surplus + 50%		Surplus + 100%	
	BAU_{RV2}	ST2	BAU_{RV2}	ST2	BAU_{RV2}	ST2	BAU_{RV2}	ST2
10	11.2	17.0	25.9	36.7	48.4	62.3	104.4	131.5
15	3.3	5.7	8.6	14.1	20.9	29.9	64.3	83.7
20	0	0.7	3.6	6.5	9.3	13.5	33.6	48.9
25	0	0	0	1.5	4.3	7.2	18.7	25.0
30	0	0	0	0	0	2.2	10.9	14.3
35	0	0	0	0	0	0	5.9	8.8
40	0	0	0	0	0	0	0.9	3.8
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0

Table S14 Number of days in a decade when the Enza MVF is released from the RV2 reservoir, and corresponding percentage (BAU_{RV2} and ST2)

	MVF days			
	Surplus	Surplus + 25%	Surplus + 50%	Surplus + 100%
BAU_{RV2}	1,321 (36.2%)	1,543 (42.3%)	1,686 (46.2%)	2,040 (55.9%)
ST2	1,554 (42.6%)	1,756 (48.1%)	1,948 (53.4%)	2,251 (61.7%)

Supplementary Figures

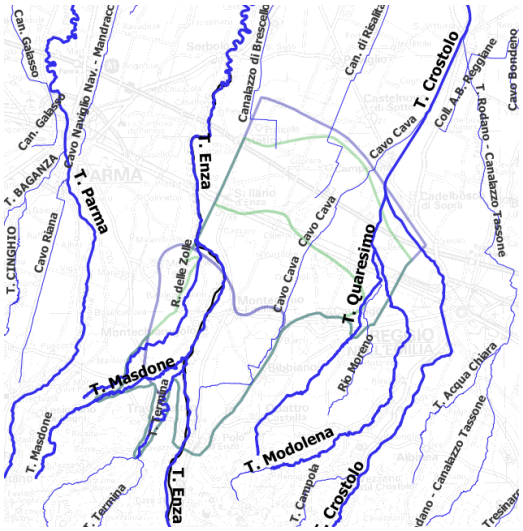
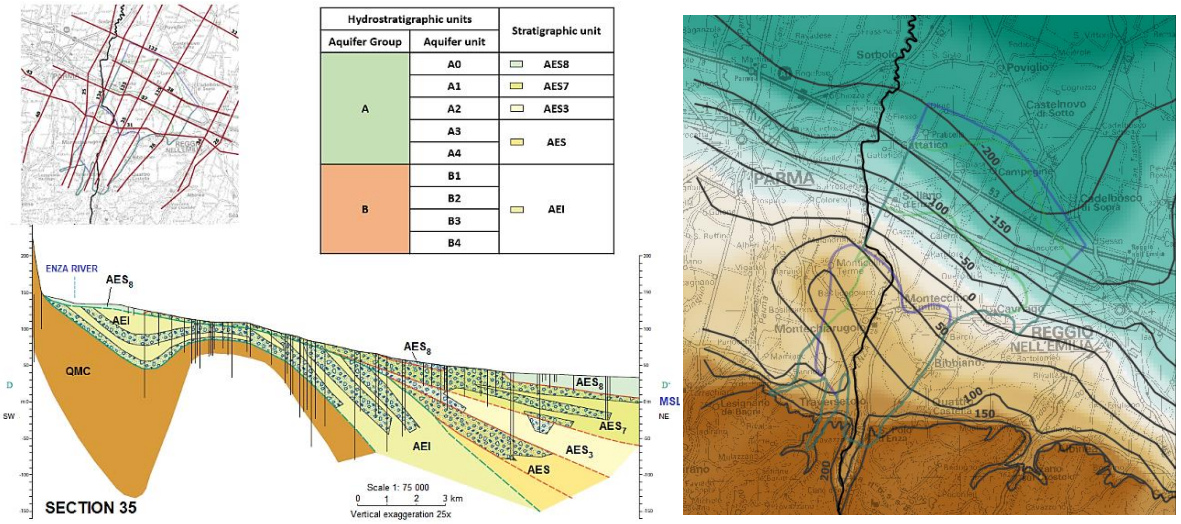


Fig. S1 Rivers in the study area



(a) (b)

Fig. S2 (a) Geological sections in the study area, with focus on Section 35 and correspondence among Aquifer Unit and Stratigraphic Unit; (b) Reconstruction of Aquifer Group A base.

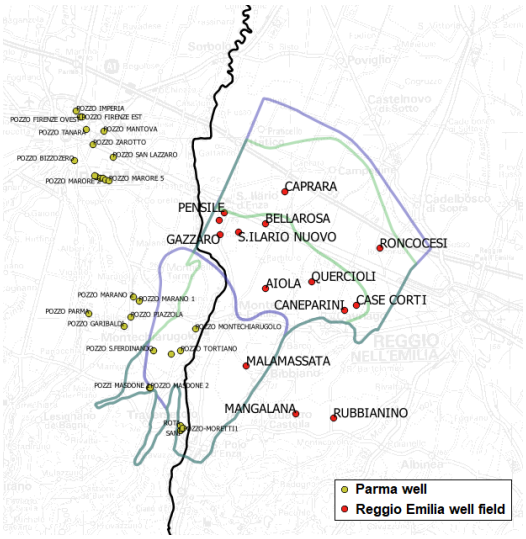
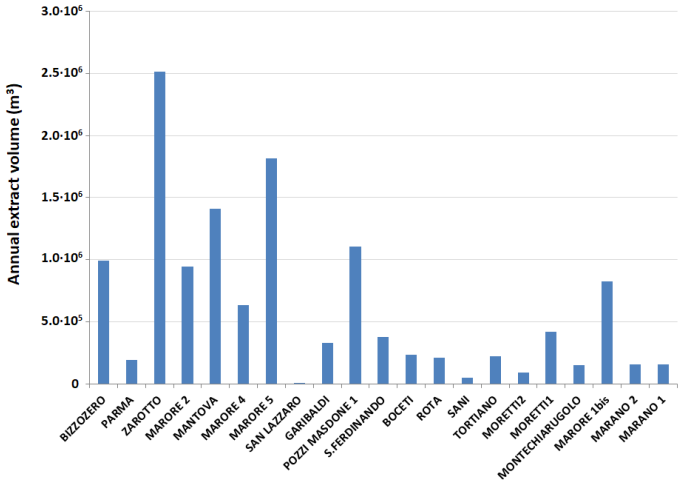


Fig. S3 Location of Reggio Emilia well fields and Parma wells



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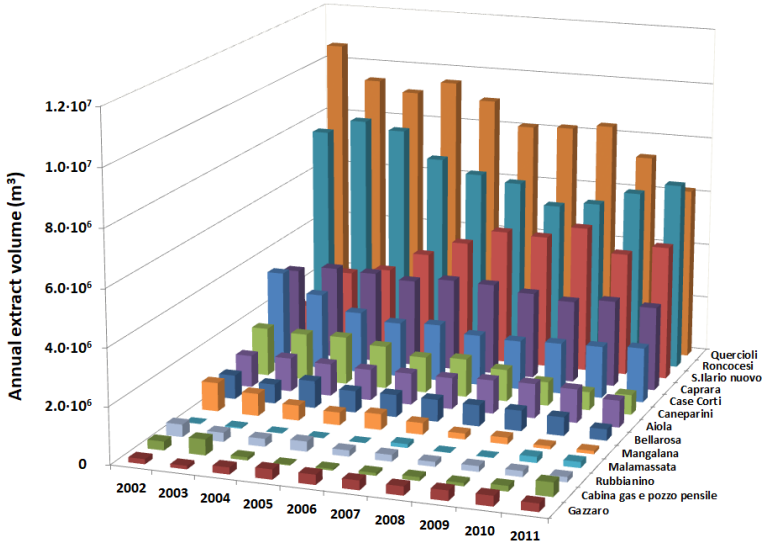
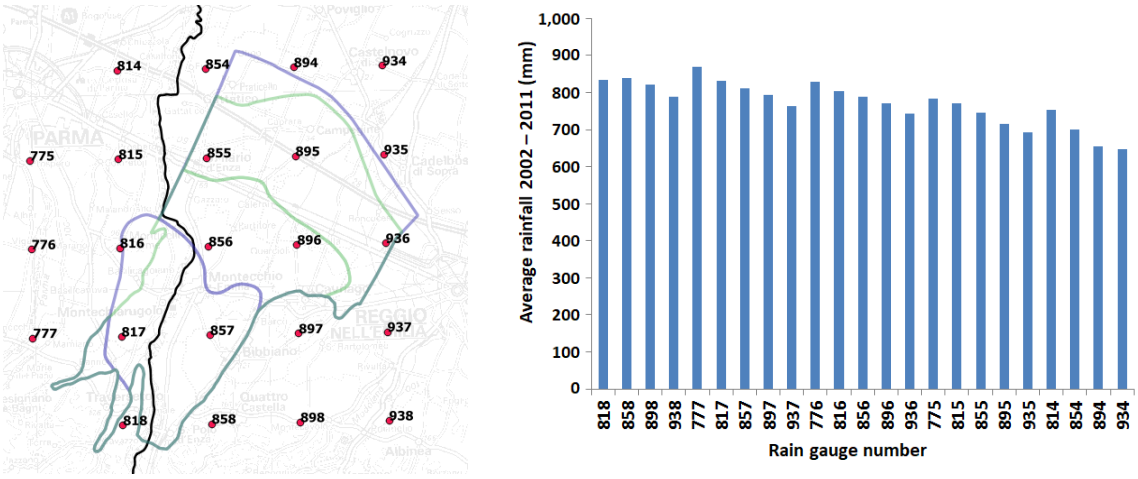


