Doctoral School in Environmental Engineering

Integrated water design for a decentralized urban landscape

figures

Marco Ranzato

UNIVERSITY OF TRENTO - Italy
Faculty of Engineering

2011

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Integrated water design for a decentralized urban landscape

The case of the low lands of the Veneto *Città Diffusa*

figures

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Doctoral thesis in **Environmental Engineering, XXII cycle**

Faculty of Engineering, **University of Trento**

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Supervisor: **Prof. Corrado Diamantini (University of Trento)**

Prof. Sybrand Tjallingii (Delft University of Tecnhology)

Prof. Maria Chiara Tosi (Università Iuav di Venezia)

Cover photo: landscape mosiac of the Veneto *Cittá Diffusa*. M. Ranzato photo

University of Trento

Trento, Italy

2011

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Chapter 1

Introduction

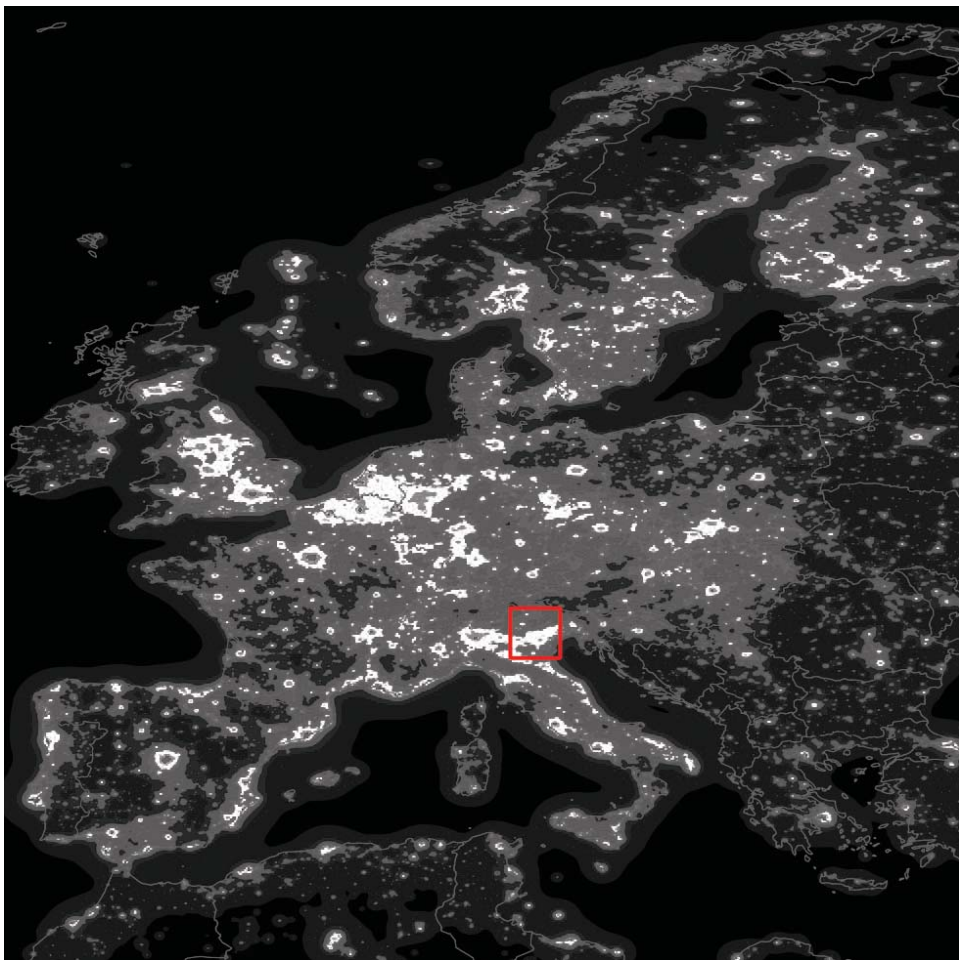

Figure 1.1. The decentralized urban landscape of the Veneto *Città Diffusa* in the night picture of Europe. Elaboration based on the Luminic Map of Europe (1996-97), www.oarval.org.

Figure 1.2. Città diffusa between Treviso and Padua. Views from an airplane window. M. Ranzato photos.

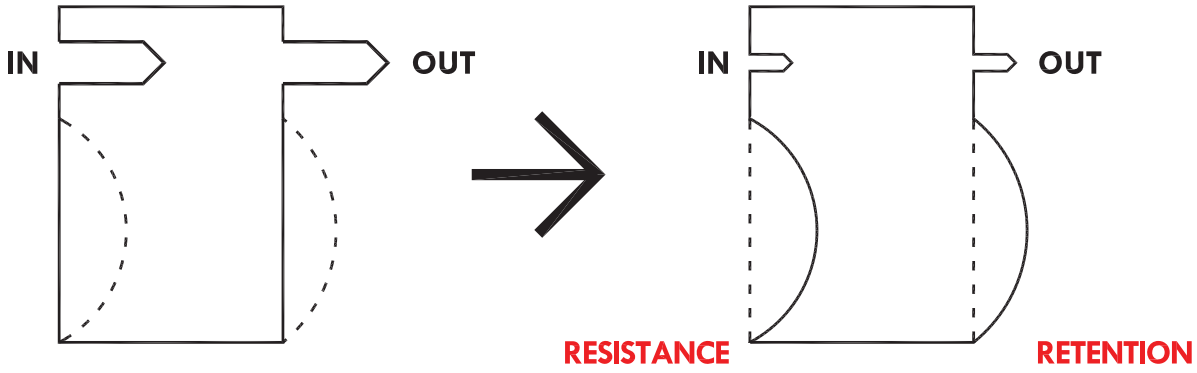

Figure 1.3. Eco-device model. The classical engineering approach is to look at the system as a regulation of in-out flows. Principles are based on increasing supply in the case of shortage, and increasing discharge in the case of excess flows (left side of the image). Van Leeuwen and Van Wirdum introduced another approach: the city is interpreted as an ecosystem. In addition to the in-out regulations (arrows), it can make use of resistant and retention capacities (concave and convex curves respectively, right side of the image). The system can resist at the external pressures absorbing part of them: temporary stormwater storage is a good example. The system can retain supply needs accommodating part of them: permanent storage of water is an appropriate example. Elaboration based on Van Leeuwen (1973) and Van Wirdum (1982).

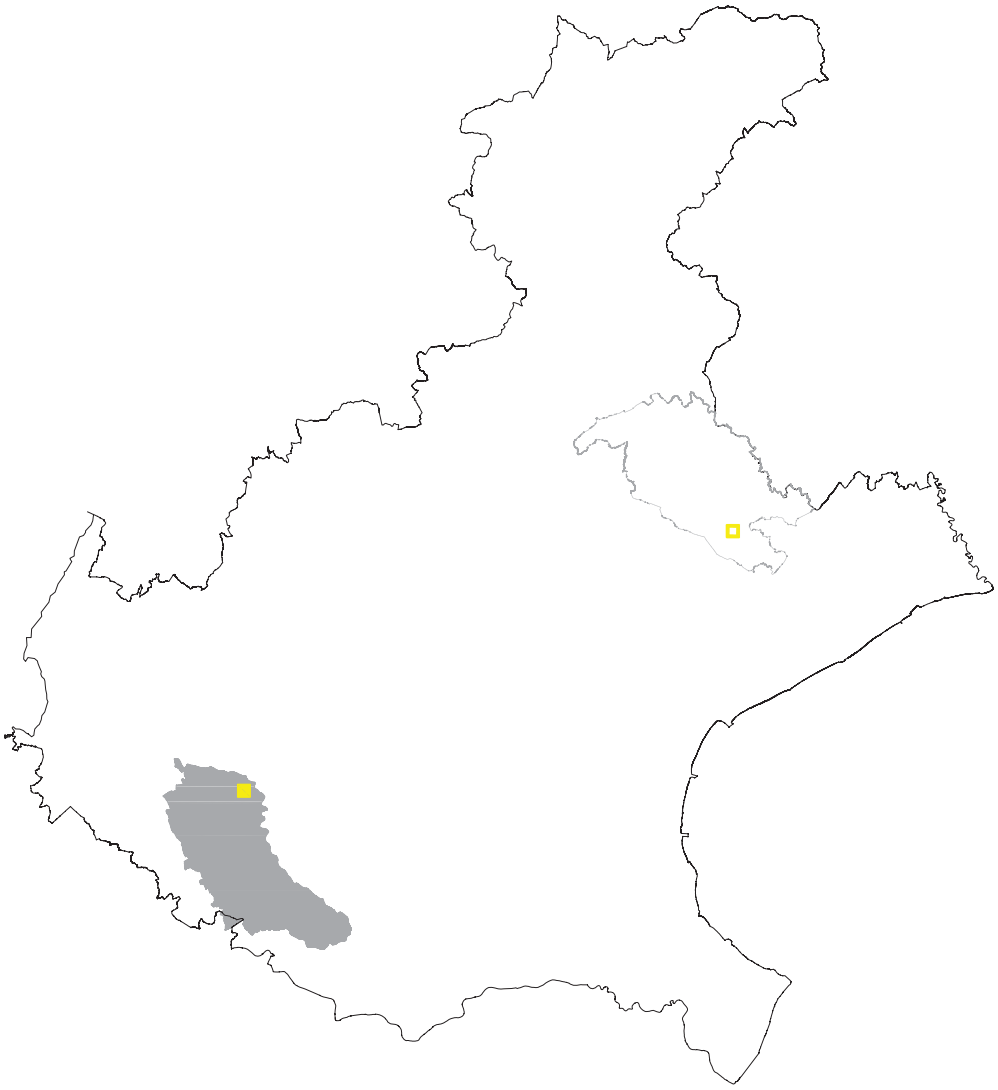

Figure 1.4. The case study area in Ronco all'Adige (yellow) in the context of Veneto Region. The area is part of the territory of the Consorzio di Bonifica Valli Grandi e Medio Veronese waterboard (grey). The map displays also the other case study, Ponte di Piave (yellow frame), and the corresponding Consorzio di Bonifica Pedemontano Sinistra Piave waterboard (grey frame) investigated by Zaccariotto (2010).

Chapter 2

Decentralized urbanization and integrated water management

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2.

3.

4.

Figure 2.1. Landscape patterns of the Veneto low lands. Roman aggeratio (via Gaffarello, Borgoricco) (1); reclamation of the XII sec. (via Rizza, Palù, Verona) (2); Villa Pindemonte, Venetian Republic period (Vò di Isola della Scala, Verona) (3); reclamation of the XIX-XX sec. (via Santa Teresa, Legnago, Verona) (4). Source: Google Maps.

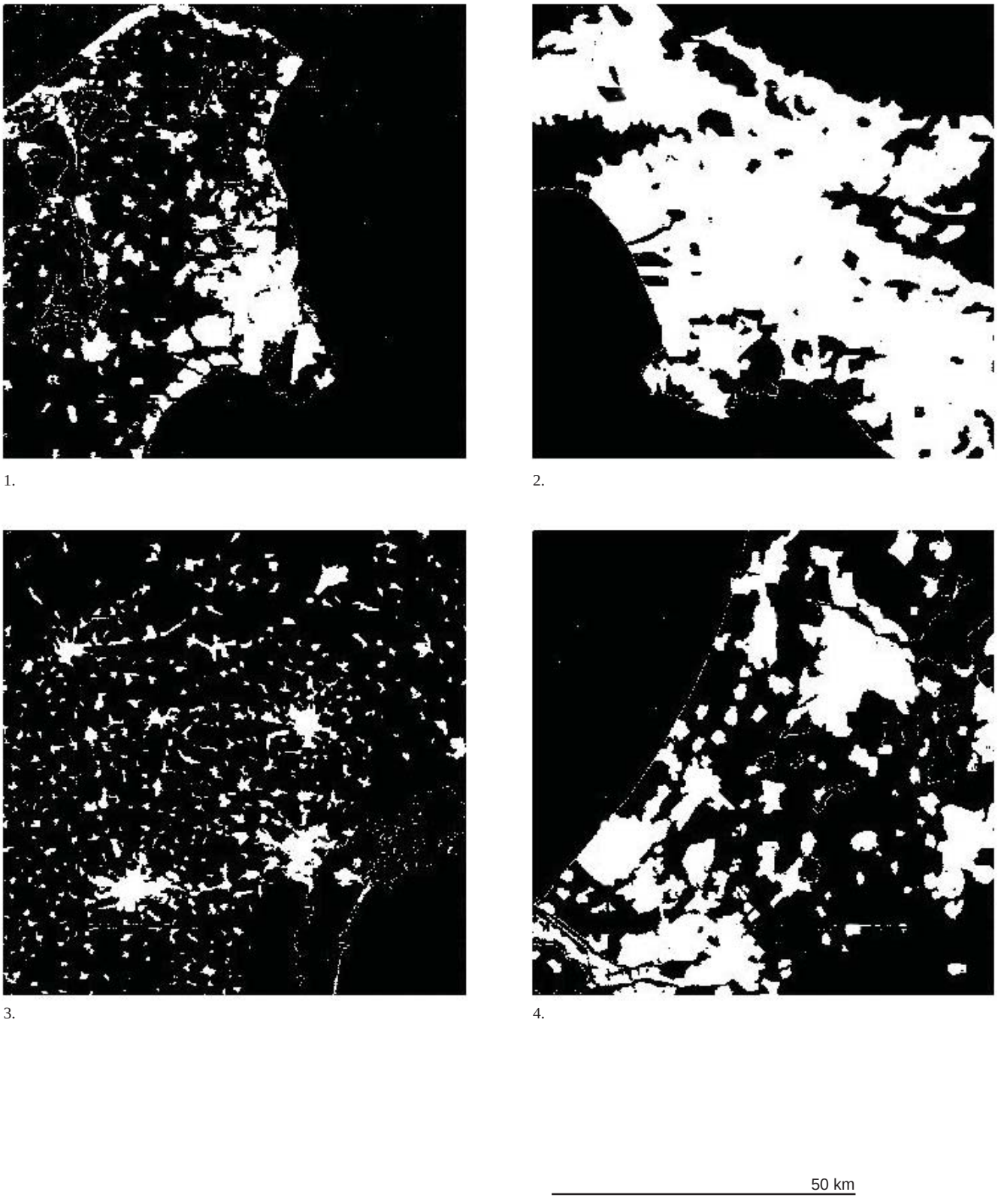
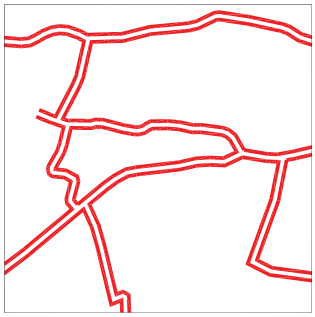


Figure 2.2. Los Angeles (1), Orestad Regionen (2), Veneto Central Area (3) and Randstad Holland (4). Voids (black); built environment (white). Elaboration based on Munarin & Tosi (2001).

1.

7.



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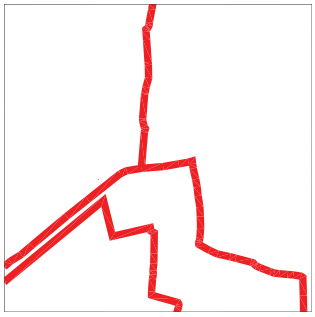

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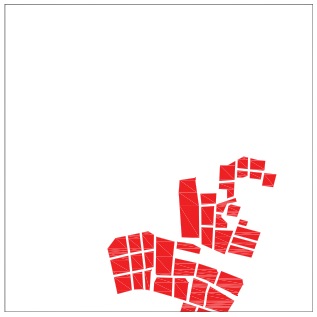


5.

4.

Figure 2.3. Possible existing storage patterns in a section of Ronco all'Adige, the case study of the research (1) (Source: Telespazio 2007). What if stormwater is temporarily stored in the existing road ditches and in the new ones opened along the existing roads (2)? What if stormwater is temporarily stored in the streams managed by the Consorzio (3)? What if stormwater is temporarily stored in the existing dirt roads of the agricultural system (4)? What if stormwater is temporarily stored in the existing private clay pits (5)? What if stormwater is temporarily stored in the agricultural ditches (6)? What if stormwater is temporarily stored in the road ditches (existing and new ones), water board streams, clay pits, dirt roads and agricultural ditches (7)?

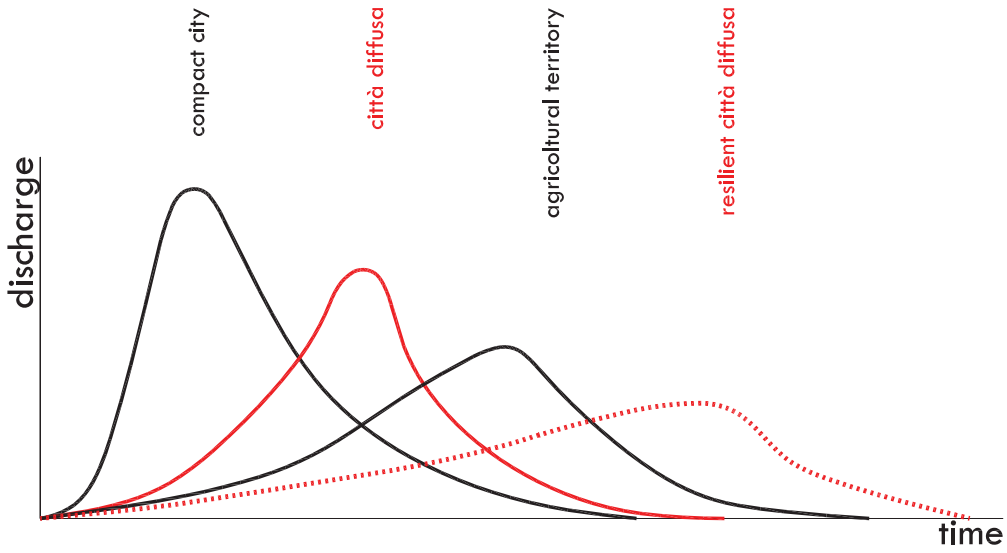


Figure 2.4. Different discharge dynamics in relation to different land uses. The conceptual hydrograph exhibits the higher potential of the *Città Diffusa* landscape to resist than more dense urban patterns since many open spaces might be easily adapted to perform as temporary water storage. The same urban landscape proves to also have higher potential in retaining water when it is convenient to adopt a few opens spaces to perform as permanent storage for buffered stormwaters. Elaboration based on Bettinetti et al. (2007: 13).

Chapter 3

Research methodology

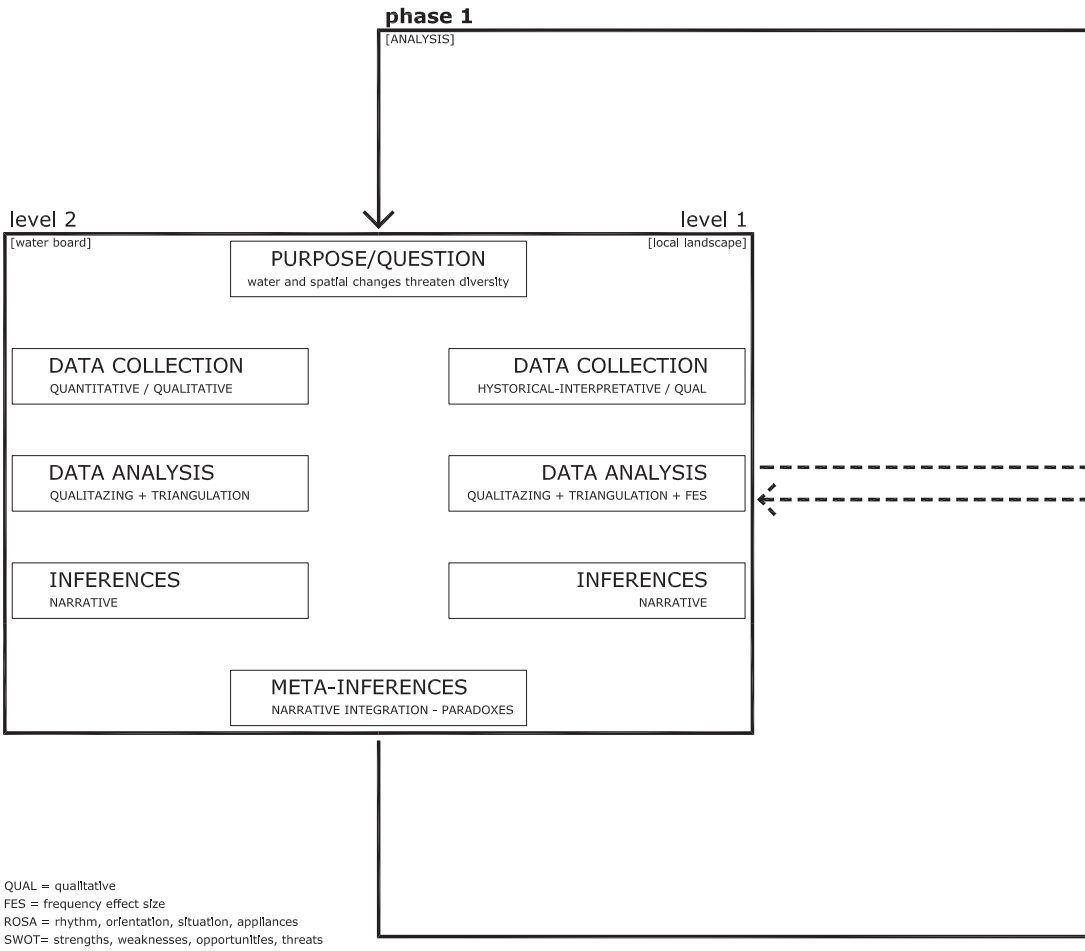
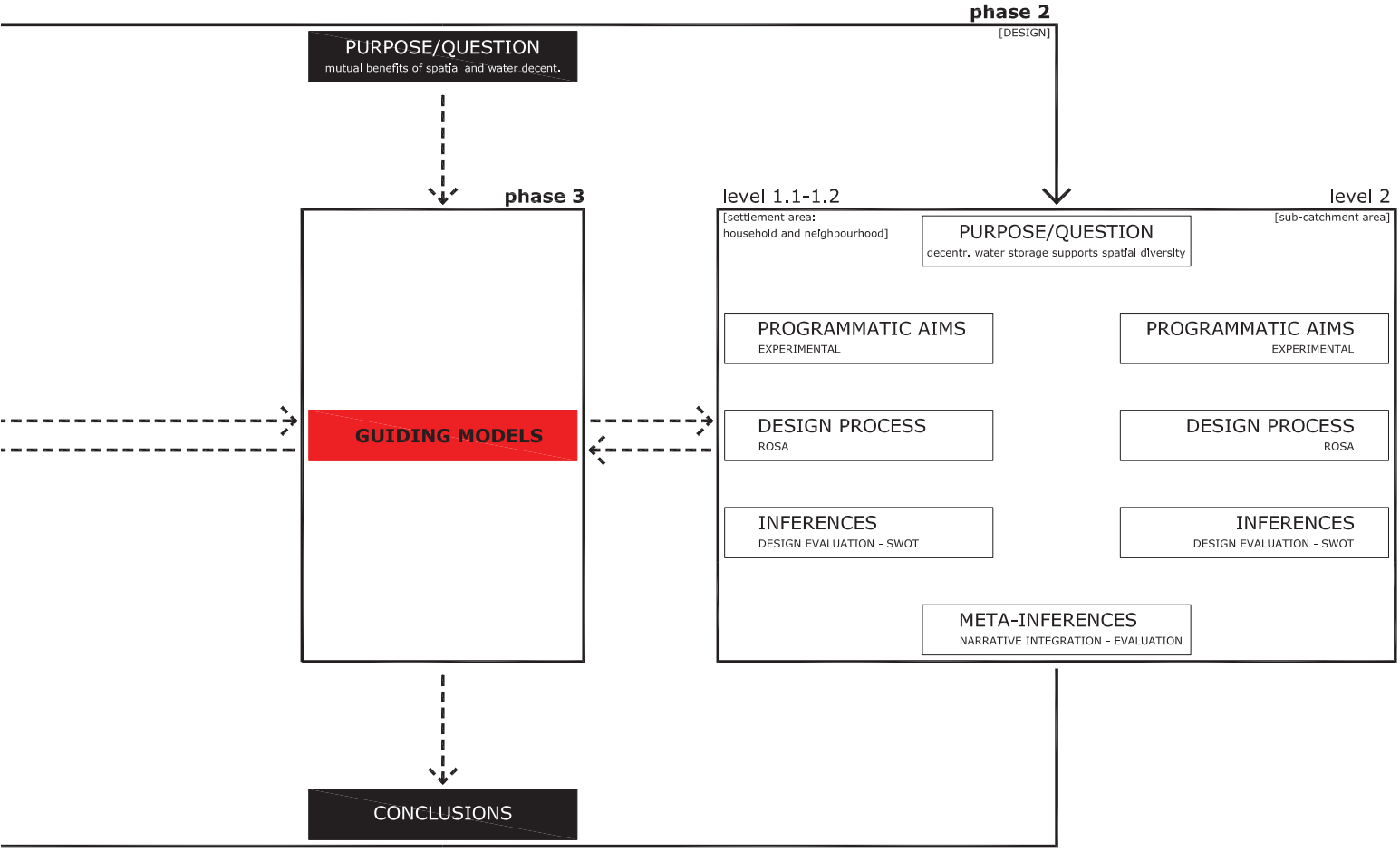


Figure. 3.1. Concurrent multilevel mixed model design. Based on Tashakkori and Teddlie (2003).


phase 2
[DESIGN]
PURPOSE/QUESTION
mutual benefits of spatial and water decent.
phase 3
level 1.1-1.2
[settlement area:
household and neighbourhood]
level 2
[sub-catchment area]
PURPOSE/QUESTION
decentr. water storage supports spatial diversity
PROGRAMMATIC AIMS
EXPERIMENTAL
PROGRAMMATIC AIMS
EXPERIMENTAL
GUIDING MODELS
DESIGN PROCESS
ROSA
DESIGN PROCESS
ROSA
INFERENCES
DESIGN EVALUATION - SWOT
INFERENCES
DESIGN EVALUATION - SWOT
META-INFERENCES
NARRATIVE INTEGRATION - EVALUATION
CONCLUSIONS

Chapter 4

Frame

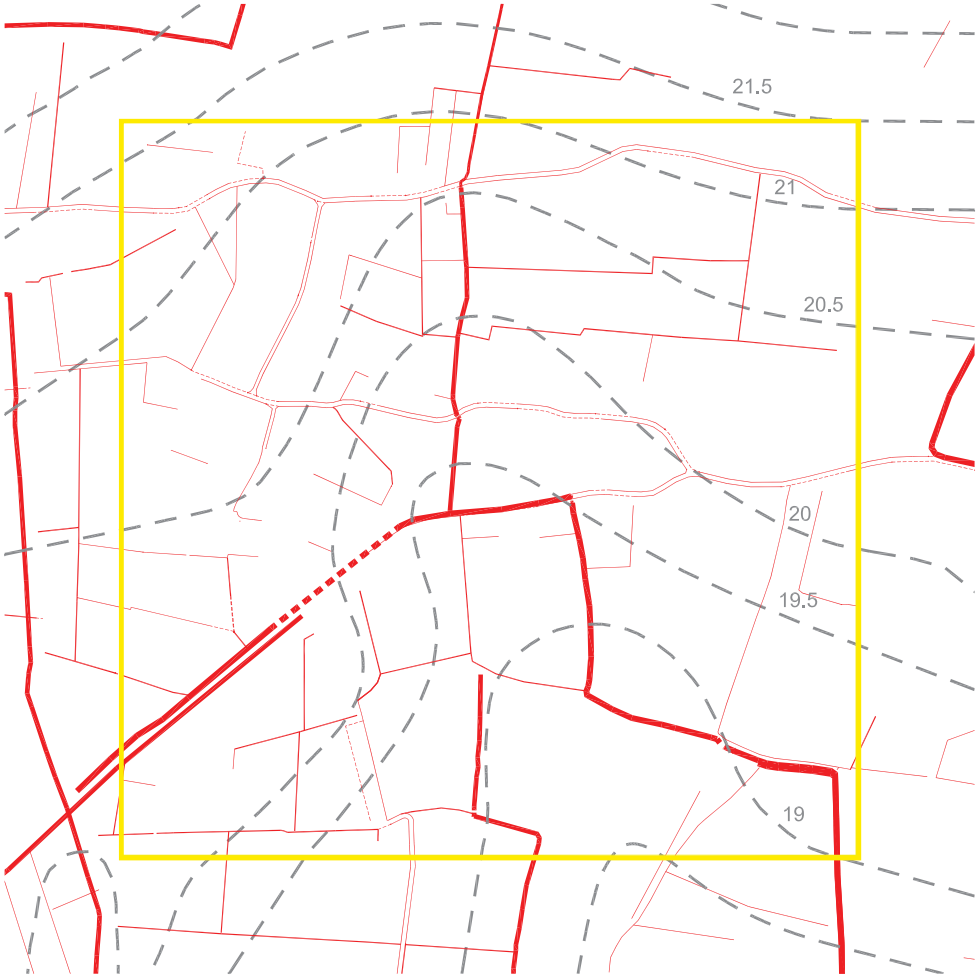


Figure 4.1. The surface water network (red lines) and the landform (dotted lines) in the case study area in Ronco all'Adige (yellow square). Interpretation of the Carta Tecnica Regionale, Regione Veneto.

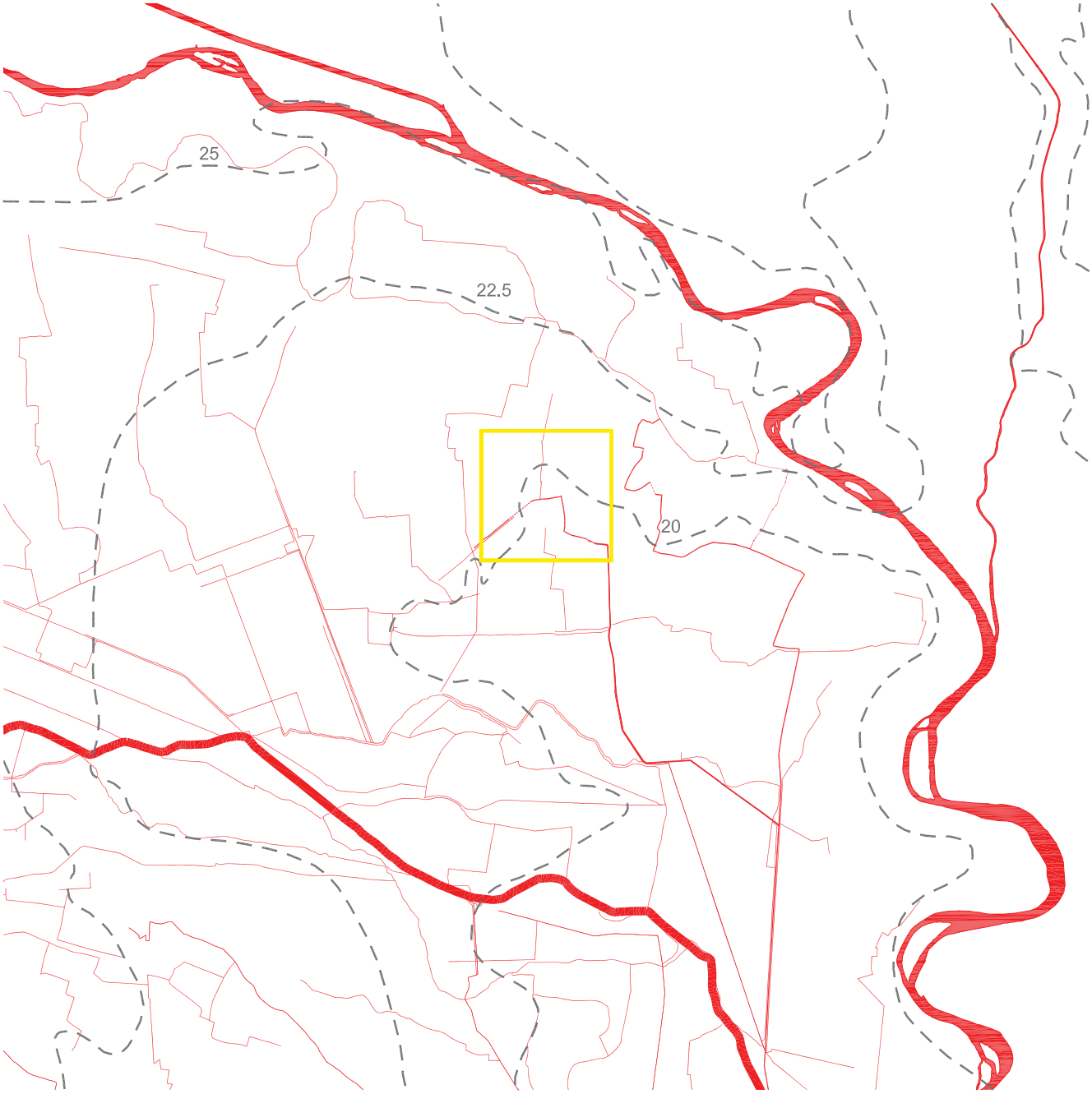


Figure 4.2. The surface water network (red lines) and the landform (dotted lines) in the case study area in Ronco all'Adige (yellow square) within a wider-angle view.

Figure 4.3. The case study area (yellow square) in the hydrographical framework of the Scolo Conduttone catchments.

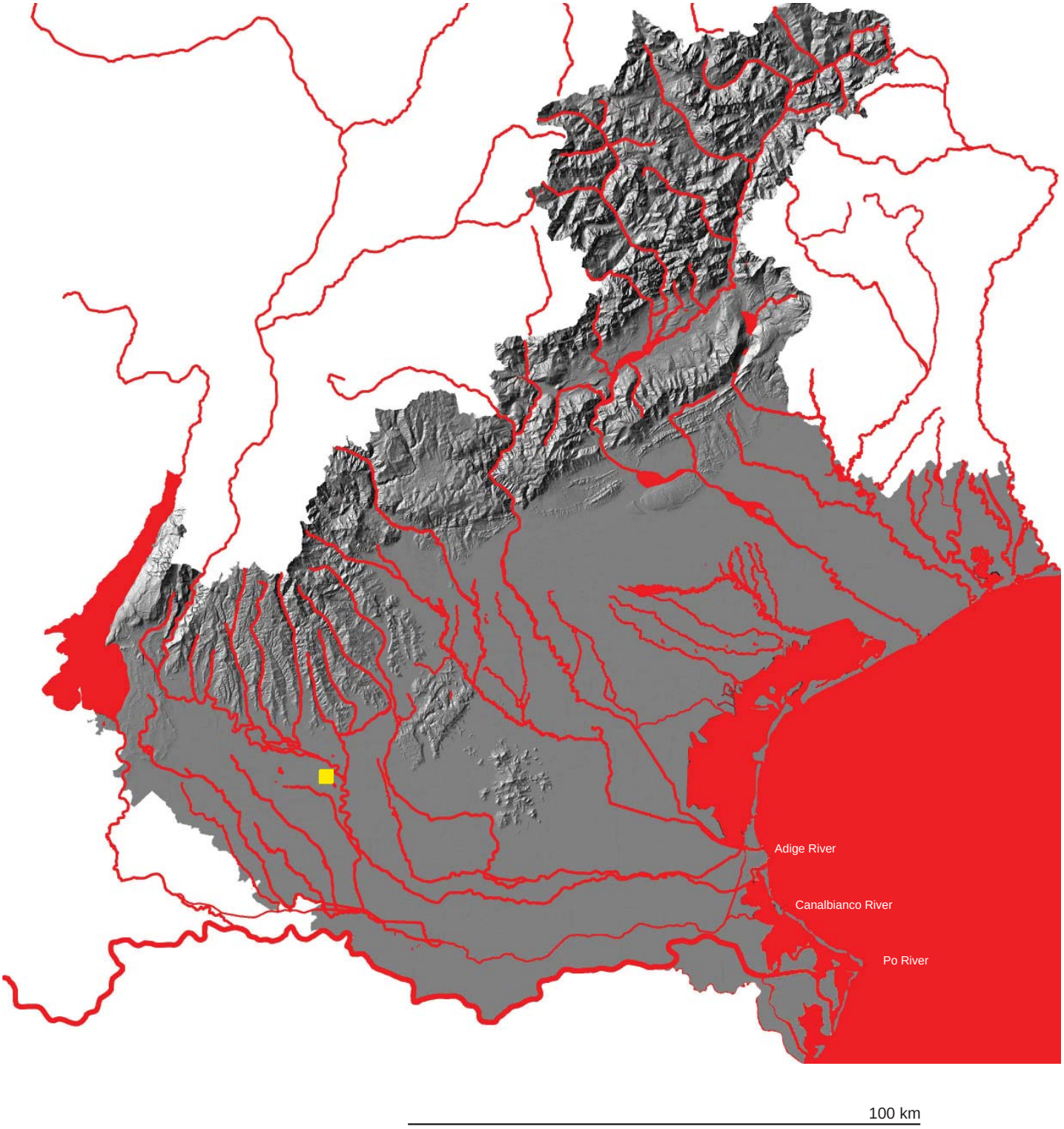


Figure 4.4. The case study area (yellow square) in the regional surface water network (red lines) and landform.