(b)

Fig. S4 (a) Annual average volume extracted from Parma wells; (b) Annual extract volume from Reggio Emilia well fields, from 2002 to 2012



(a) (b)

Fig. S5 (a) Rain gauges location in the study area; (b) Average rainfall in 2002-2012 decade at each rain gauge

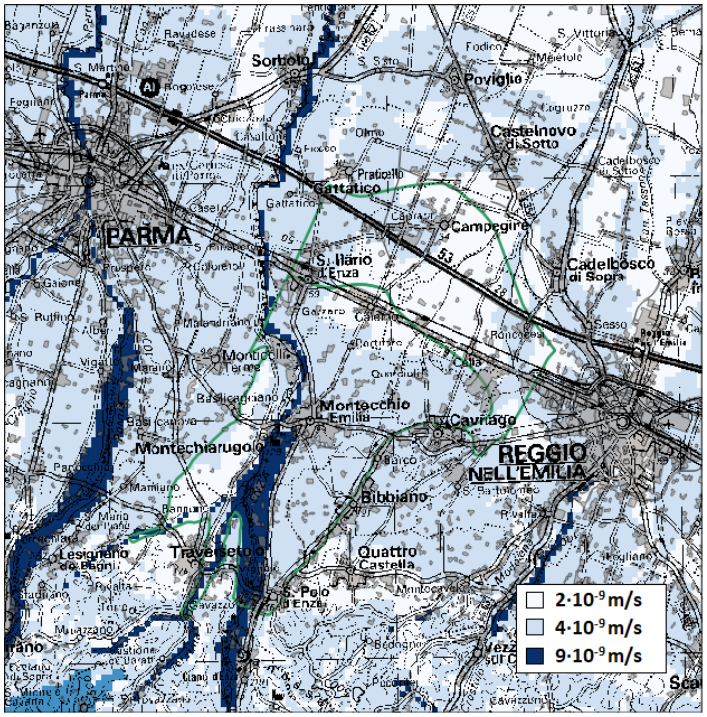
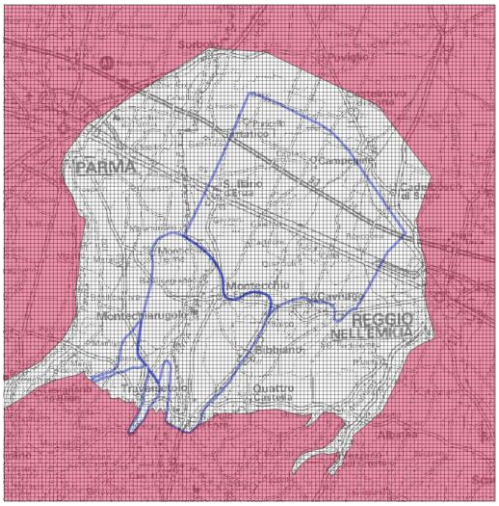


Fig. S6 Distribution of recharge rate by soil type (urban impermeable areas in grey).



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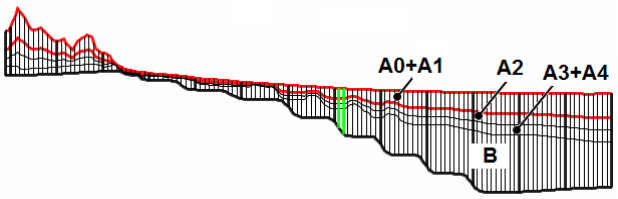

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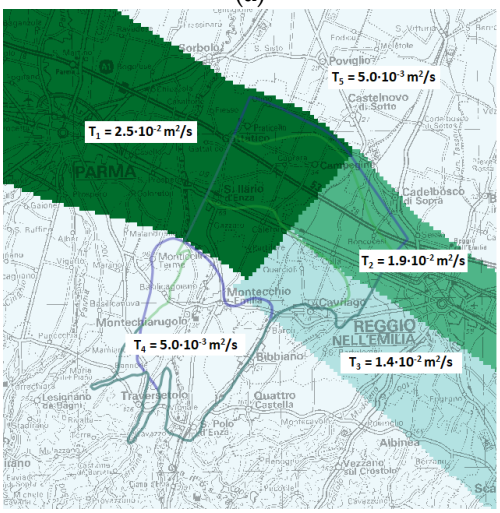

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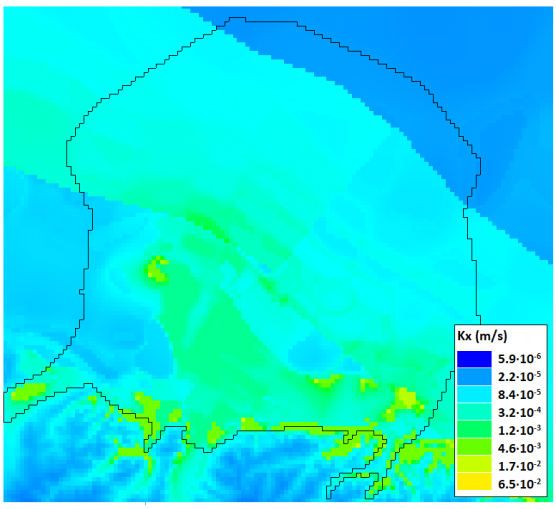
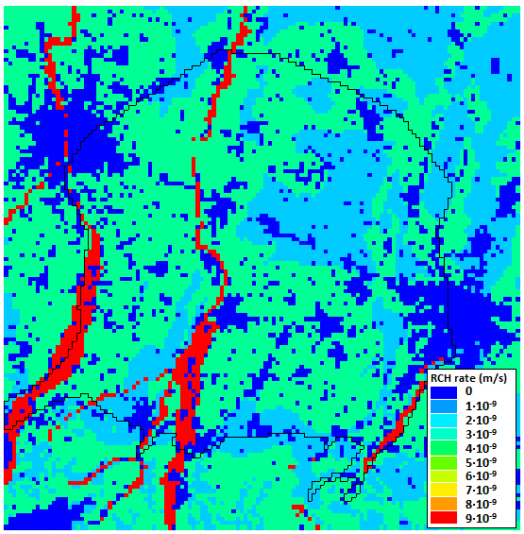


(d)

Fig. S7 (a) Active area of the model (white area); (b) Vertical schematization of the model; (c) Transmissivity distribution (m^2/s), for aquifer Group A; (d) k_{hor} distribution for the first three layers.



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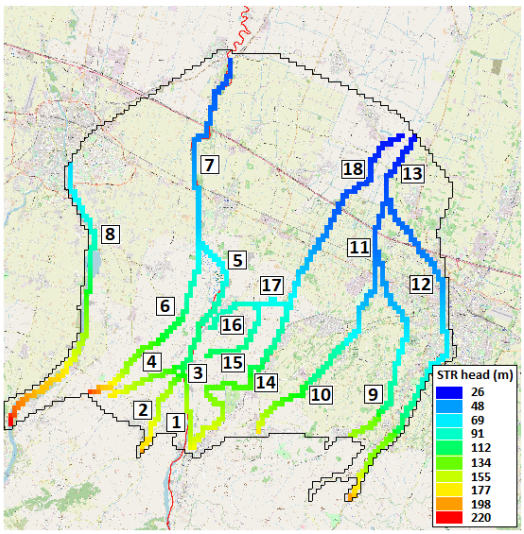