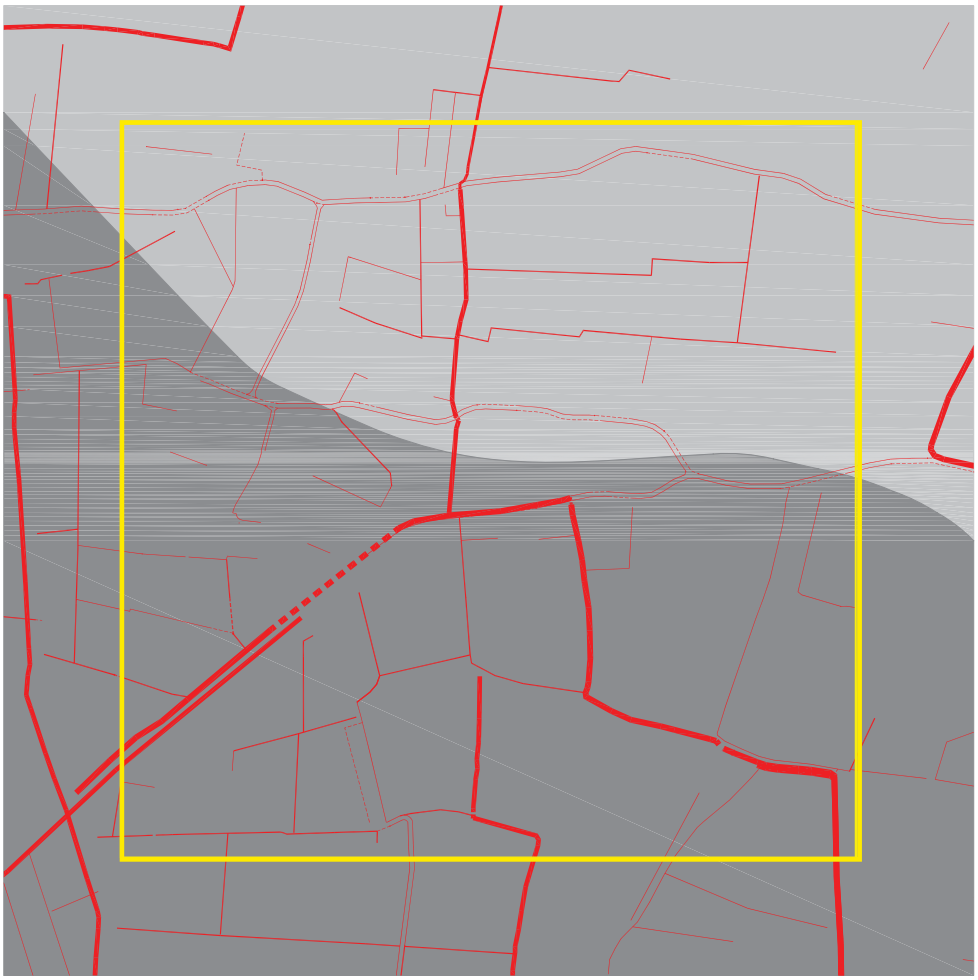


Figure 4.5. The surface water network (red lines) and the soil space in the case study area in Ronco all'Adige (yellow square). Light grey: Sand-loam (A) (light grey), clay-loam (B) (dark grey).

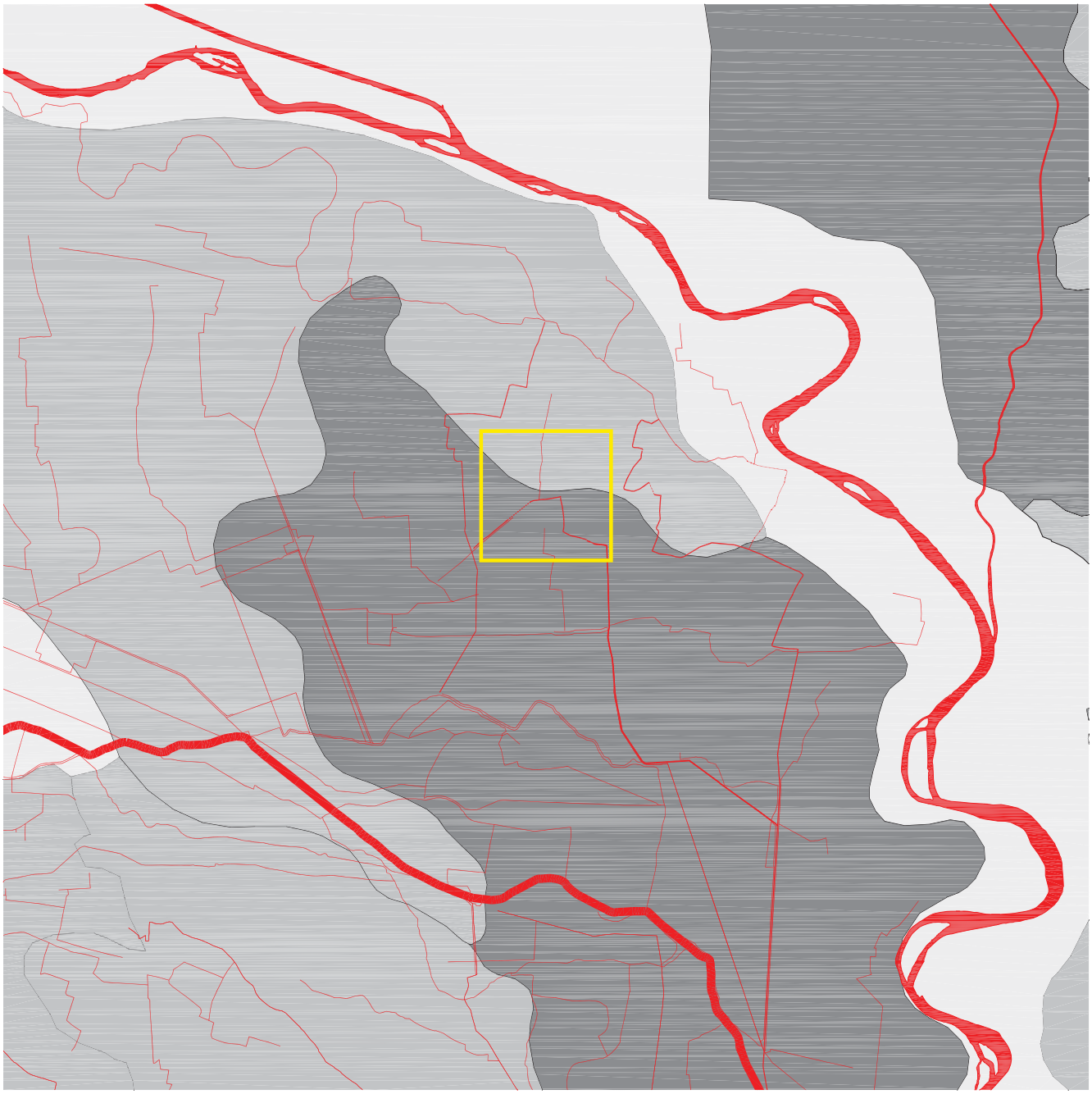


Figure 4.6. The surface water network (red lines) and the soil scape (dotted lines) in the case study area in Ronco all'Adige (yellow square) within a wider-angle view. Sand-loam, the ridge of the Adige River (C) (white); sand-loam, the fluvial terraces (light grey); sand-loam (A) (grey); clay-loam soil (B) (dark grey).

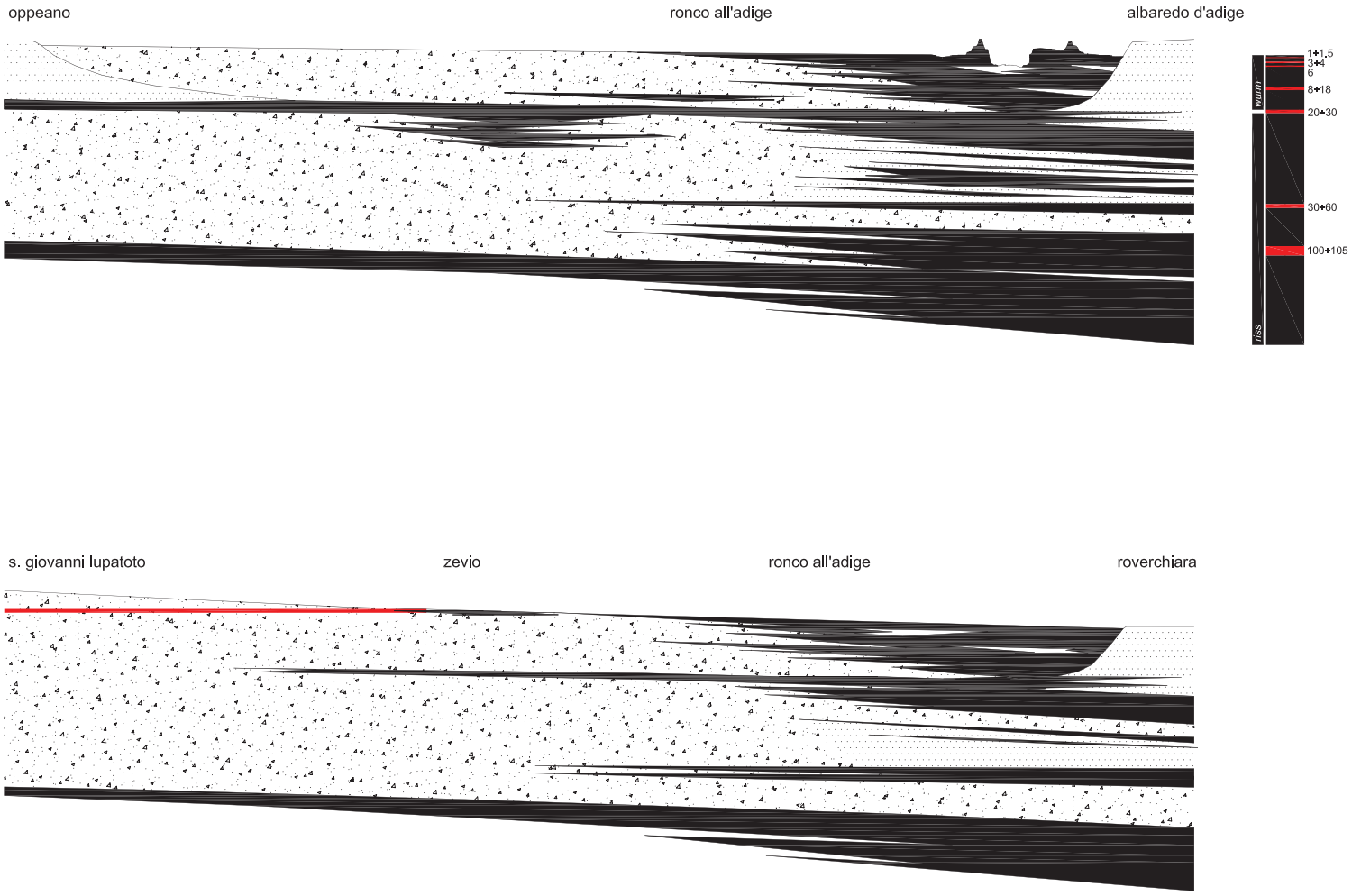


Figure 4.7. Transversal (top) and longitudinal (bottom) hydrological sections of the case study area. Clay (black), sand (fine dots), gravel (coarse dots), groundwater (red). Elaboration based on Gregnanin, 1985.

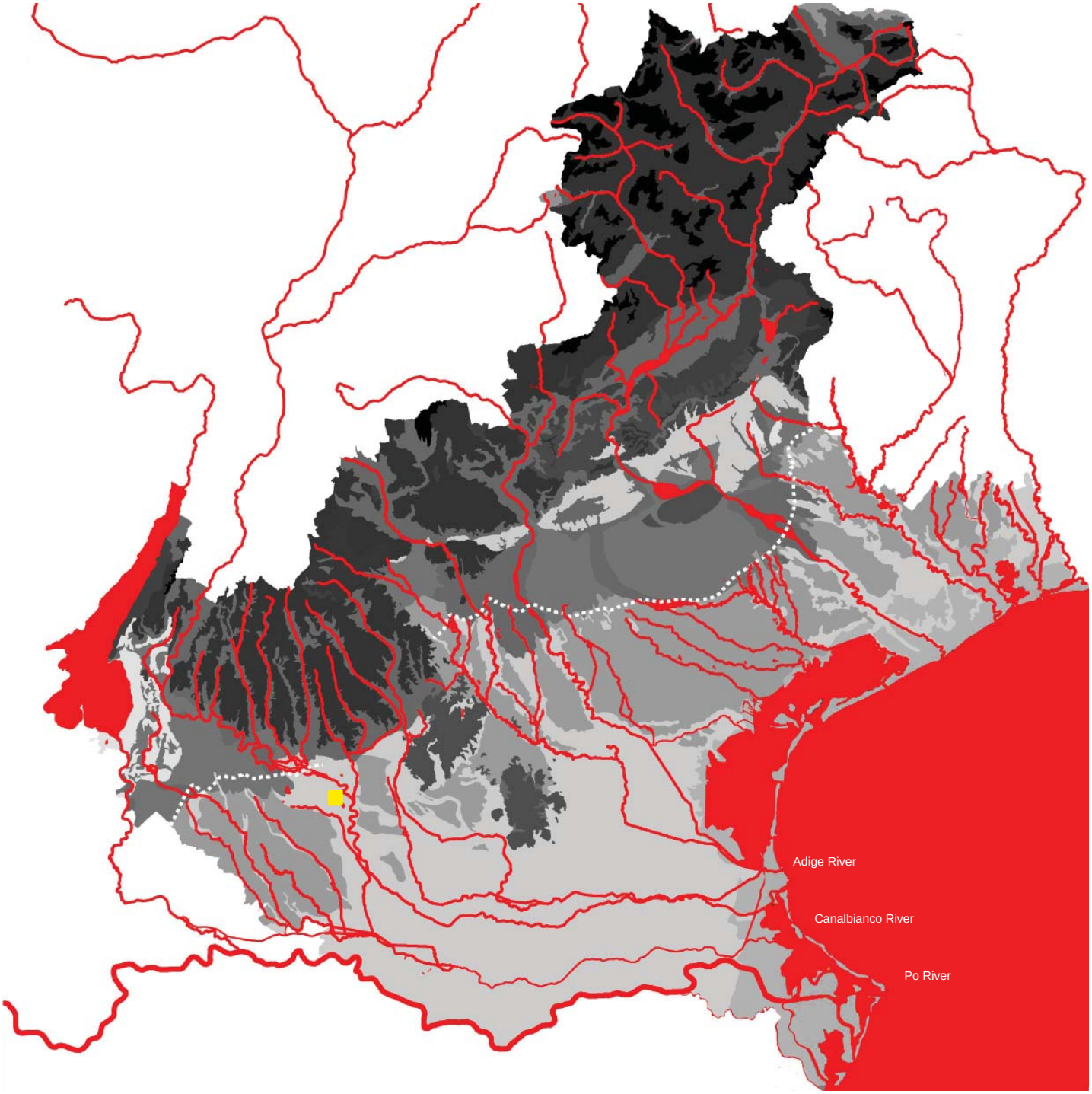


Figure 4.8. The case study area (yellow square) in the regional surface water network (red lines) and soil scape. Dolomites peaks, mountainous ridges, steep mountainsides, hills (dark grey). Mountainous valleys, old (lighter) and recent (darker) high plain (grey). Hilly morainic formations (almost withe), eastern hills, old (darker) and recent (lighter) low plain, dunes and lowlands (light grey). The spring line (withe dotted line).

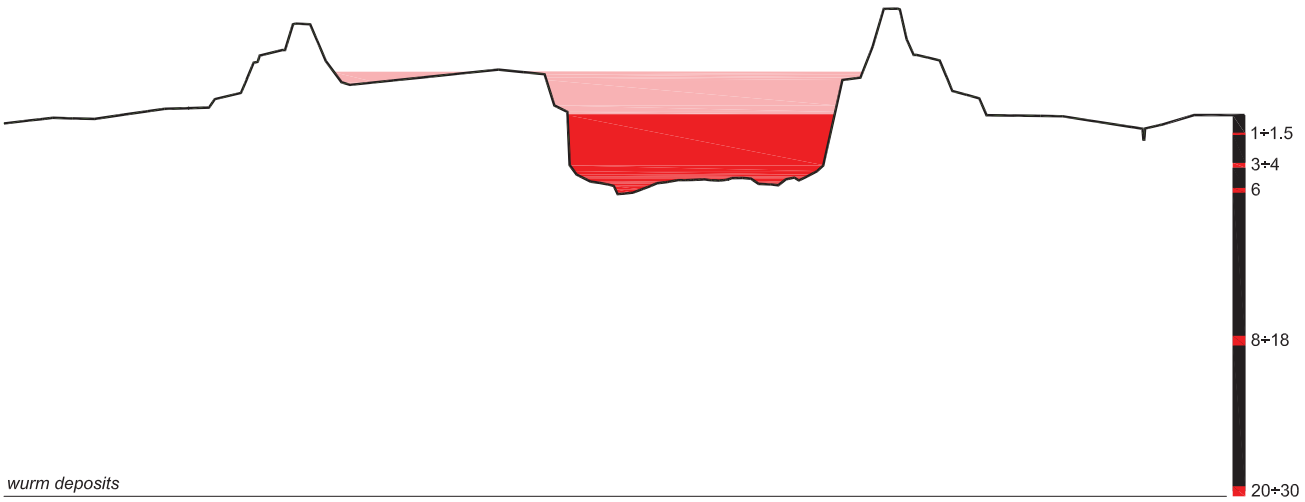


Figure 4.9. The relation between the cross section of the Adige River and the groundwater in the municipality of Albaredo a few kilometers far from the case study area.

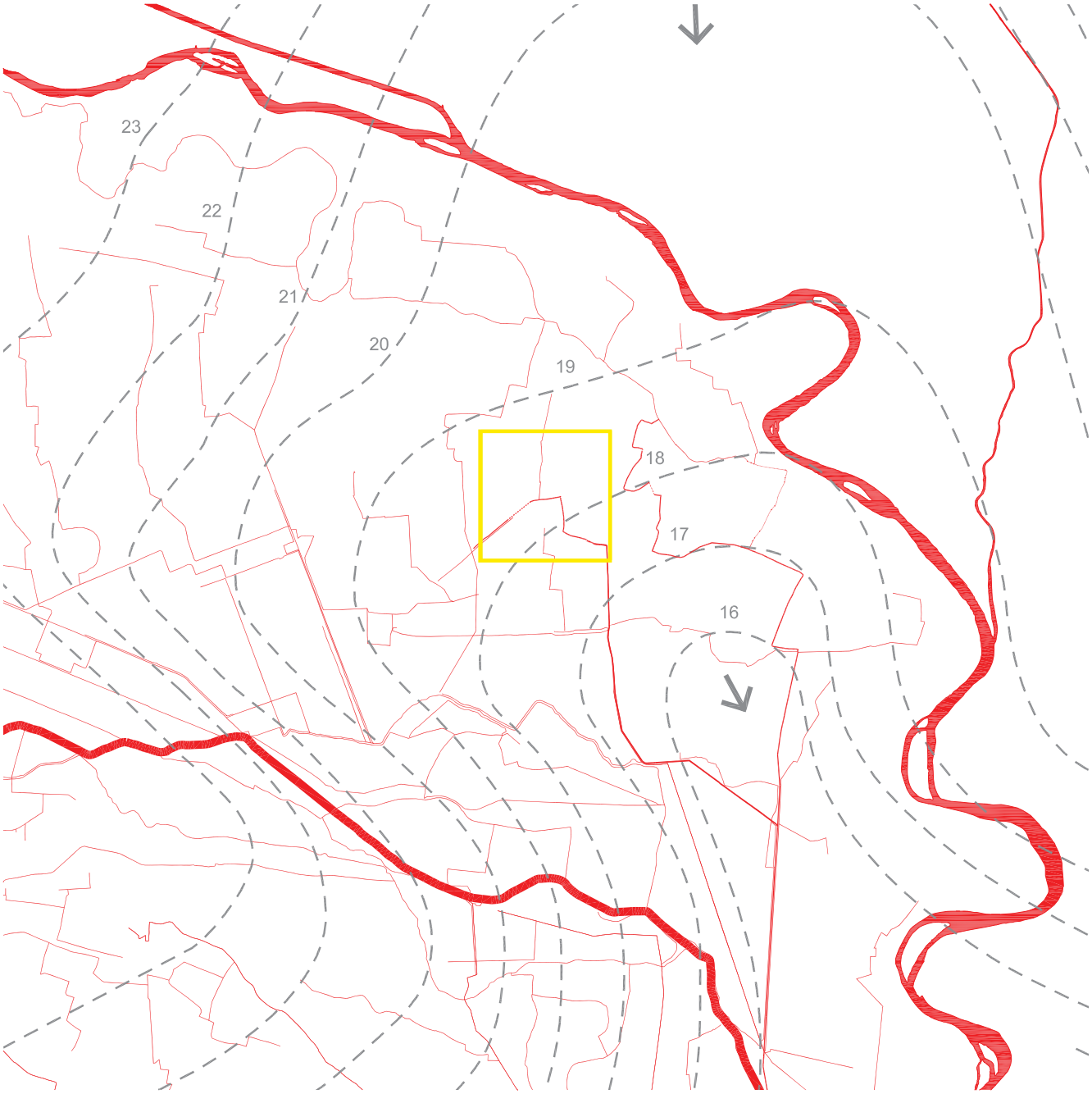


Figure 4.10. The surface water network (red lines), the iso-phreatic lines (dotted lines) and the case study area in Ronco all'Adige (yellow square). Interpretation of the Carta Idrogeologica dell'Alta Pianura Veronese Orientale (Dal Prà et al., 1997).

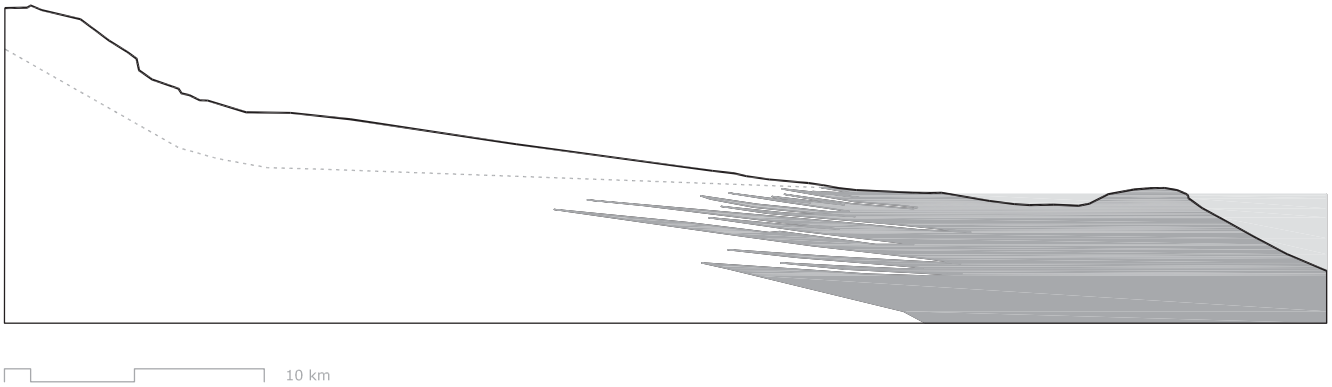


Figure 4.11. Conceptual section of the Veneto Region. Impermeable layers (dark grey), groundwater (dotted line). Elaboration based on Altissimo and Dal Prà, 2003.

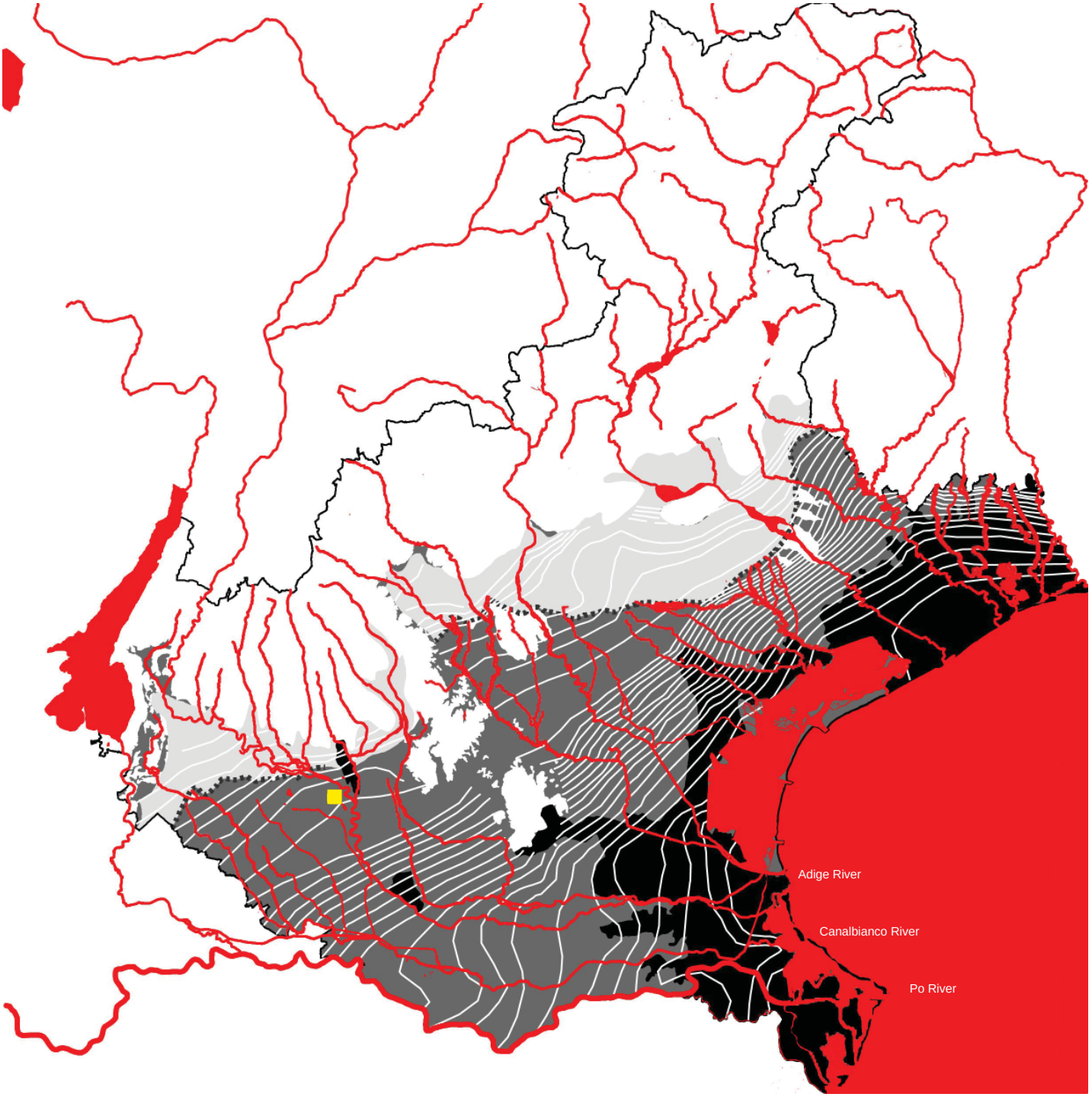


Figure 4.12 The case study area (yellow square) in the regional surface water network (red lines) and phreatic groundwater. Groundwater recharge area in the high plain (light grey). Low lands with water table under the level of the ground (grey). Lowlands under the sea level (dark grey). Iso-phreatic lines (white lines). Spring line (black dotted lines).

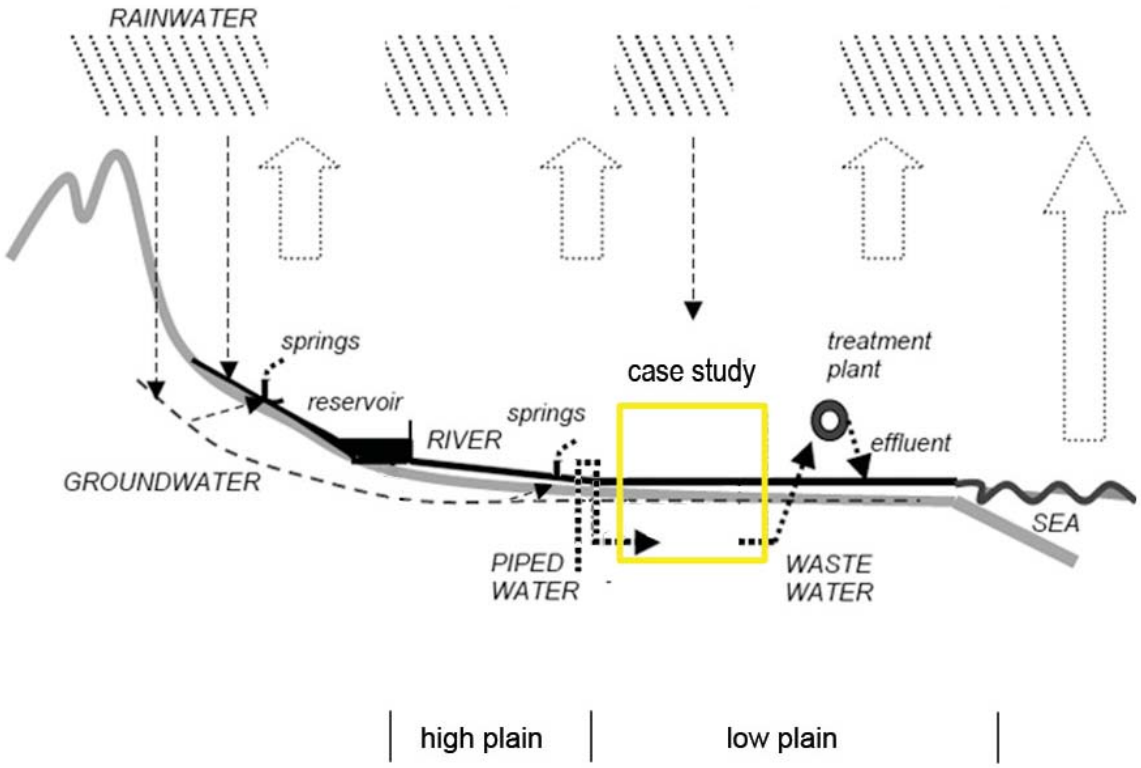


Figure 4.13. Natural and man made water cycle of Veneto Region. Author: Sybrand Tjallingii.

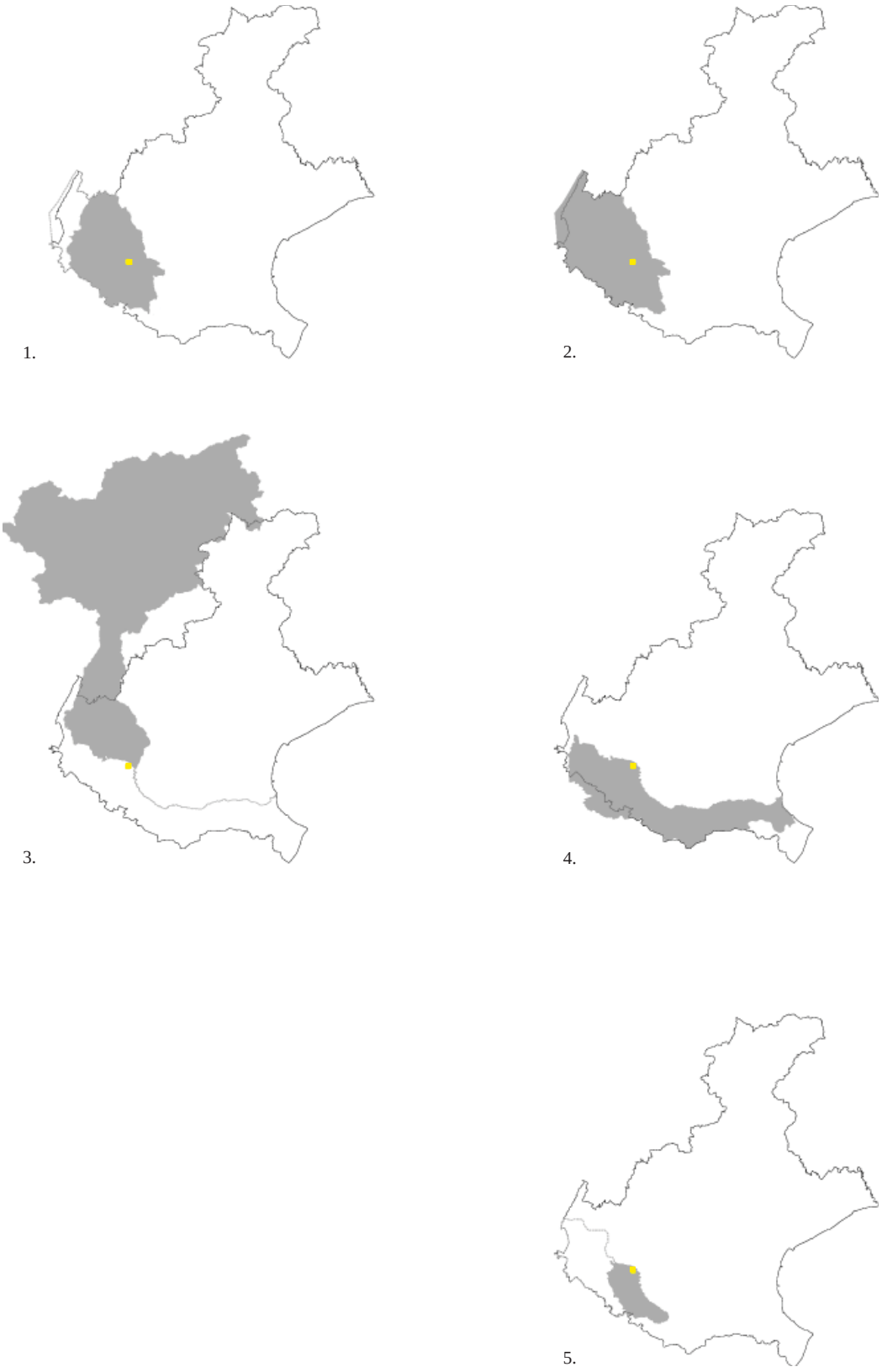


Figure 4.14. The administrative areas of the agencies responsible for the water flows and related infrastructures crossing or related to the case study area. The AATO Veronese (dotted line) and Acque Veronese Scarl. (gray) (1). The Province of Verona (2). The Autorità di Bacino del Fiume Adige waterboard (3). The Autorità di Bacino Fiume Fissero-Tartaro-Canalbianco waterboard (4). The Consorzio di Bonifica Veronese waterboard (dotted line) and the Consorzio di Bonifica Valli Grandi e Medio Veronese waterboard (grey) (5).