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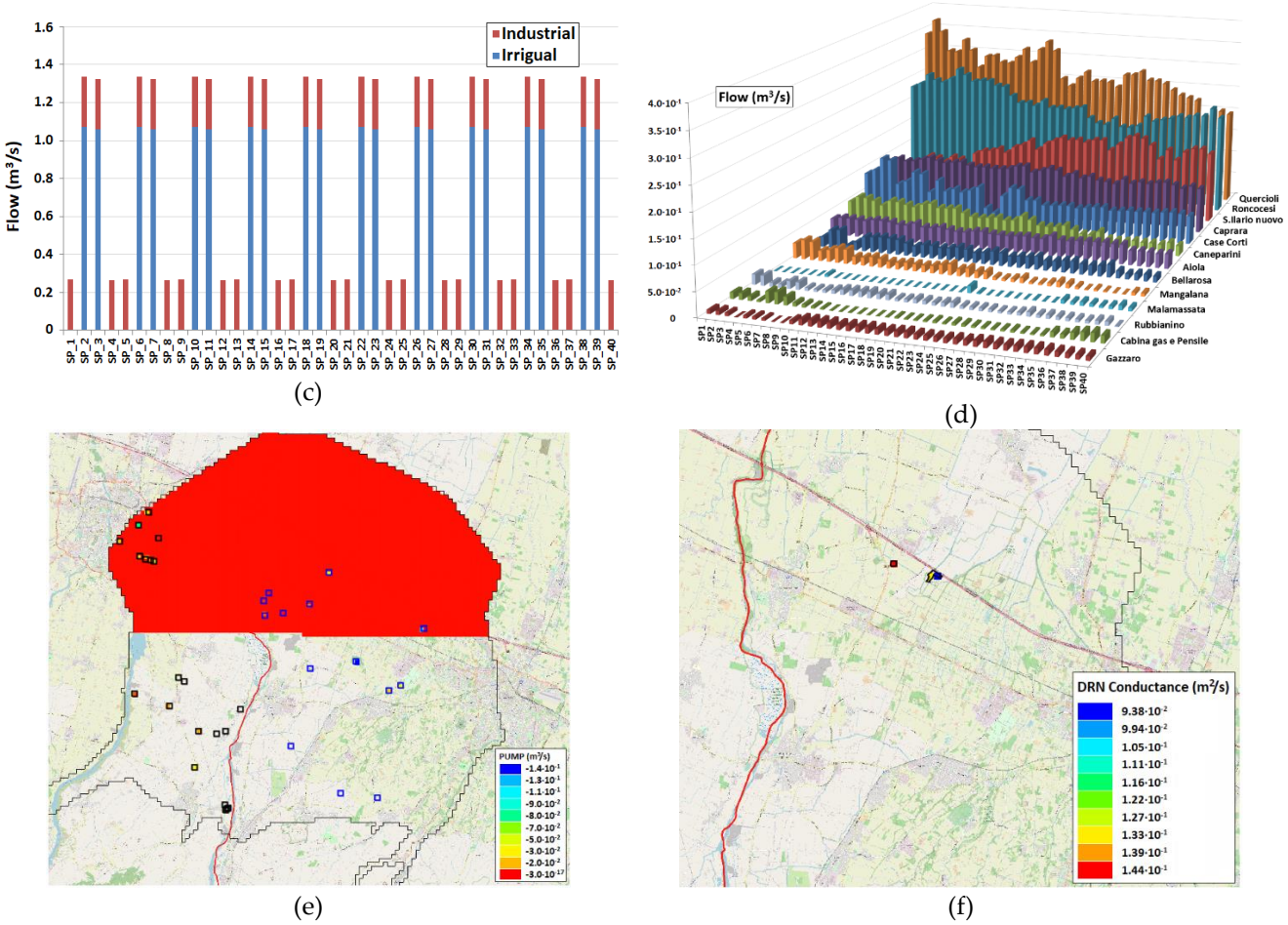
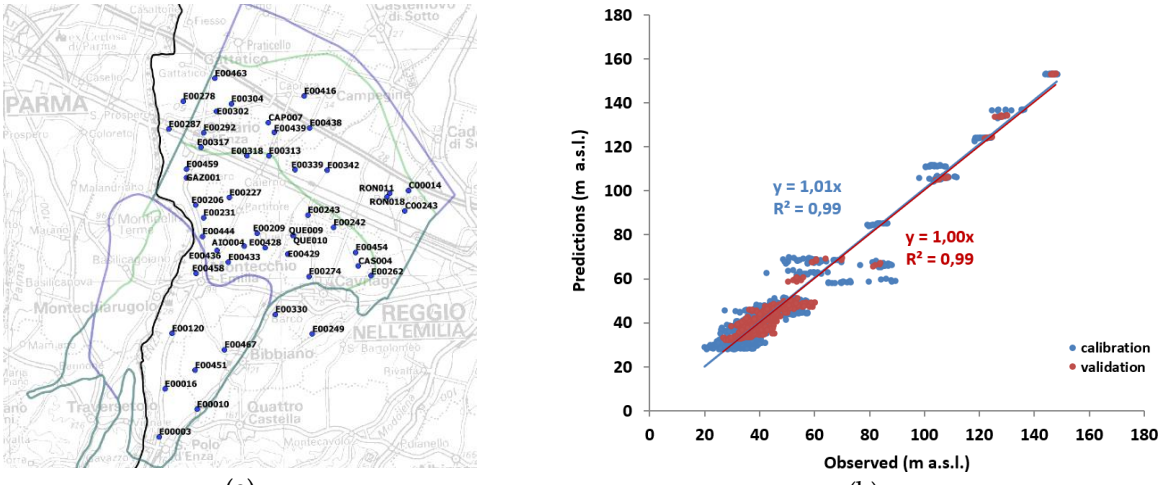


(c) (d)

(e) (f)

Fig. S8 (a) Effective recharge rate; (b) Hydrographic network, with hydraulic head and hierarchy of rivers; (c) Irrigation/industrial and (d) civil withdrawals from the well fields of Reggio Emilia Province, over the 2002-2012 period; (e) Civil (blue and black squares) and irrigation/industrial (red) withdrawals; (f) "Fontanili" inserted in the model



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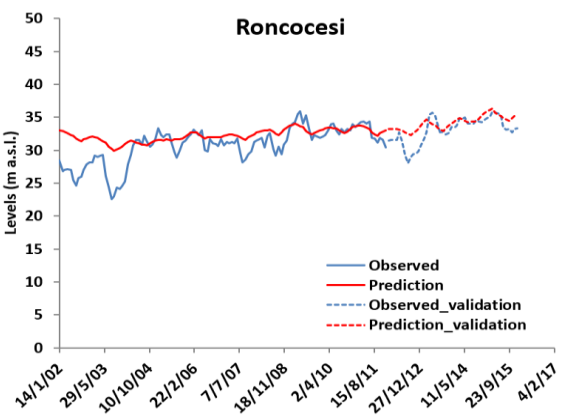

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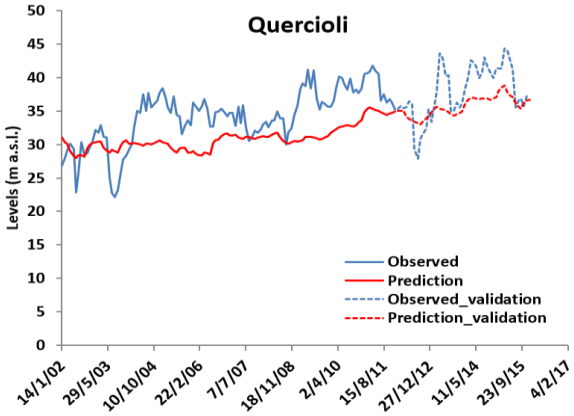


(d)

Fig. S9 (a) Location of wells (water company and private) used for calibration and validation; (b) Observed values vs. predictions; (c) - (d) Trend of observed vs. predicted levels in calibration and validation, for Roncocesi and Quercioli wells

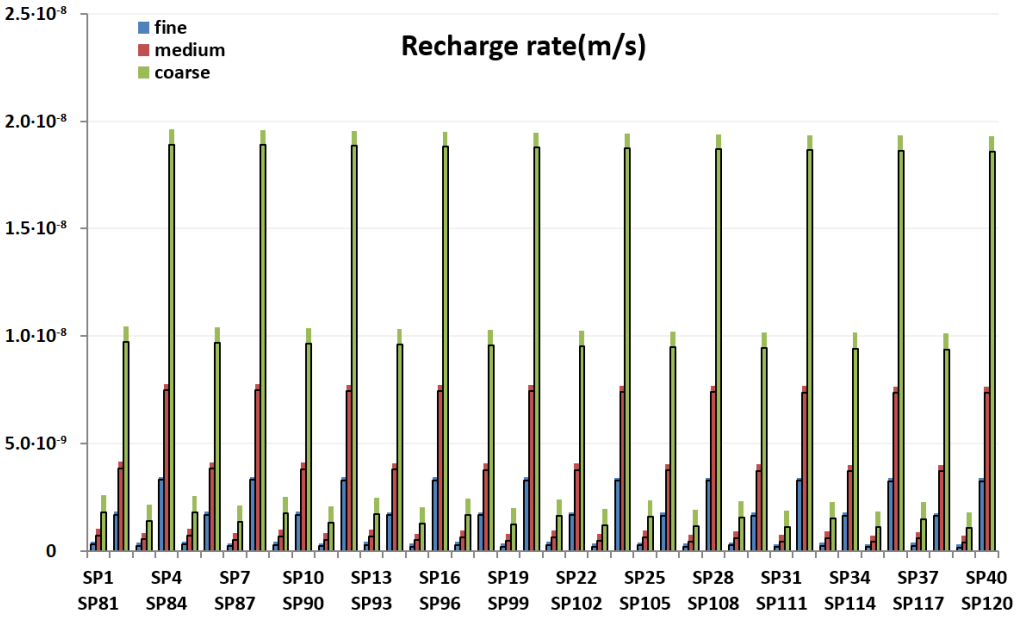


Fig. S10 Recharge rate (m/s) for different soil types, for the first (SP1 - SP40) and last (SP81 - SP120) decade of 30-year time horizon, in ST1 model. The histogram of the decade SP81 - SP120 has black borders