Chapter 5

Landscape processes

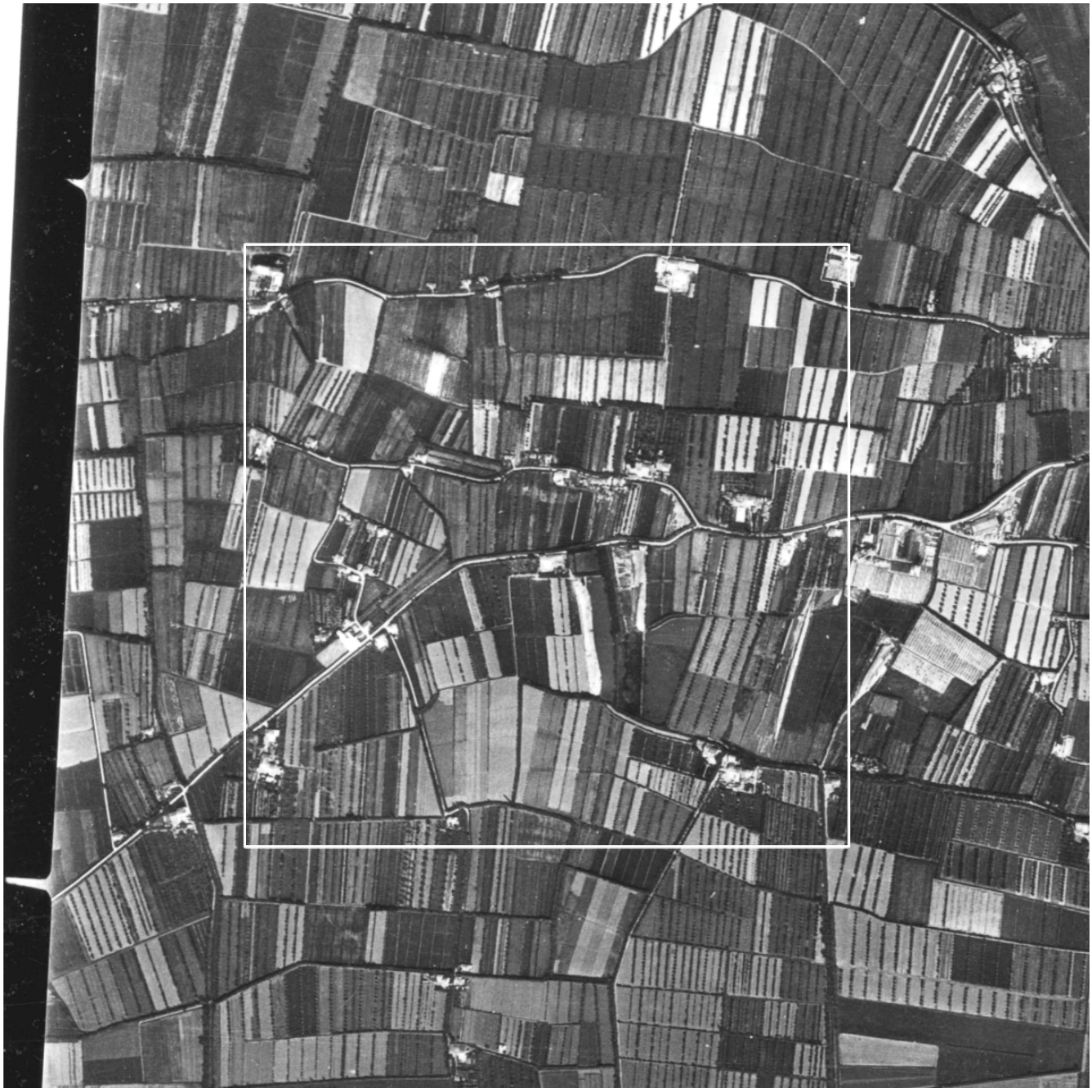


Figure 5.1. Ronco all'Adige. Aerial views of the case study area. 1955 (left), source RAF 1955, Circe Iuav; 2007 (right), source Telespazio 2007.

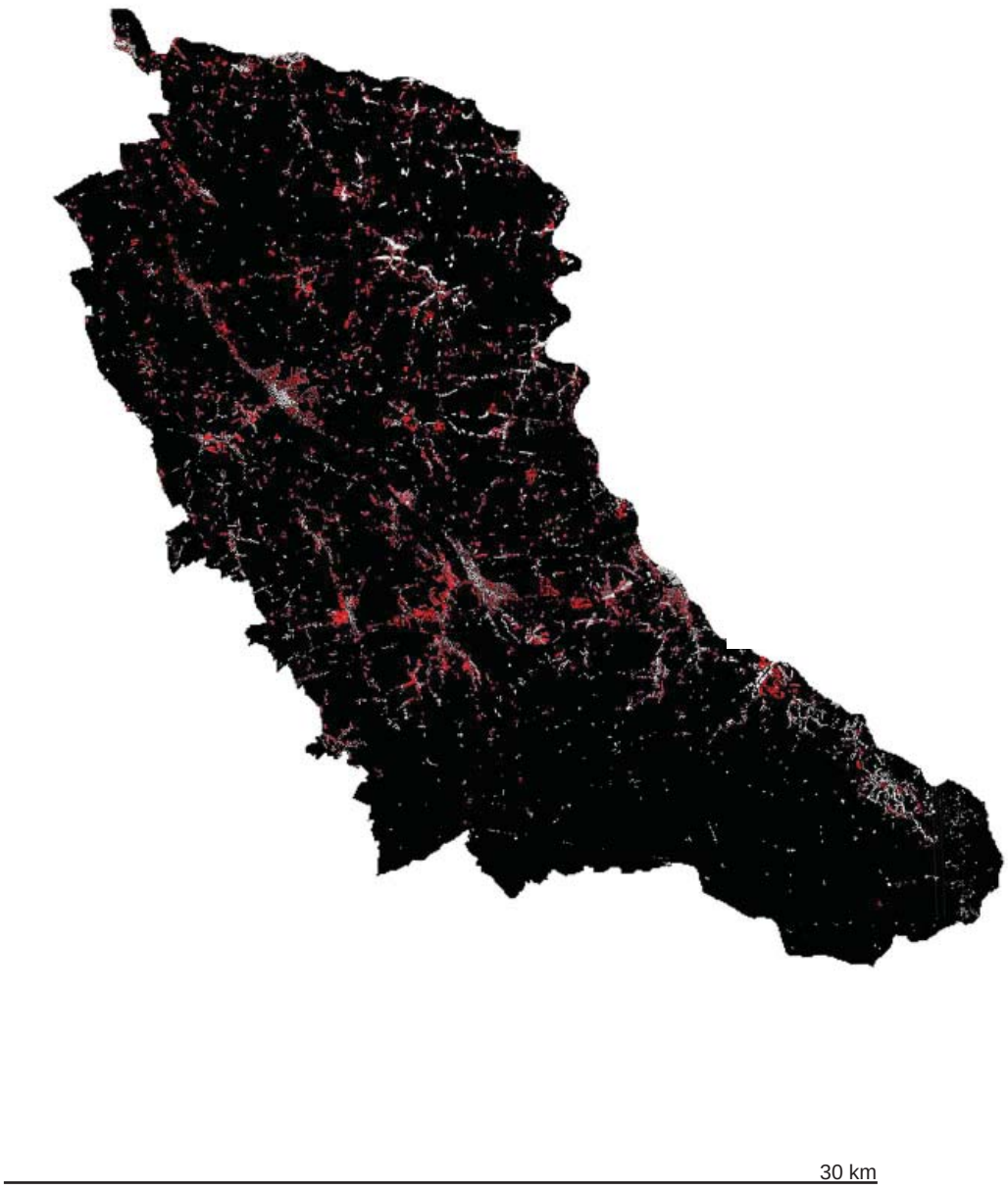


Figure 5.2. Consorzio di Bonifica Valli Grandi e Medio Veronese Water board. Built environment in the 50s (white dots) and 00s (red dots). The analysis is based on national and regional cartography, the1953 IGM for the 50s and the 1997 CTR for the 00s.

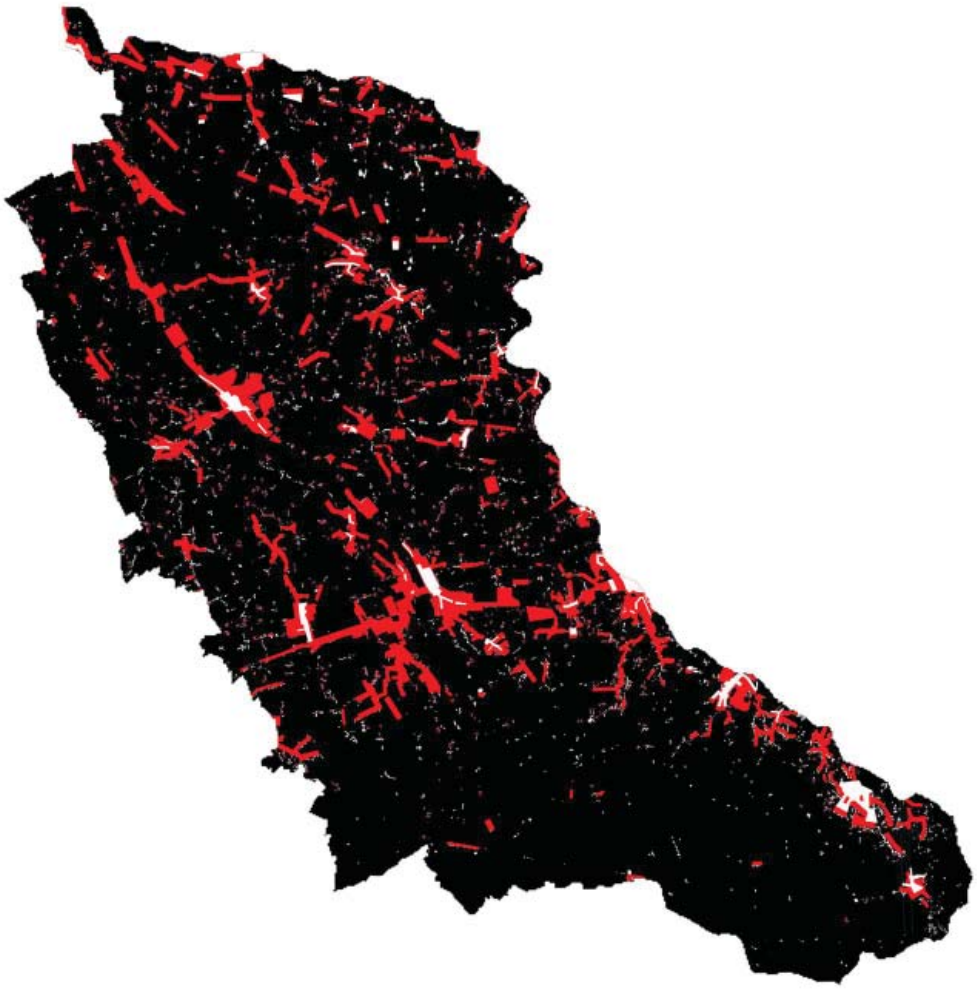


Figure 5.3. Consorzio di Bonifica Valli Grandi e Medio Veronese Water board. Interpretation of the main configuration in the development of the built environments between the 50s (white) and the 00s (red). The spatial categories (fragmented, linear and dispersed configurations) used in the interpretation of the map are the same used by other researchers for other parts of the Veneto plains. See for example Munarin and Tosi (2001: 57).

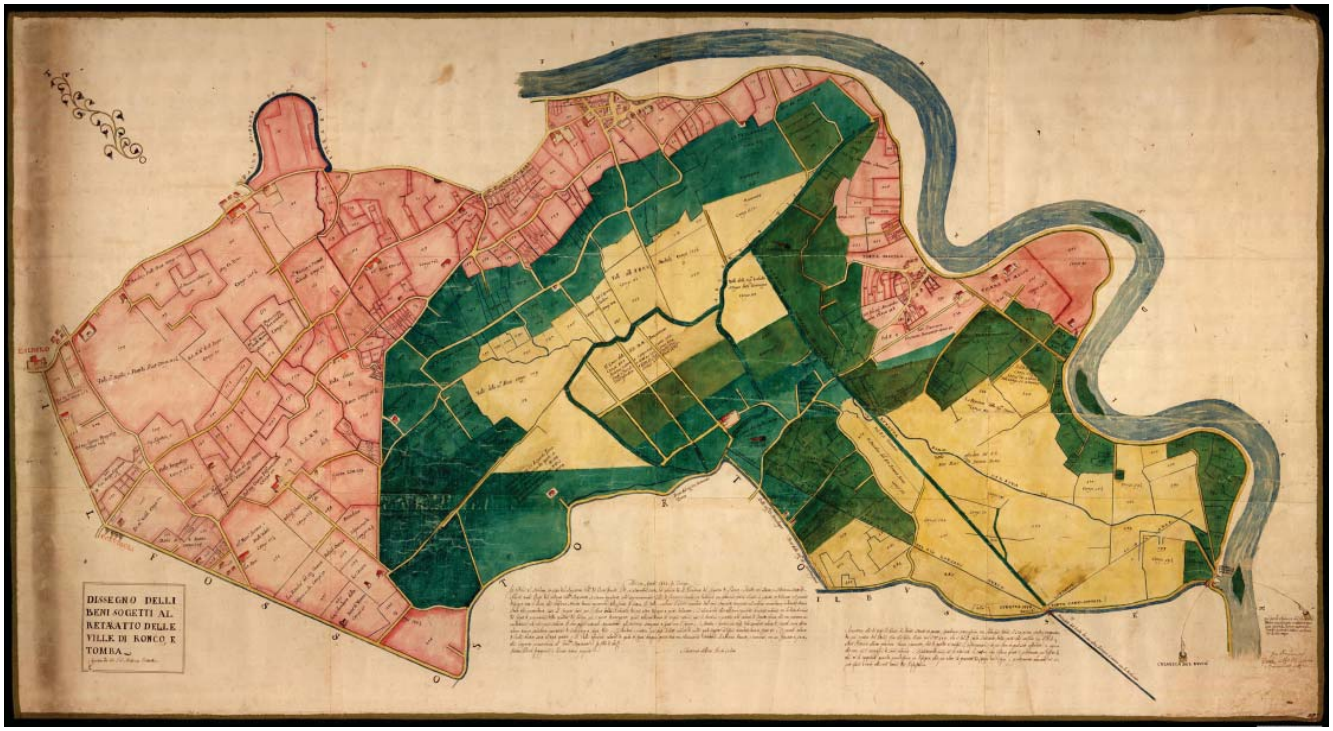
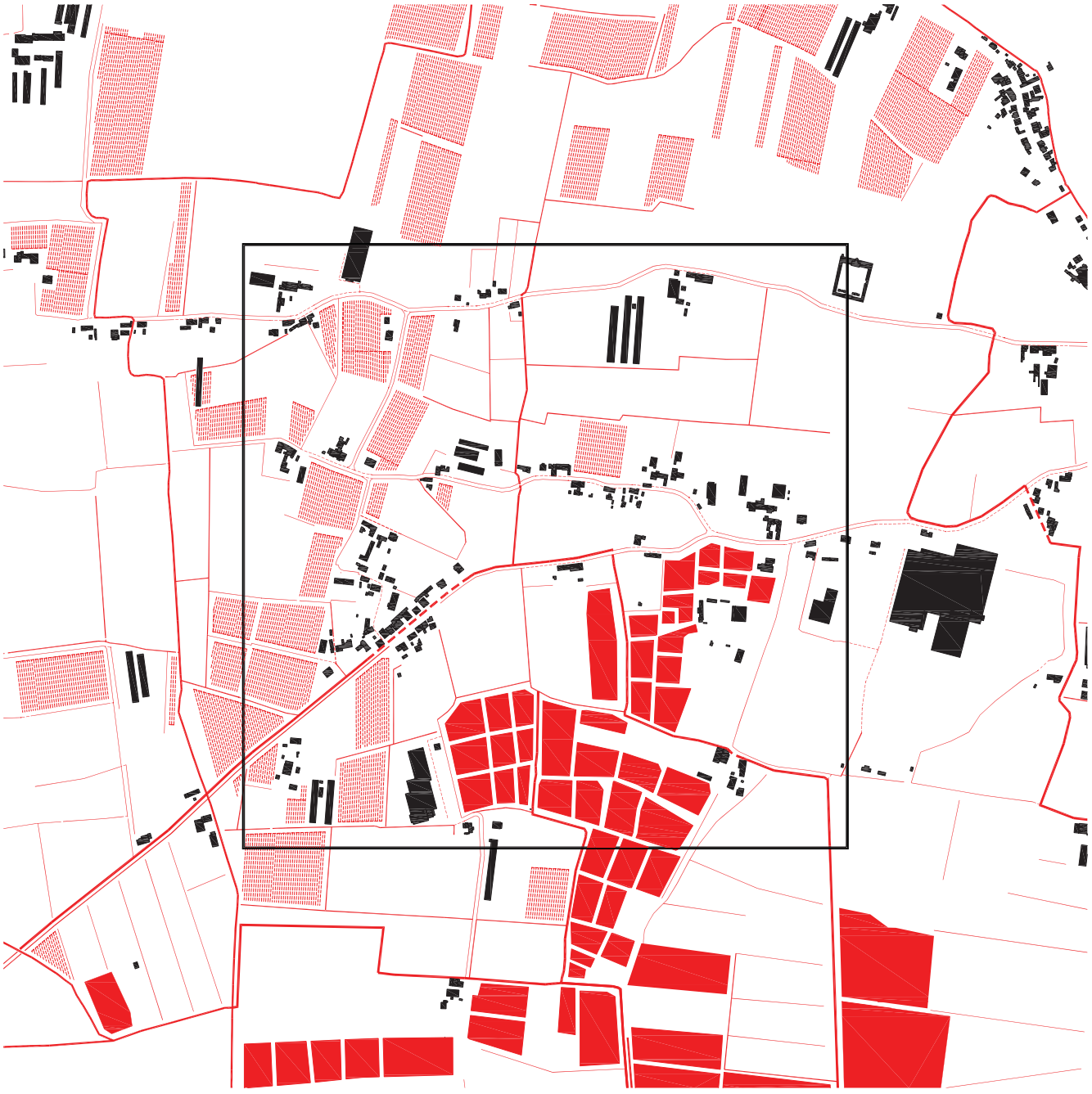


Figure 5.4. Alberti, S., 1684, Dissegno delli beni sogetti al retratto delle ville di Ronco, e Tomba. Courtesy of Archivio di Stato di Verona.

Chapter 6

Water processes

Figure 6.1. Irrigation and drainage systems from 1955 (left) and 2007 (right) located in the case study area.



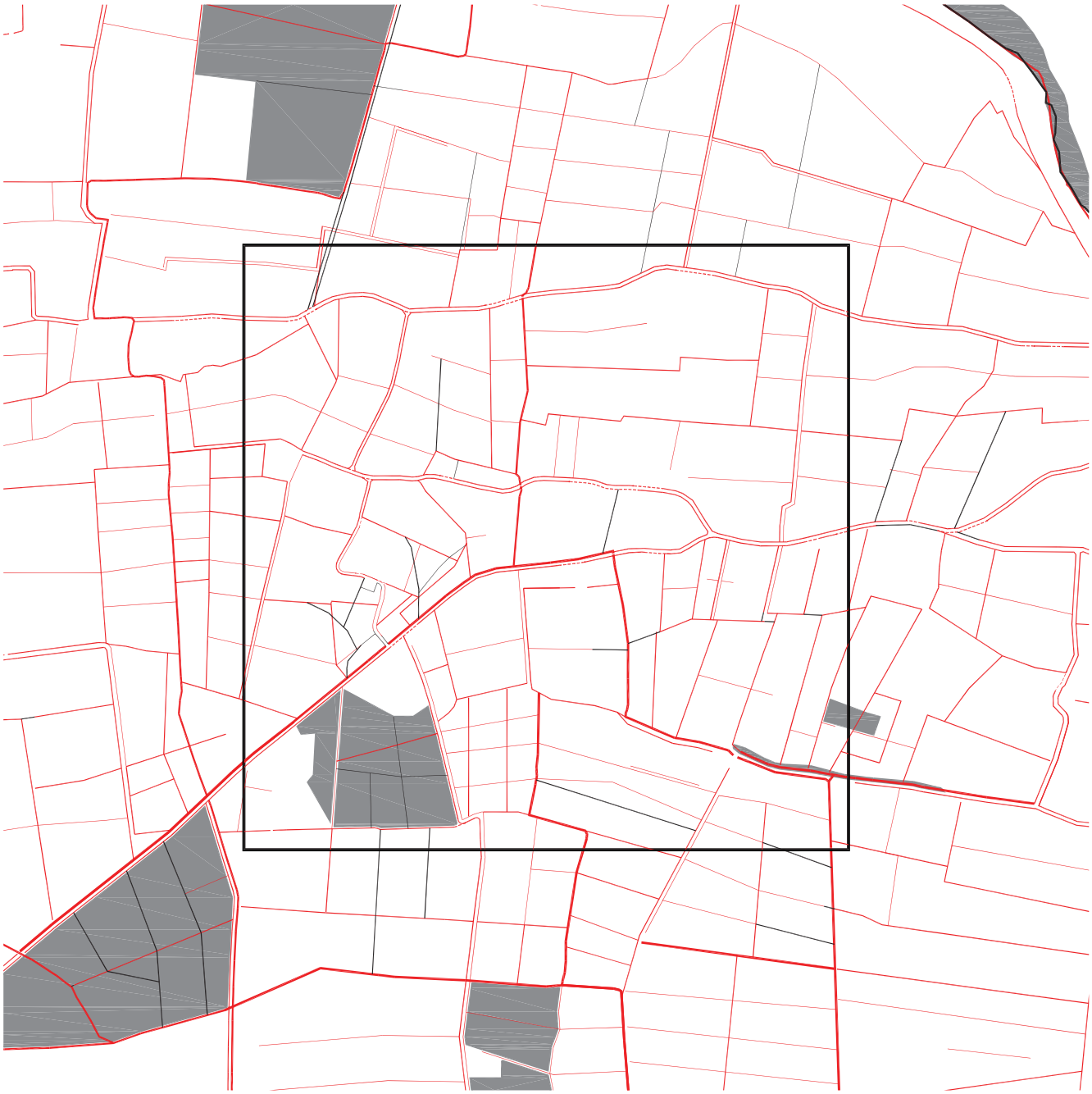


Figure 6.2. Overlapping of the irrigation and drainage systems from 1888 (dark grey) and 1955 (red) in the case study area. The map exhibits also wetlands, meadows and rice paddies from 1888 (grey patches).

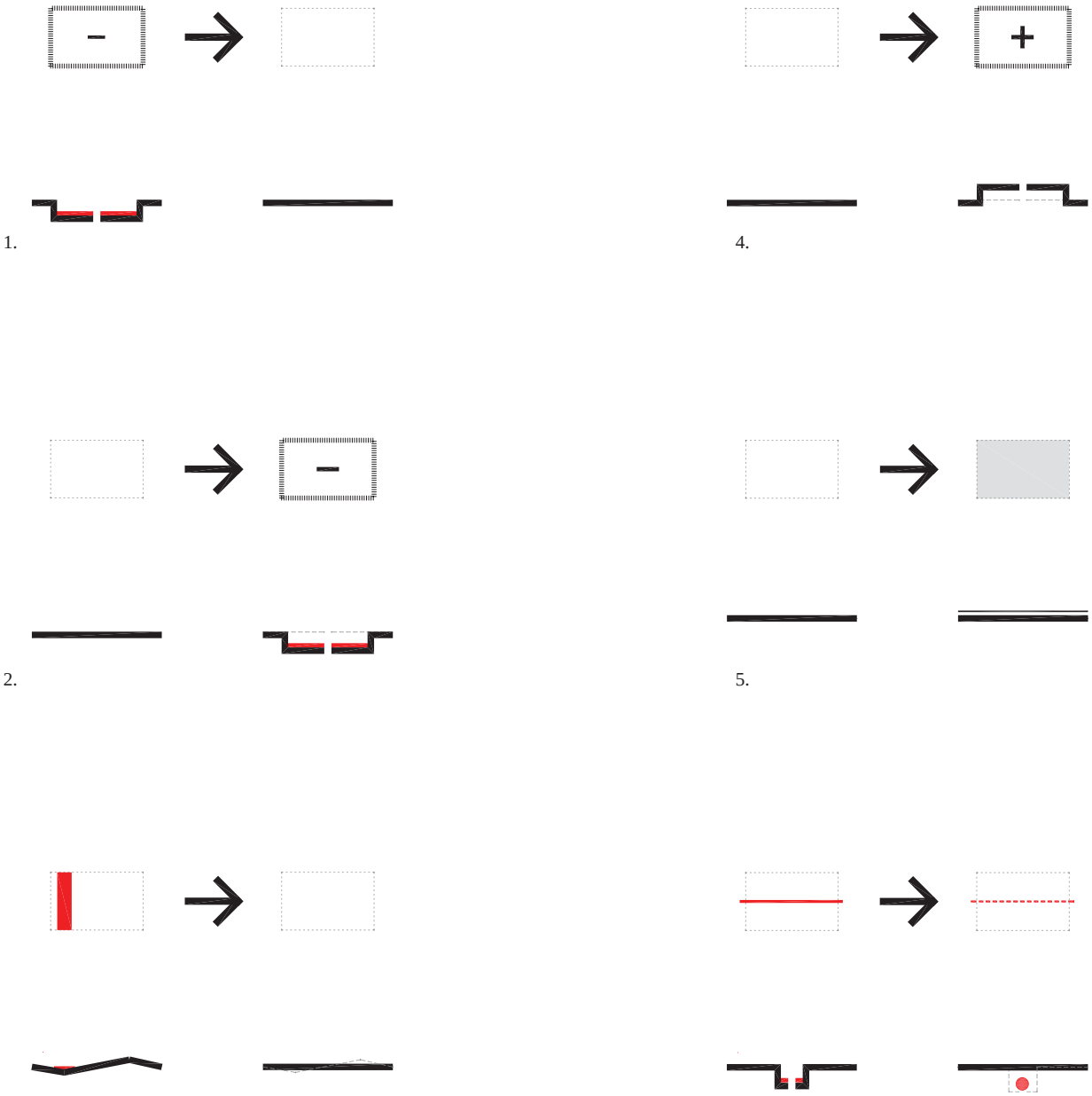


Figure 6.3. The basic operations effectuated on the water-flows landscape structures. Filling up (1). Excavating (2). Levelling (3). Rising (4). Sealing (5). Piping (6).

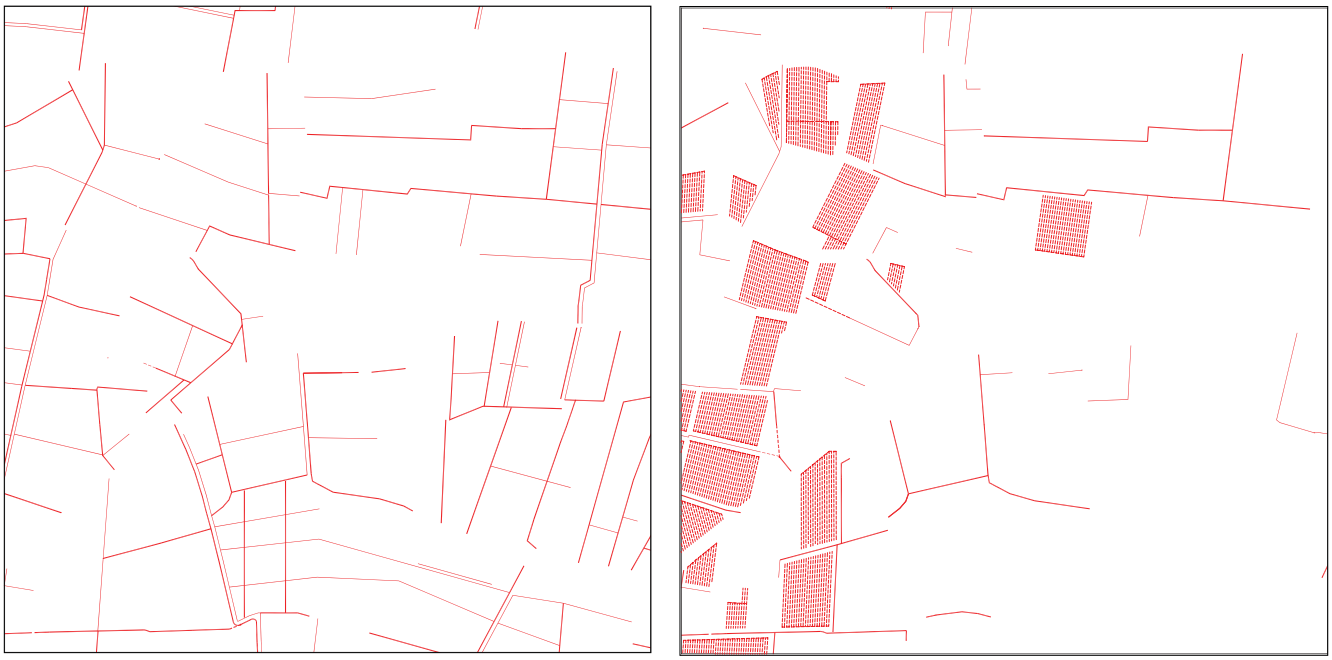


Figure 6.4.(top) The patterns of the field water system of 1955 (left) and 2007 (right) in the case study area.

Figure 6.5.(bottom) Field system, past situation (left) (source: Scola Gagliardi, 2009: 103) and present situation (right).

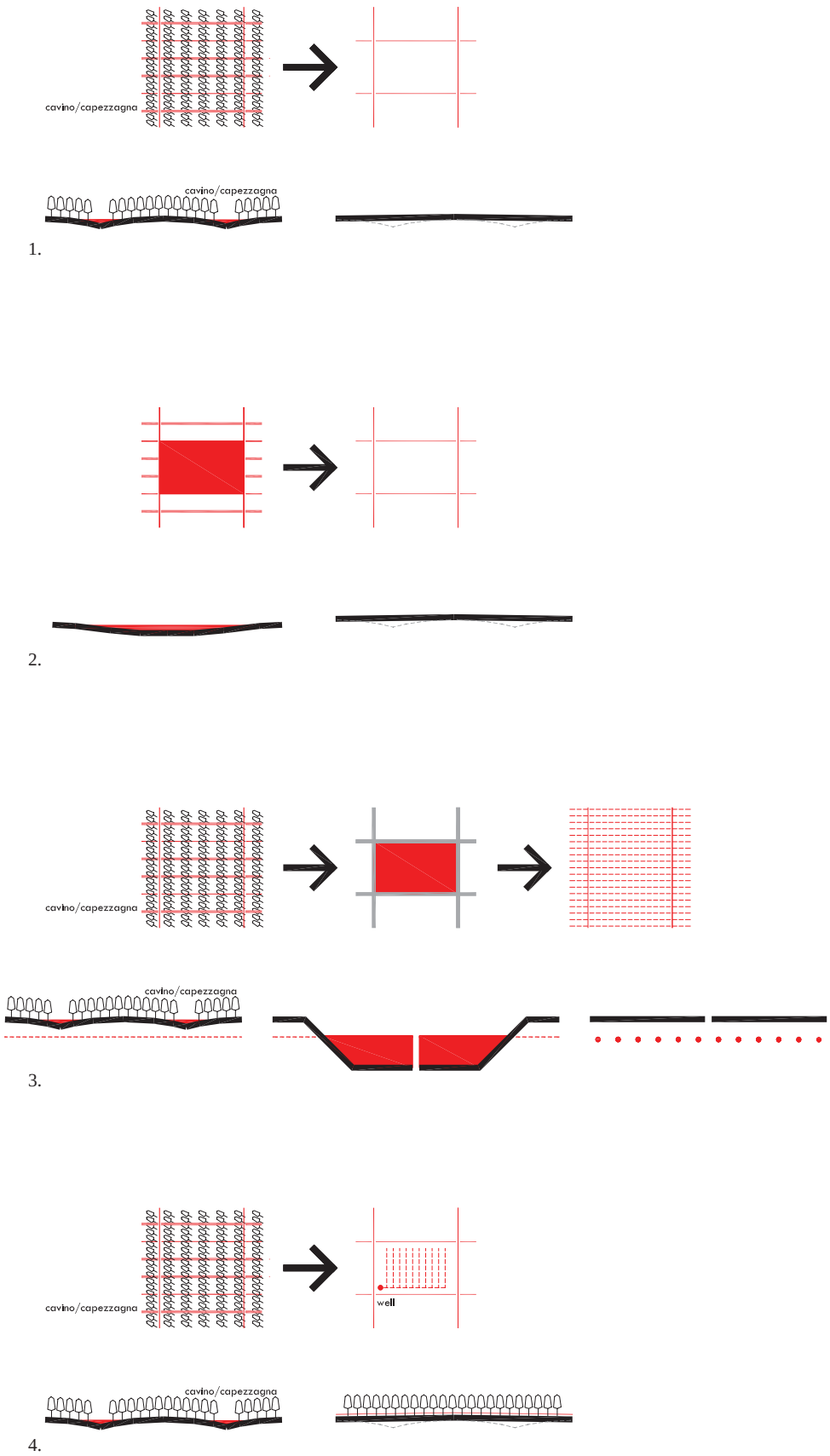


Figure 6.6. Field system models 1955-2007. Structures and processes of change. Levelling (1). Filling (2). Excavating, filling and piping (3). Levelling and piping (4).

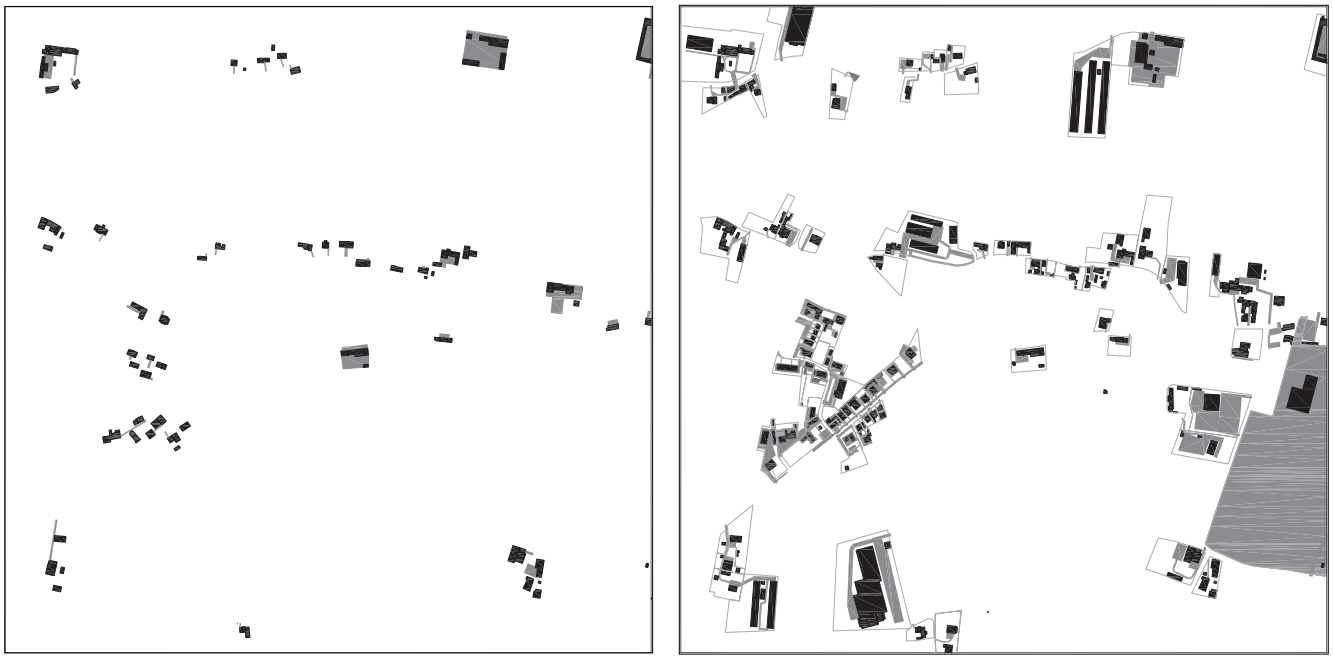


Figure 6.7.(top) The patterns of the impervious covering of the built lot system of 1955 (left) and 2007 (right) in the case study area. Paved areas (black), semi-paved areas (grey).