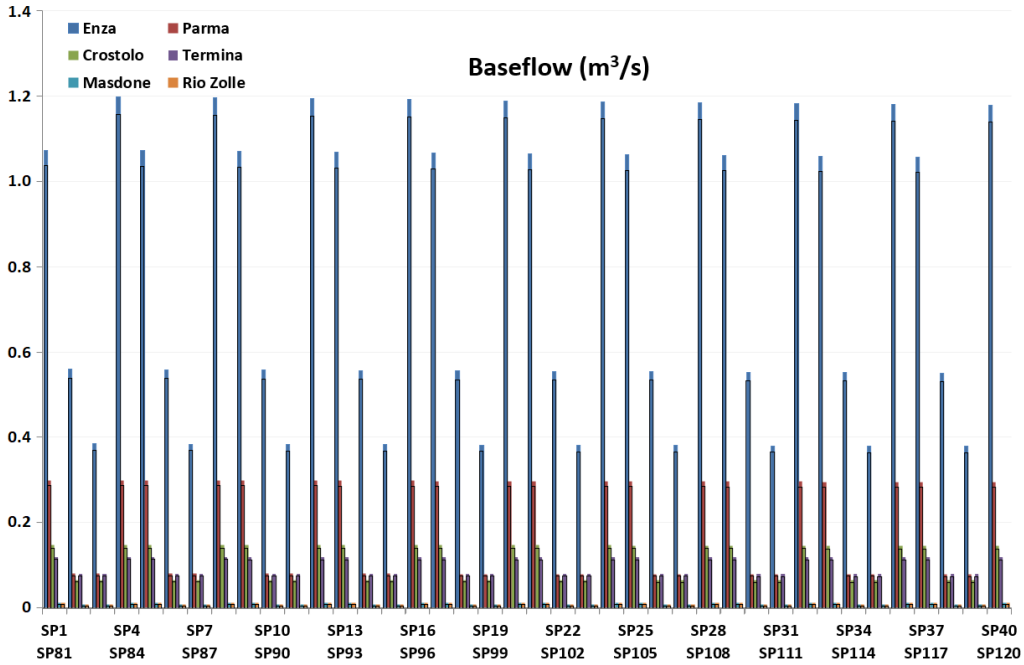
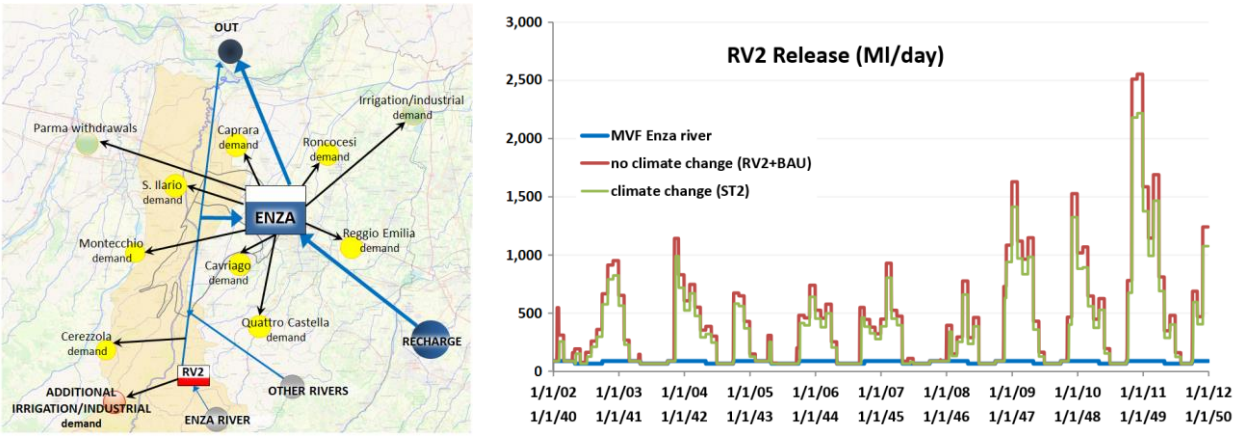


Fig. S11 Baseflow (m^3/s) of main rivers in the ST1 model, and for the first (SP1 - SP40) and last (SP81 – SP120) decade of 30-year time horizon. The histogram of the decade SP81 - SP120 has black borders



(a) (b)

Fig. S12 (a) Schematization of water supply network; (b) Release from RV2, with and without climate changes, compared with Enza's MVF.

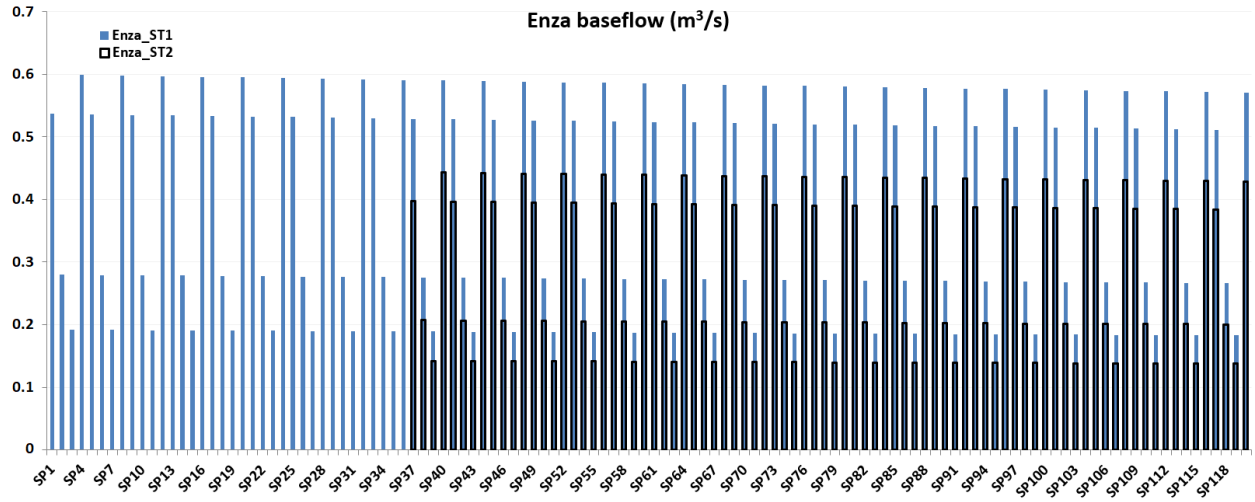


Fig. S13 Comparison between Enza baseflow in ST1 and ST2

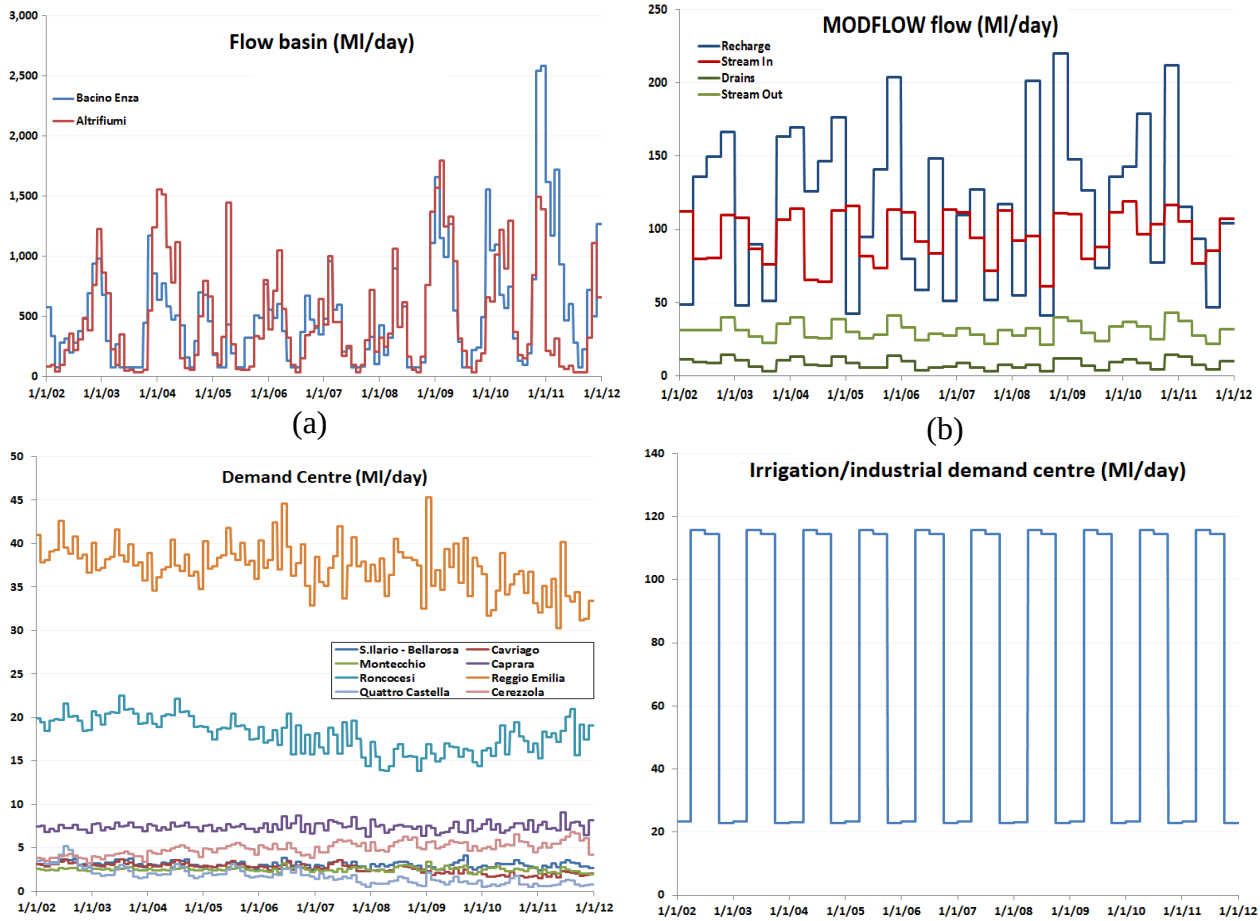


Fig. S14 (a) Surface water flows for Enza basin and Altrifiumi, in the 2002-2012 period; (b) Flow time series derived by BAU (MODFLOW); (c) Flow time series associated with the demand centers served by the well fields in of Reggio Emilia Province; (d) Time series of irrigation and industrial withdrawals.

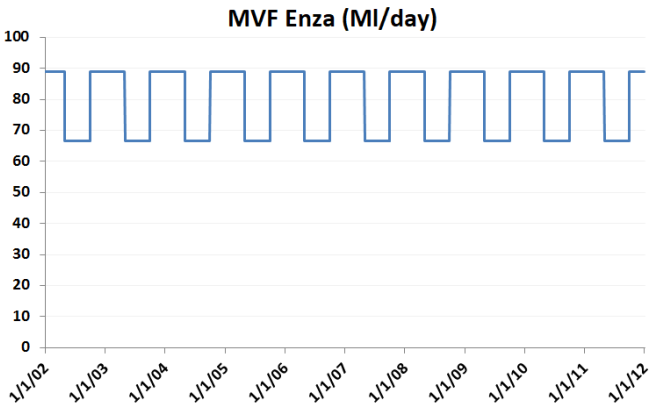
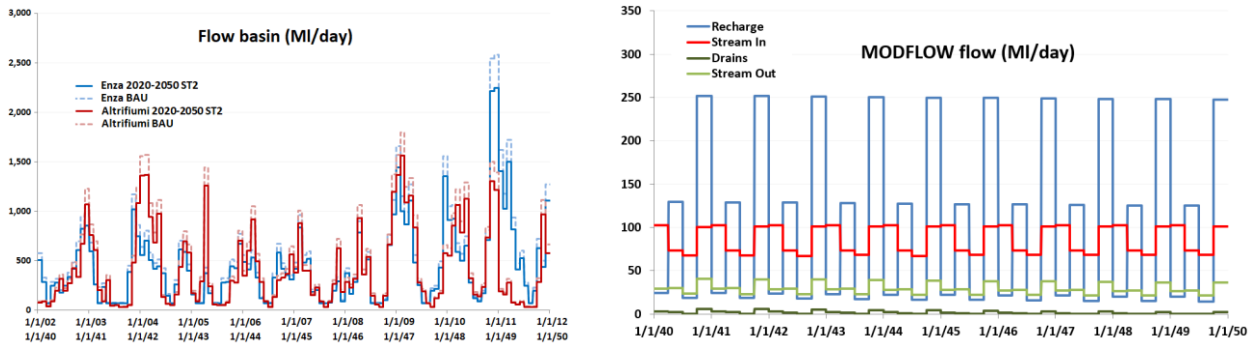
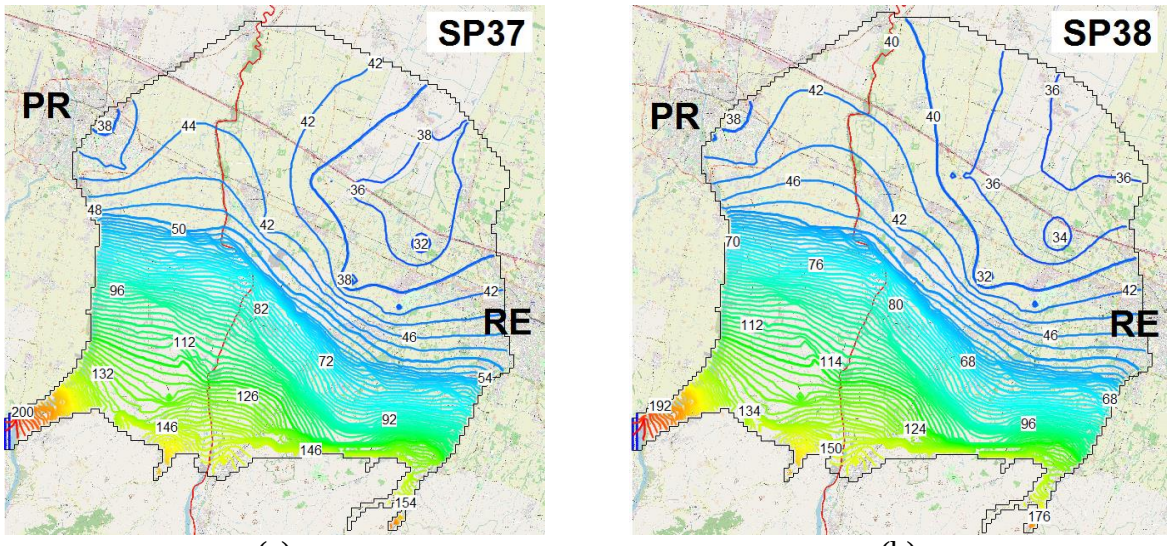


Fig. S15 Daily time series of Enza MVF

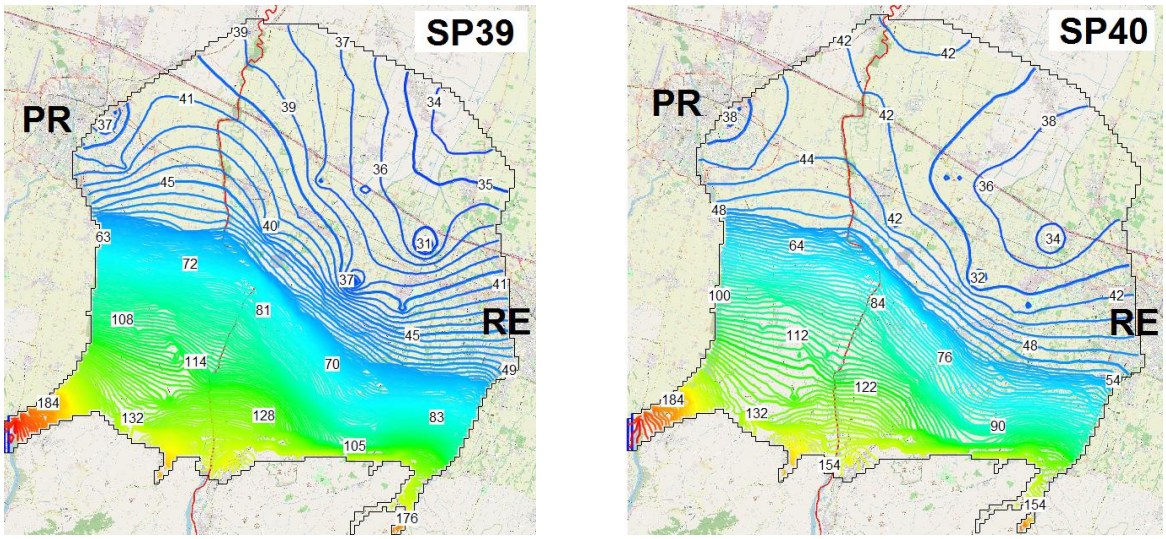


(a) (b)

Fig. S16 (a) Flow from Enza basin and Altrifiumi, for ST2 and BAU simulation; (b) Flow time series derived by ST2 (MODFLOW)