Figure 6.8.(bottom) Built lot system, past situation (left) (source: Scola Gagliardi, 2009: 118) and present situation (right).

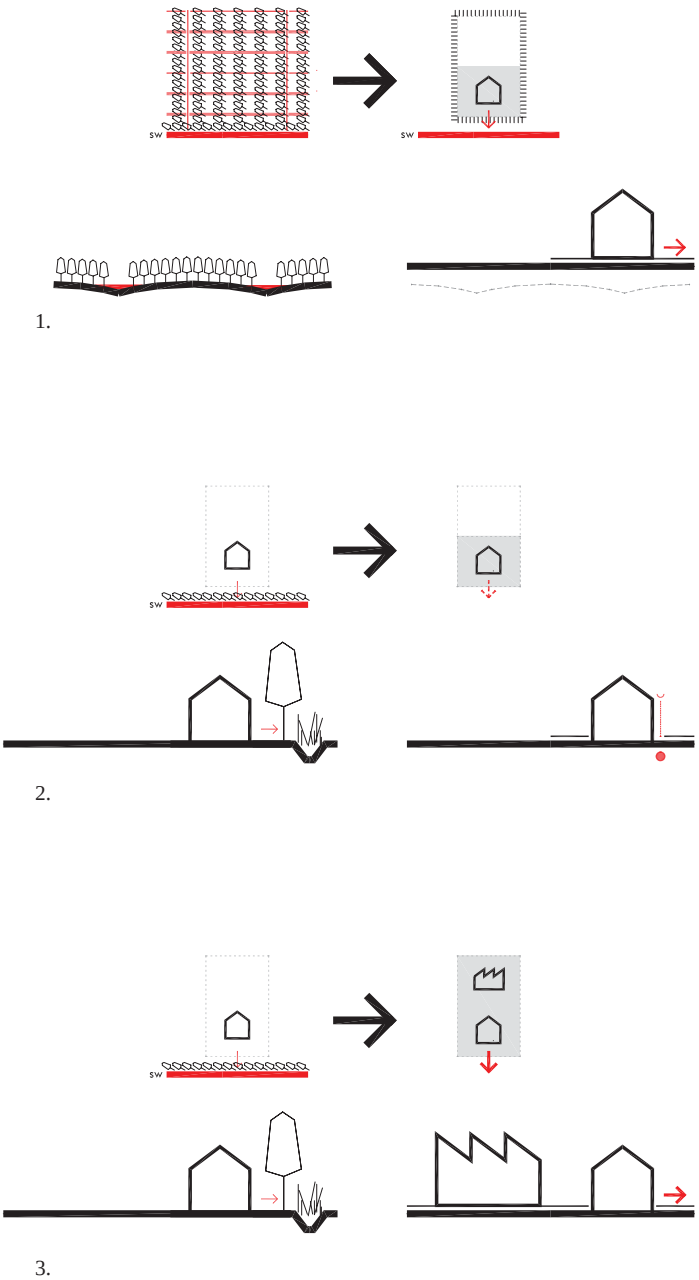


Figure 6.9. Built lot system models 1955-2007. Structures and processes of change. Rising and sealing (1). Filling up, piping and sealing (2). Filling up, piping and sealing (3).

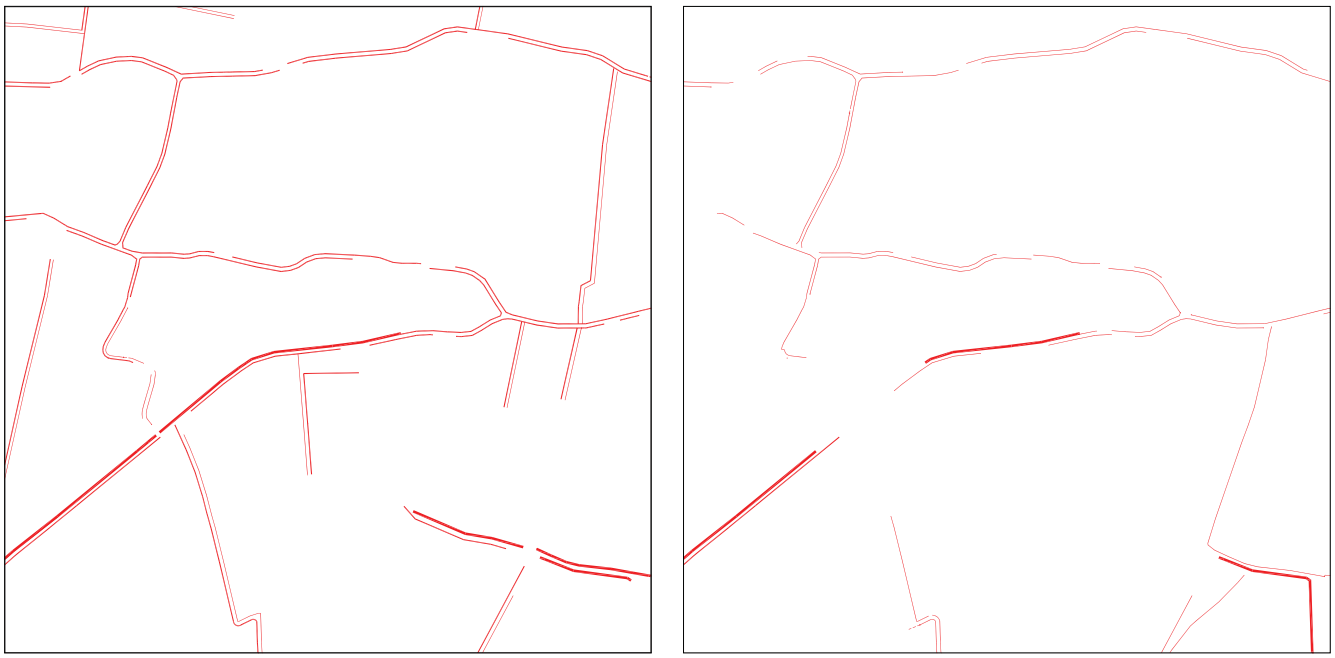


Figure 6.10.(top) The patterns of the road system, 1955 (left) and 2007 (right).

Figure 6.11.(bottom) Road system, past situation (left) (source: Scola Gagliardi, 2009: 97) and present situation (right).

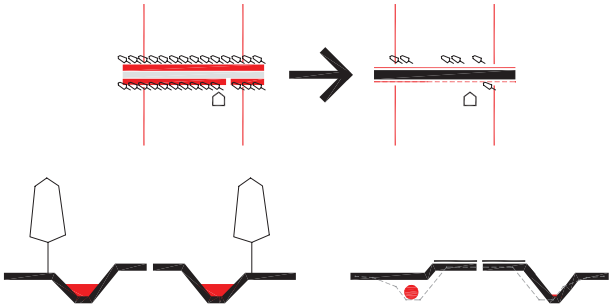


Figure 6.12. Road system models 1955-2007. Structures and processes of change. Filling up, piping and sealing.

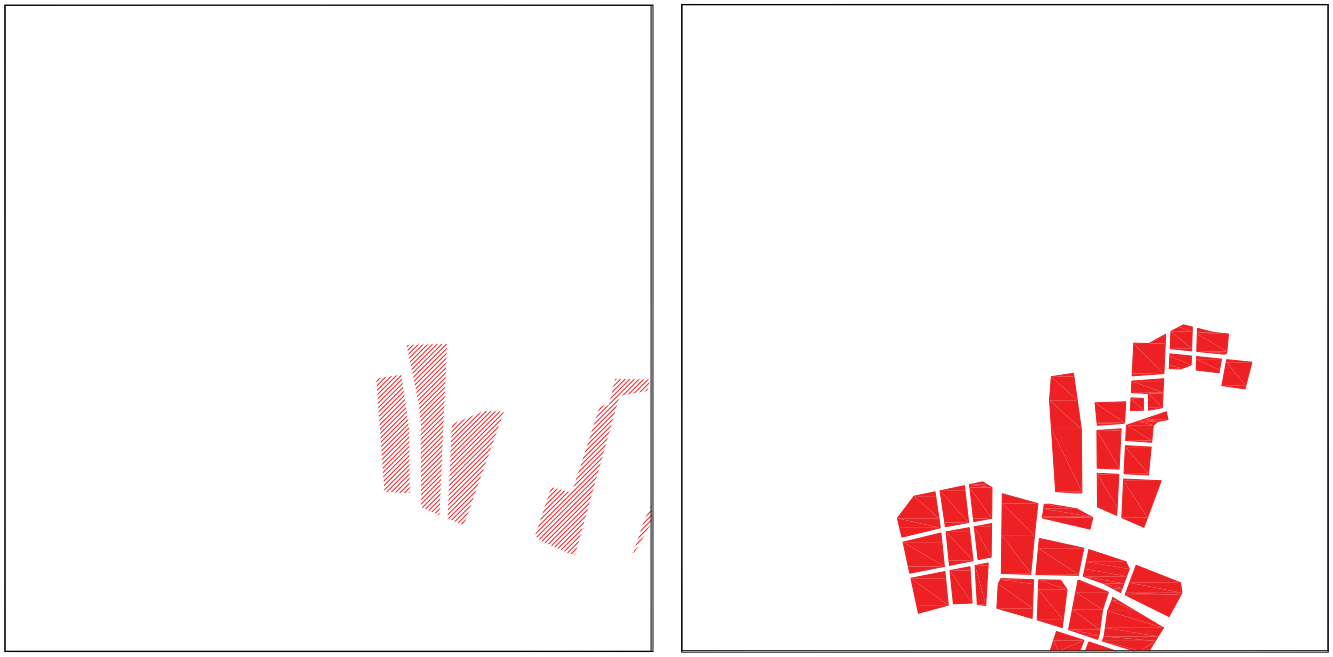
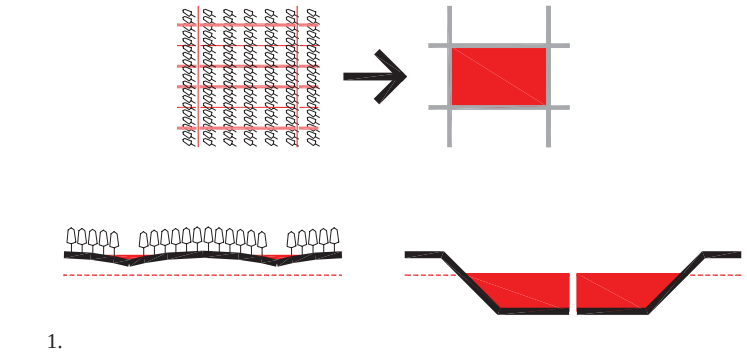
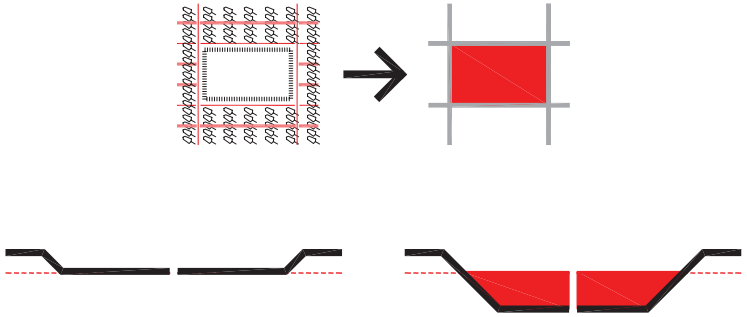


Figure 6.13.(top) The patterns of the excavation site system of 1955 (left) and 2007 (right) in the case study area.

Figure 6.14.(bottom) Excavation site system, past situation (right) (source: Dittongo e Santi, 1999: 129) and present situation (right).



1.



2.

Figure 6.15. Excavation site system models 1955-2007. Structures and processes of change. Excavating (1, 2).

Figure 6.16.(top) The patterns of the stream system of 1955 (left) and 2007 (right) in the case study area.

Figure 6.17.(bottom) Stream system, past situation (left) (source: Scola Gagliardi, 2009: 91) and present situation (right).

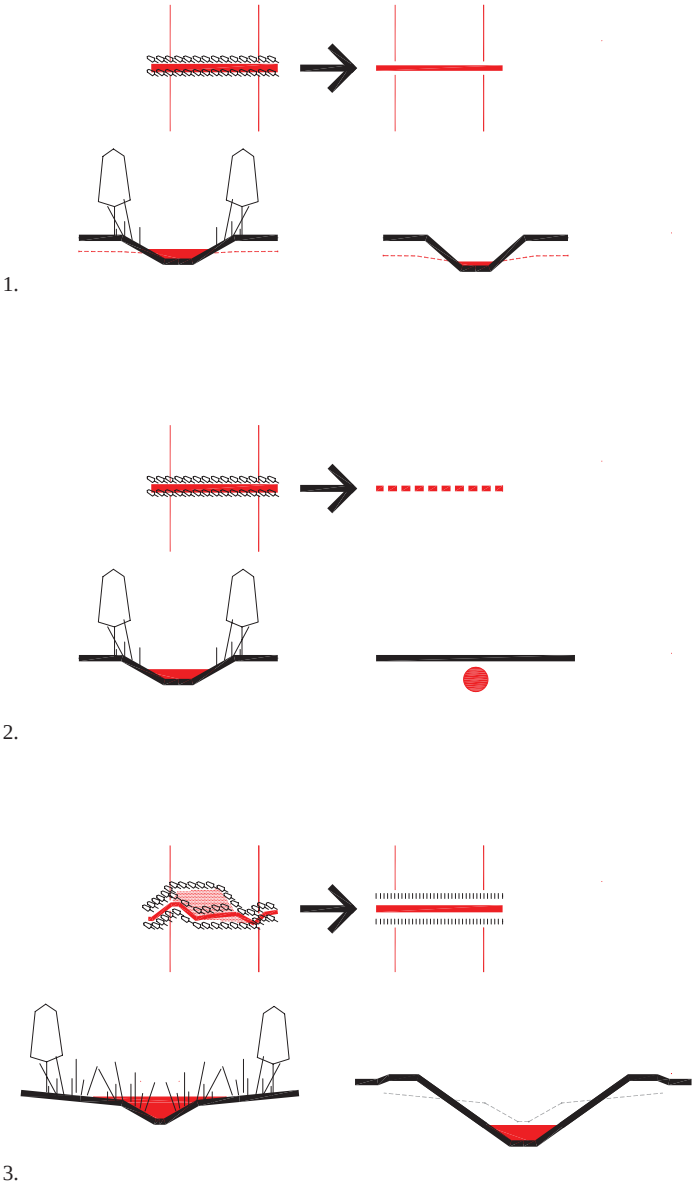


Figure 6.18. Stream system models 1955-2007. Structures and processes of change. Filling up and excavating (1). Filling up and piping (2). Filling up, excavating and rising (3).