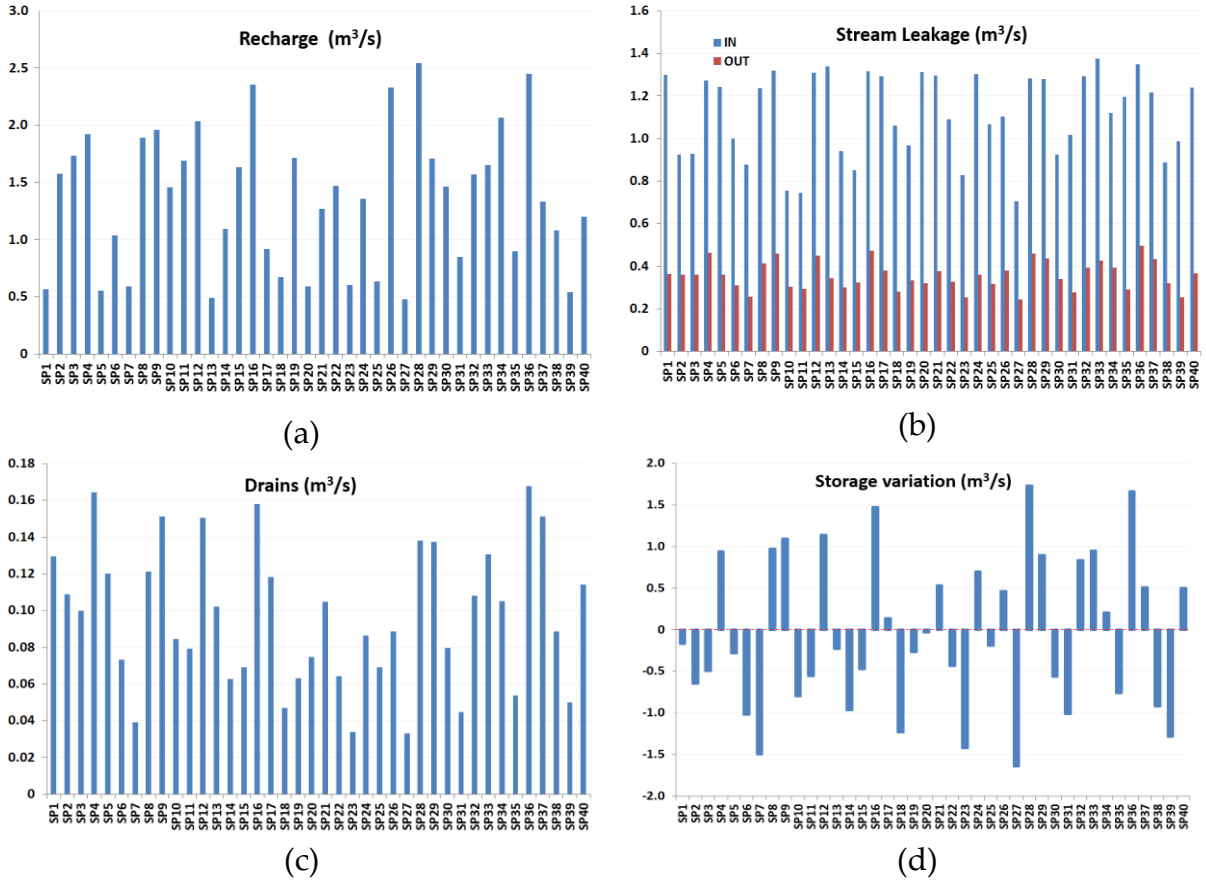


(a) (b)



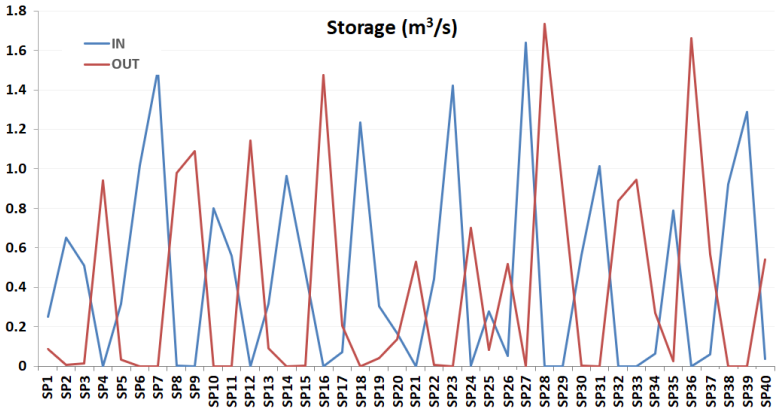
(c) (d)

Fig. S17 (a) – (d) Hydraulic head within layer 1, BAU scenario, last year of simulation (2011)



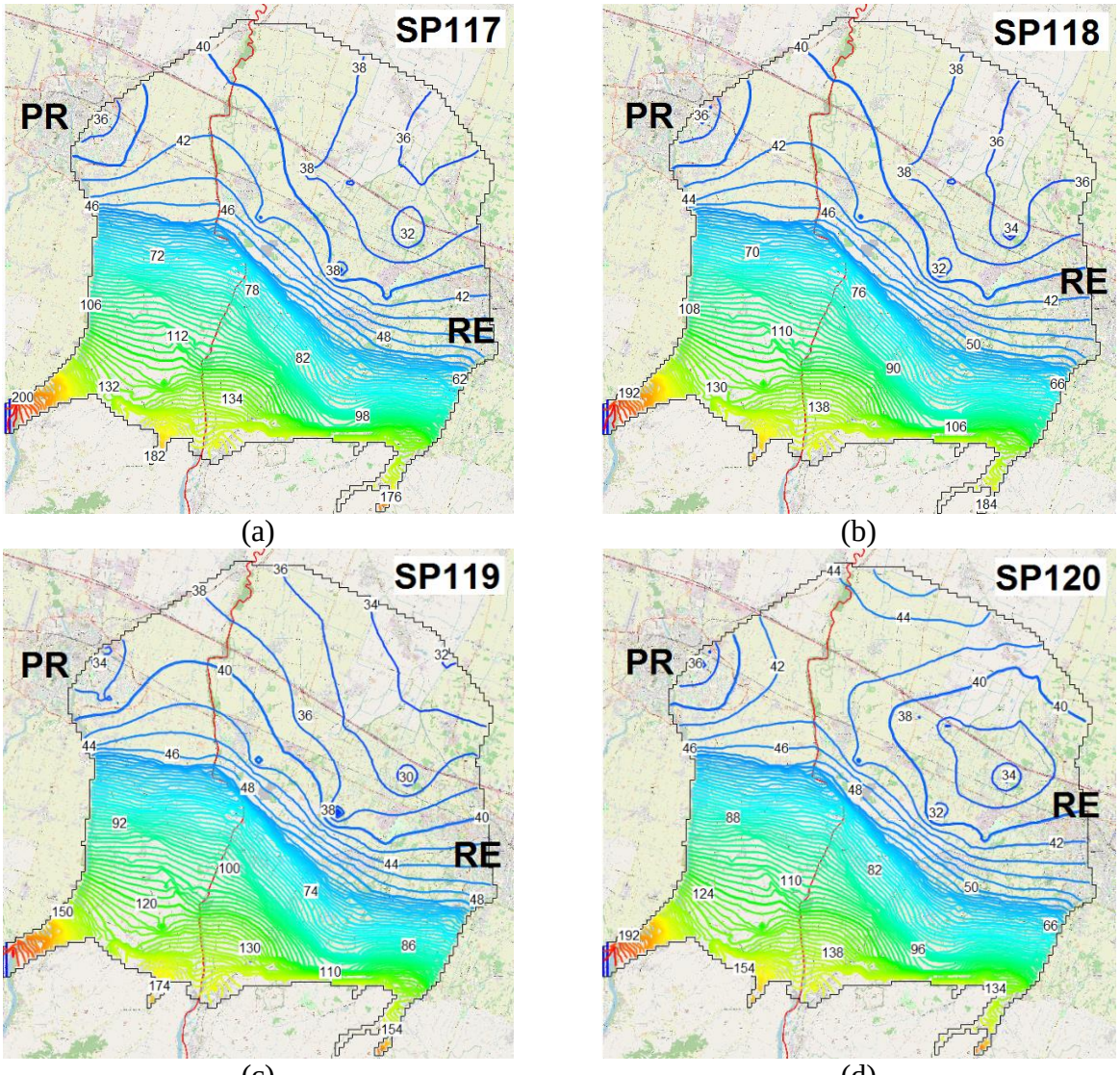
(a) (b)

(c) (d)



(e)

Fig. S18 (a) – (e) Volumetric budget, derived by BAU model: Recharge, Stream leakage In/Out, Drains, Storage variation, and Storage In/Out



(a) (b)

(c) (d)

Fig. S19 (a) – (d) Hydraulic head within layer 1, ST1 scenario, last year of simulation (2049)

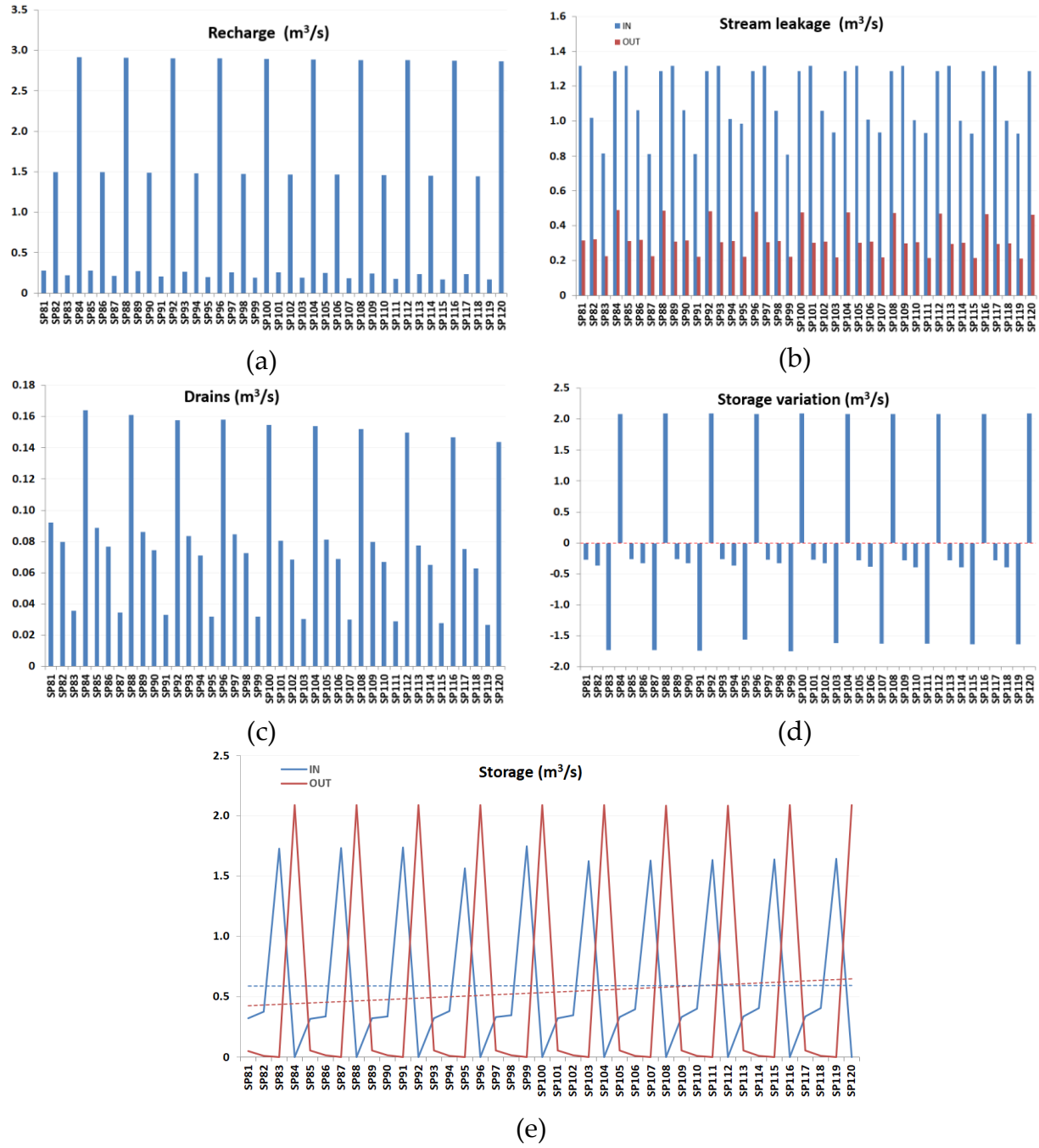
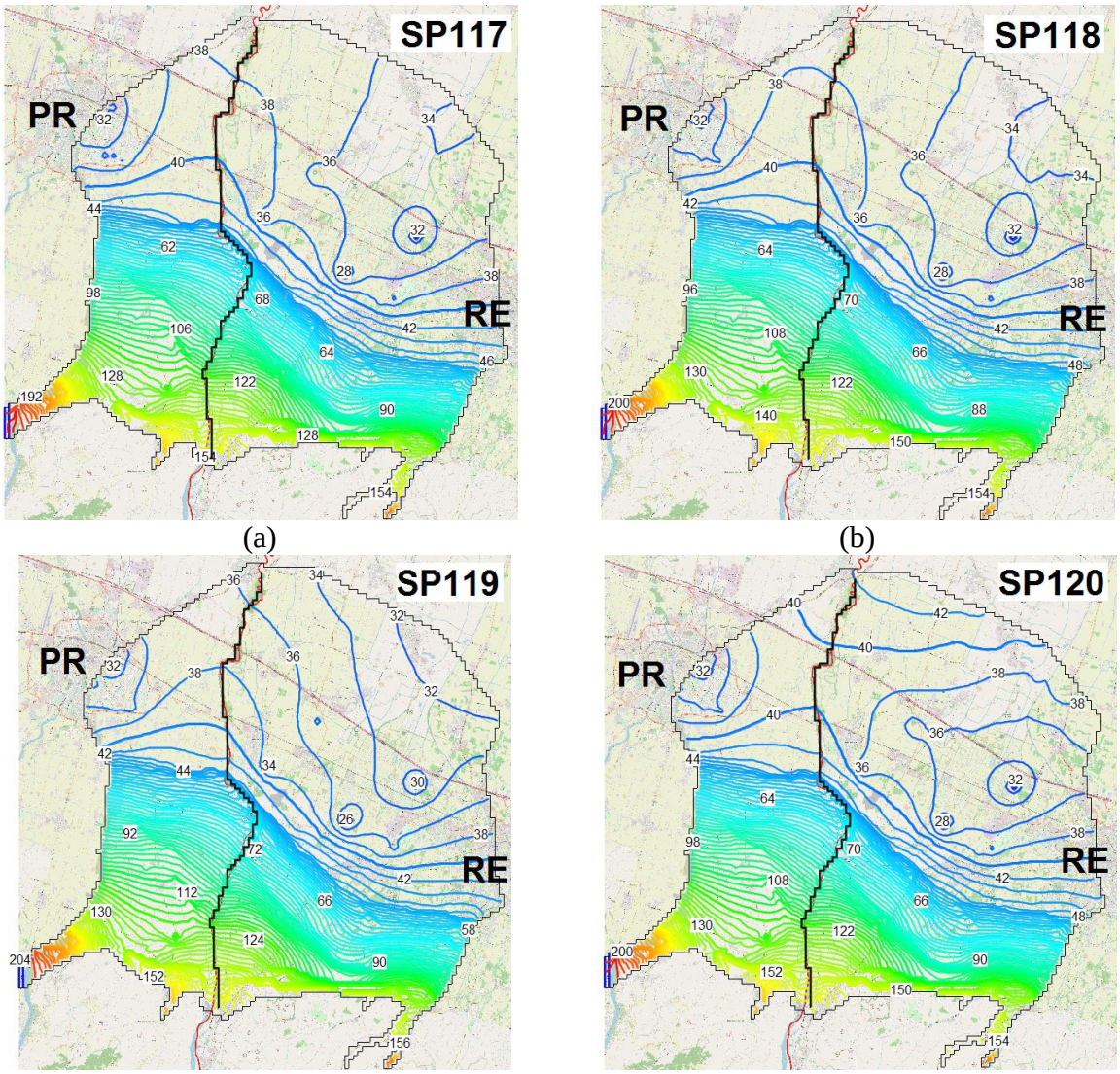


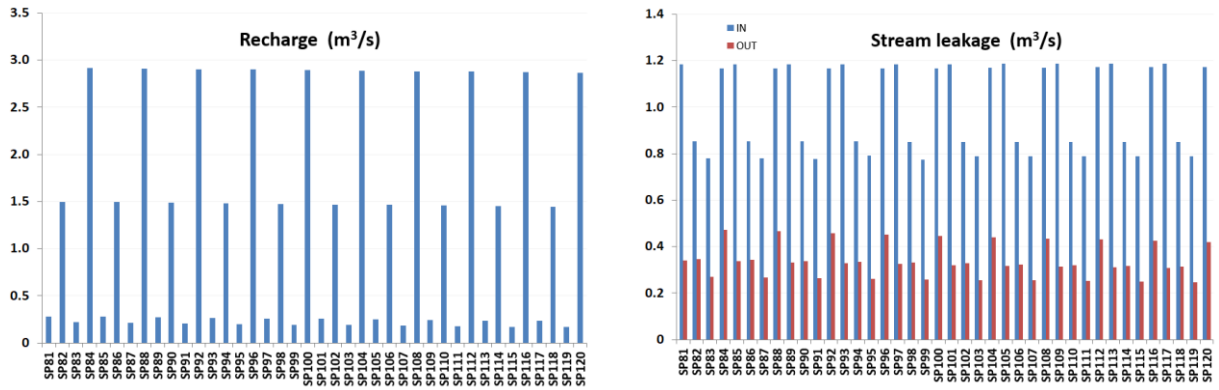
Fig. S20 (a) – (e) Volumetric budget, derived by ST1 model: Recharge, Stream leakage In/Out, Drains, Storage variation, and Storage In/Out.



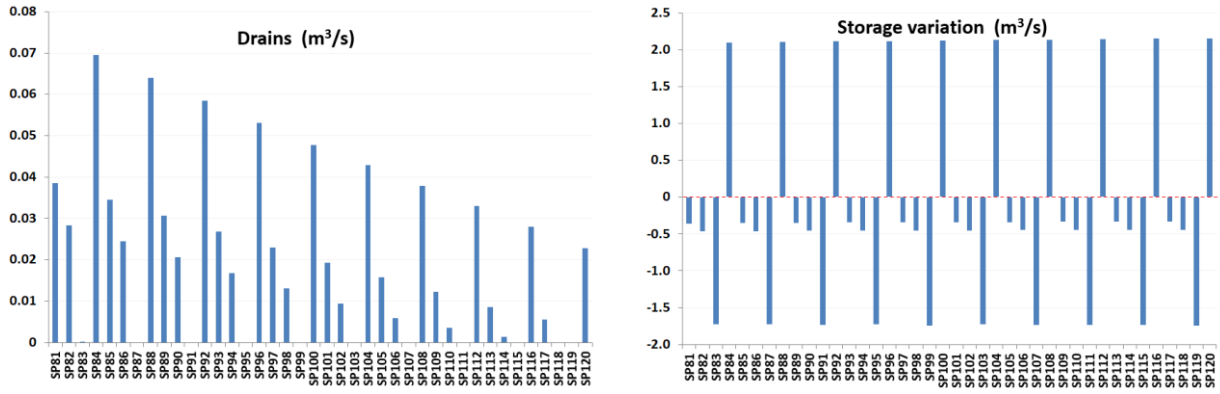
(a) (b)

(c) (d)

Fig. S21 (a) – (d) Hydraulic head within layer 1, ST2 scenario, last year of simulation (2049)

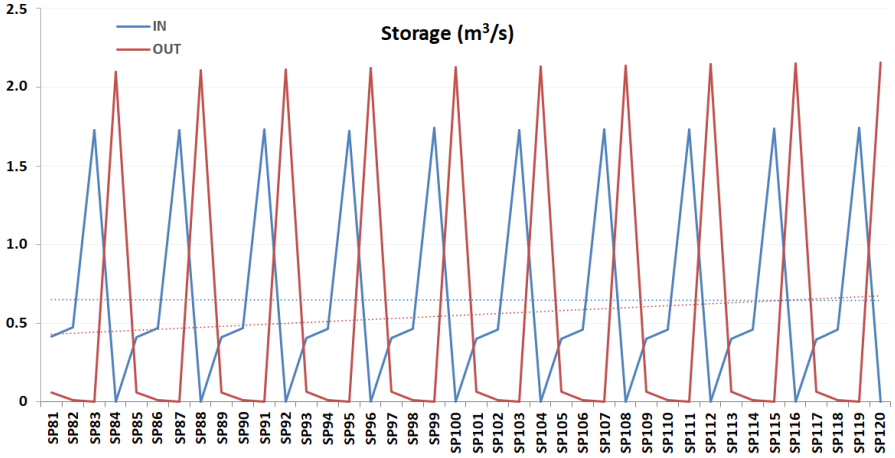


(a) (b)



(c)

(d)



(e)

Fig. S22 (a) – (e) Volumetric budget, derived by ST2 model: Recharge, Stream leakage In/Out, Drains, Storage variation, and Storage In/Out.

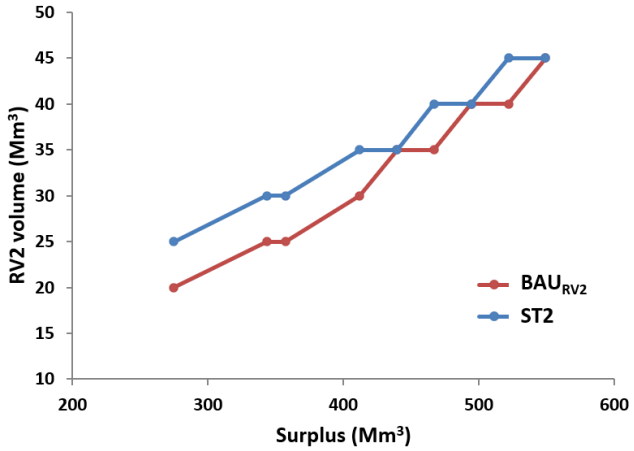
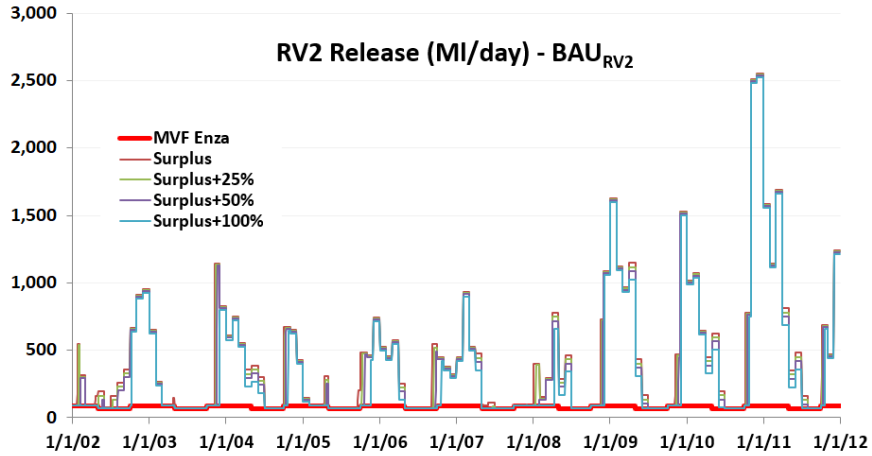
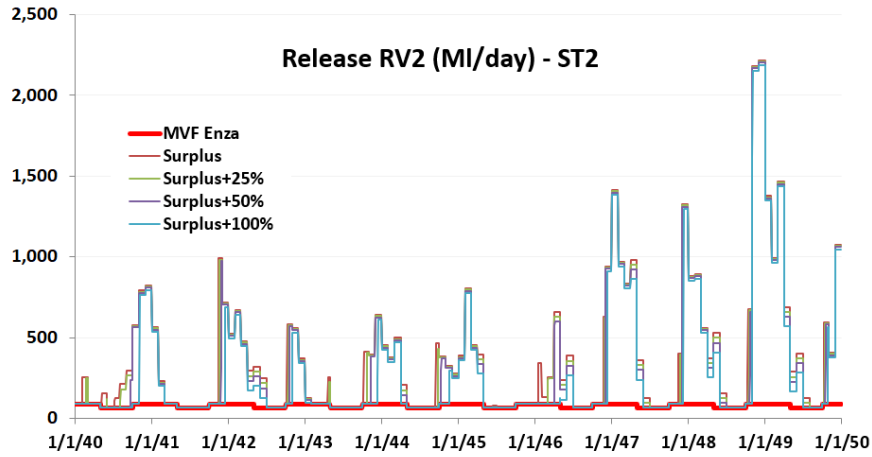


Fig. S23 RV2 volume able to satisfy a given irrigation/industrial Surplus for Aquator scenarios BAURV2 and ST2.



(a)



(b)

Fig. S24 Release from RV2 reservoir in scenario BAU_{RV2} (a) and ST2 (b)

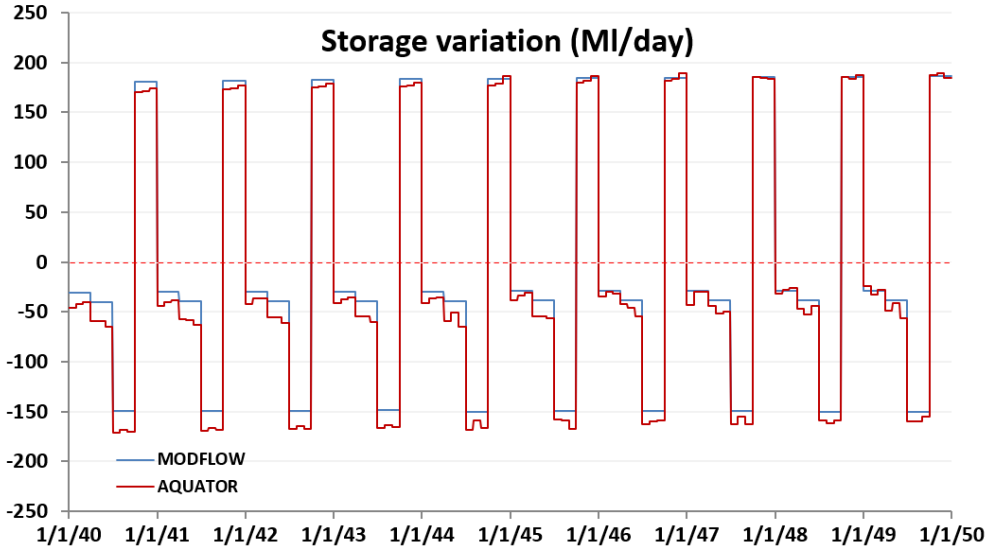


Fig. S25 Enza storage variation in MODFLOW and Aquator models, for ST2