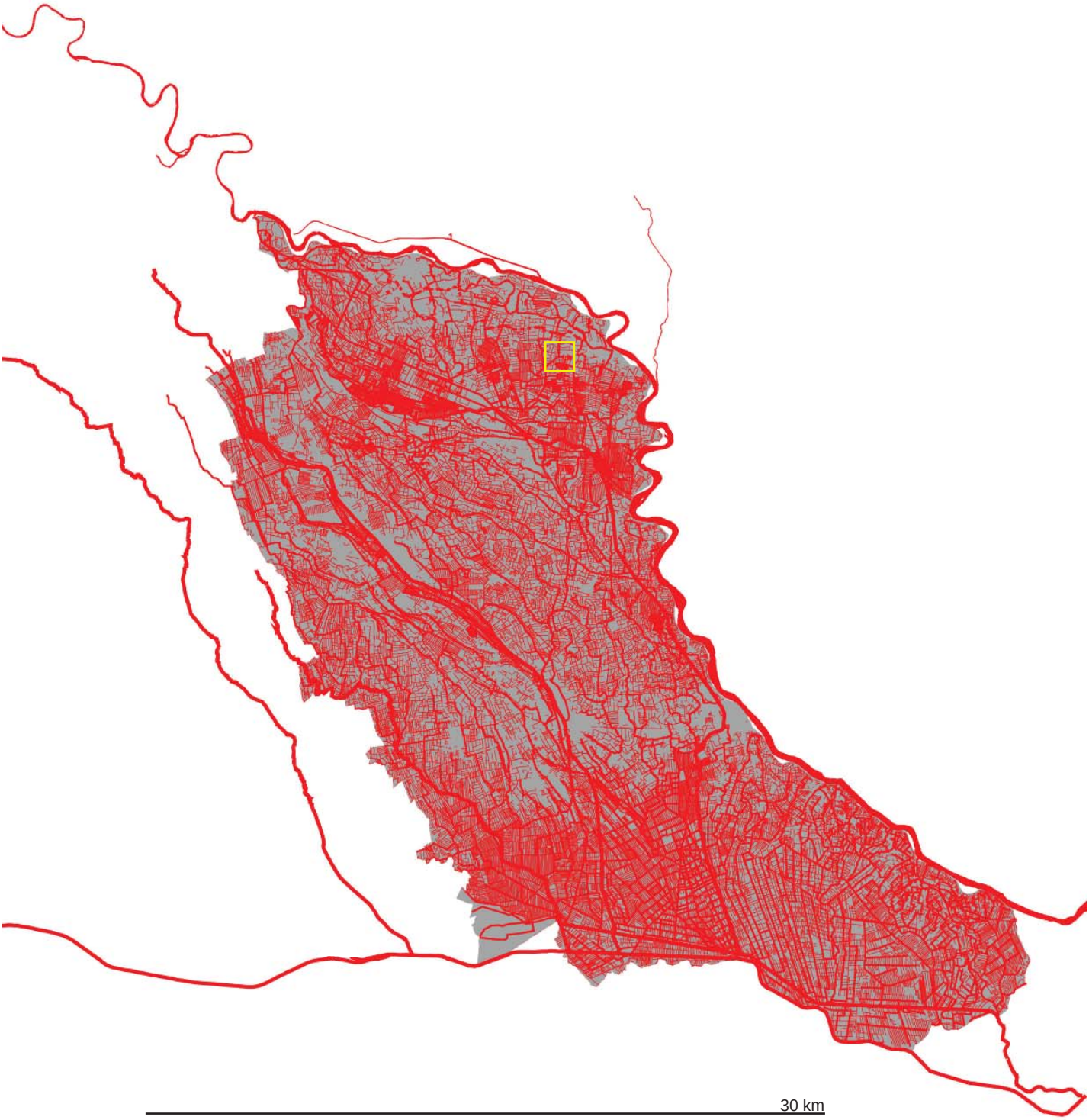


Figure 6.19. The surface water system in the waterboard Consorzio Valli Grandi e Medio Veronese. Network (red lines), case study area (yellow).

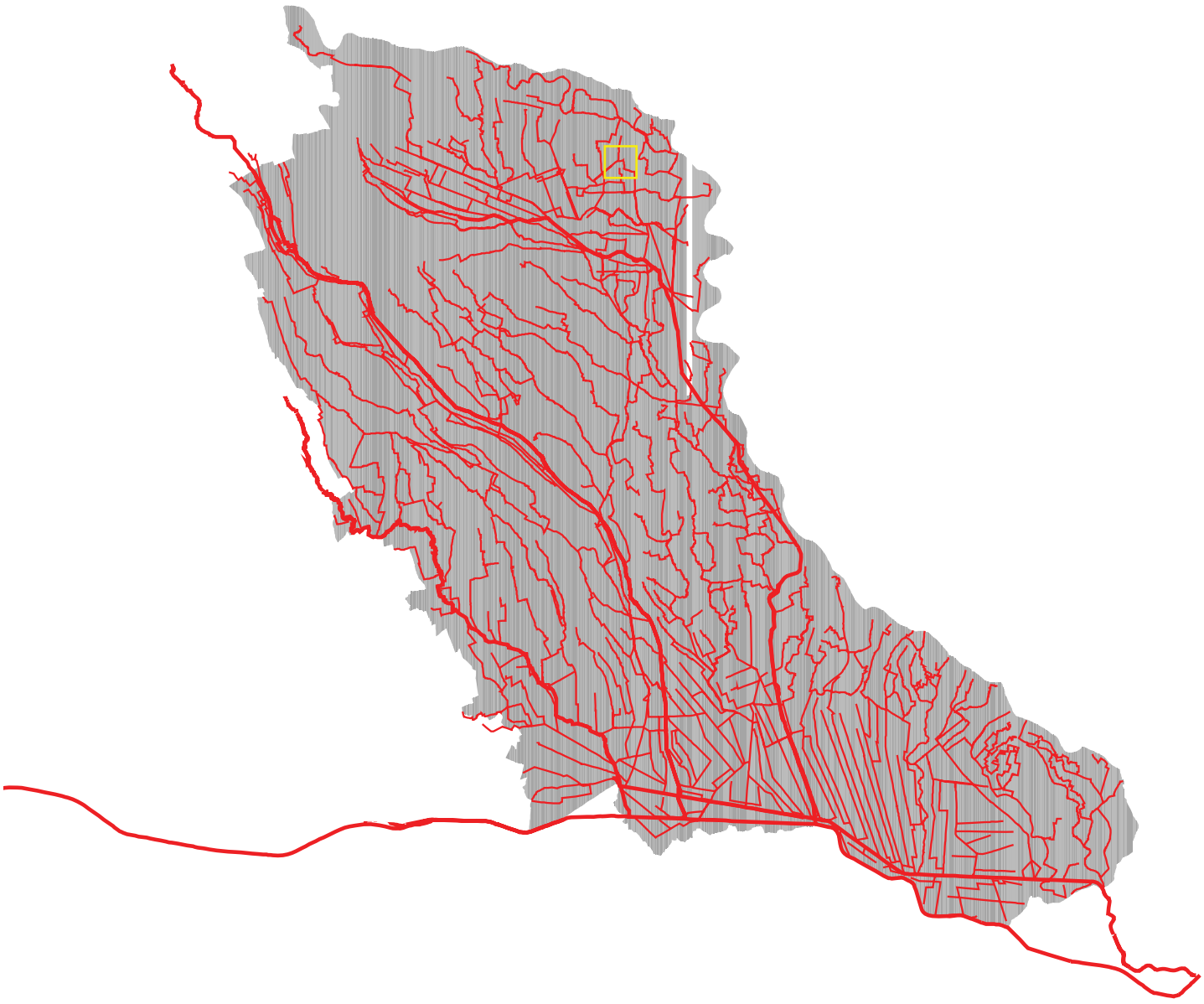


Figure 6.20. The main drainage system over the agricultural matrix of the Consorzio Valli Grandi e Medio Veronese waterboard. Network (red lines), case study area (yellow).

Figure 6.21. Flooded areas in May 2002 (solid hatch) and March 2004 (net hatch) in the Consorzio Valli Grandi e Medio Veronese waterboard. According to the waterboard, in May 2002 the flooded areas were about 390 ha, and in March 2004 they were about 430 ha. Source: Consorzio di Bonifica Veronese.

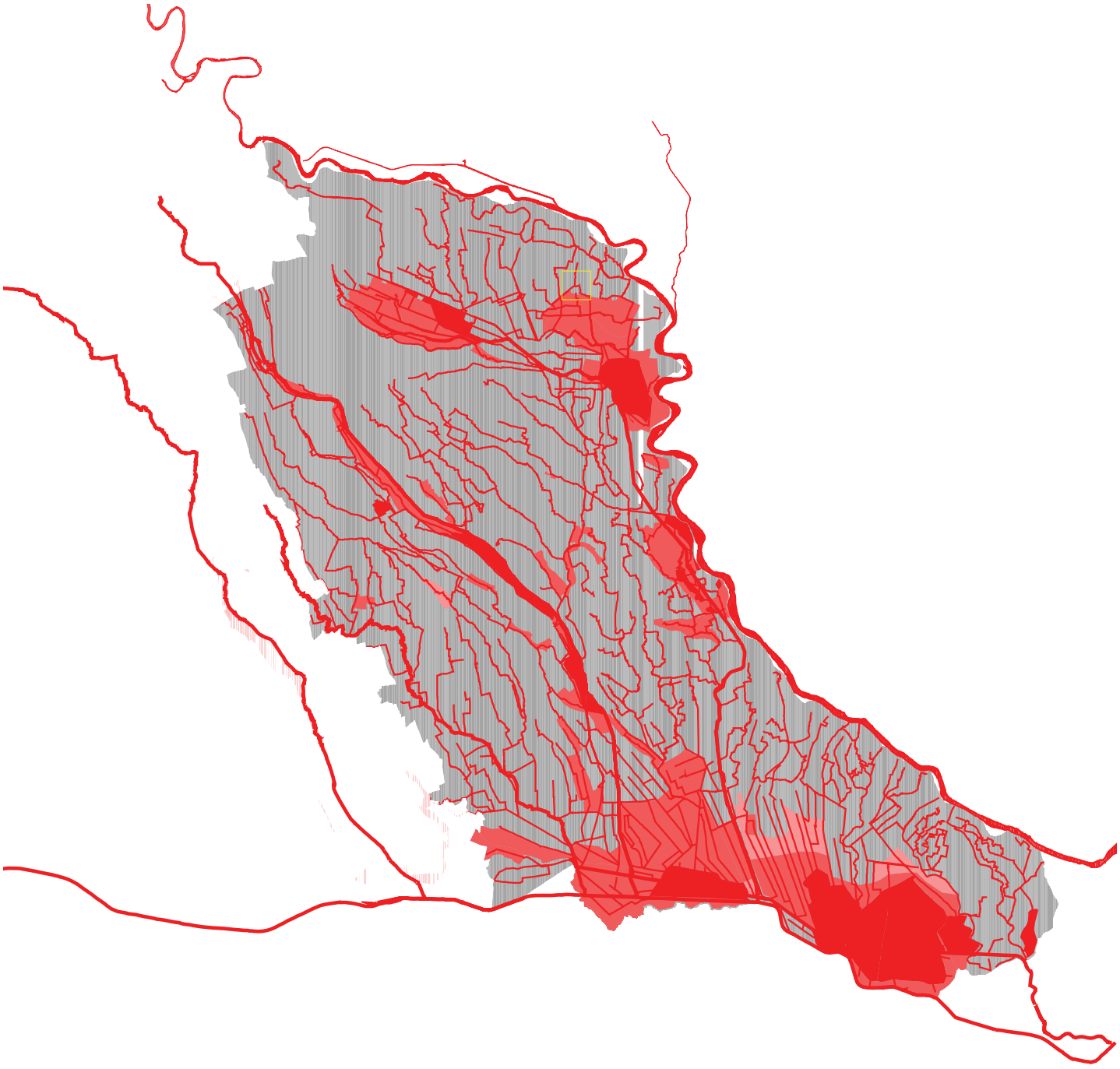


Figure 6.22. Floodable areas in the catchment area of the Consorzio Valli Grandi e Medio Veronese waterboard in the case of a storm with an Average Recurrence Interval of 30 years. Areas where the risks of flood is low (very light red), moderate (light red) and high (red).

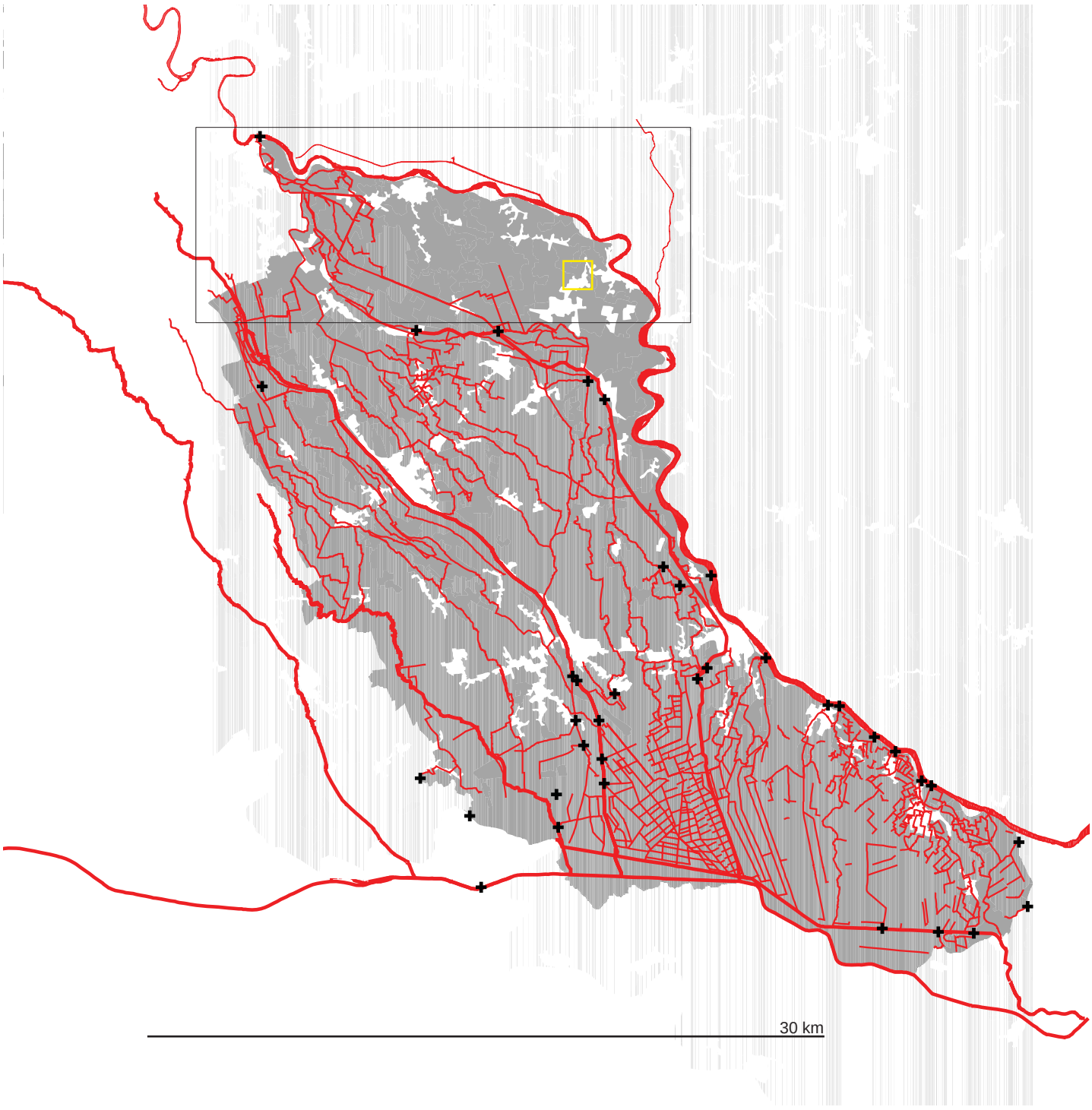


Figure 6.23. The main irrigation system over the agricultural matrix of the Consorzio Valli Grandi e Medio Veronese waterboard. Network (red lines), nodes of diversions (black crosses), case study area (yellow).

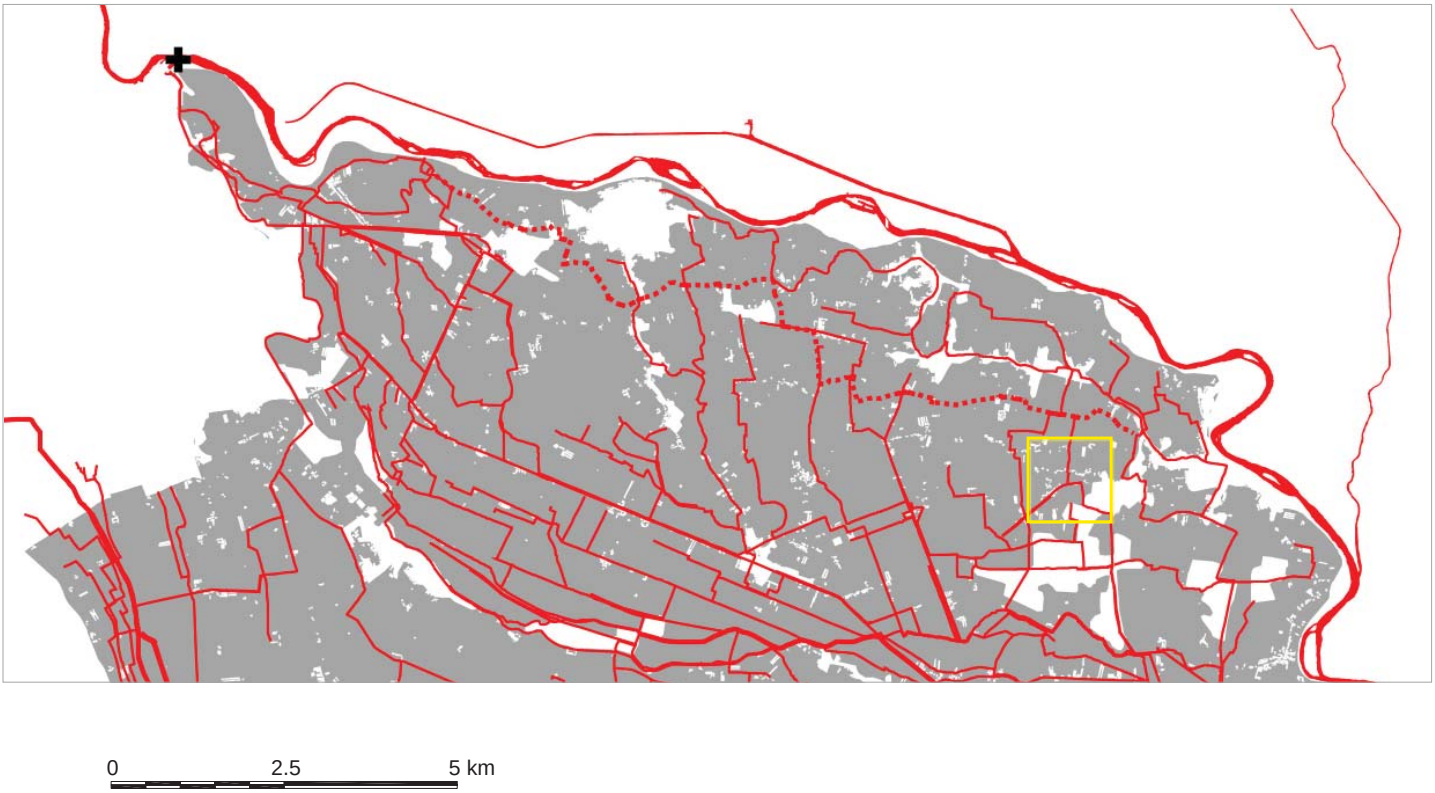
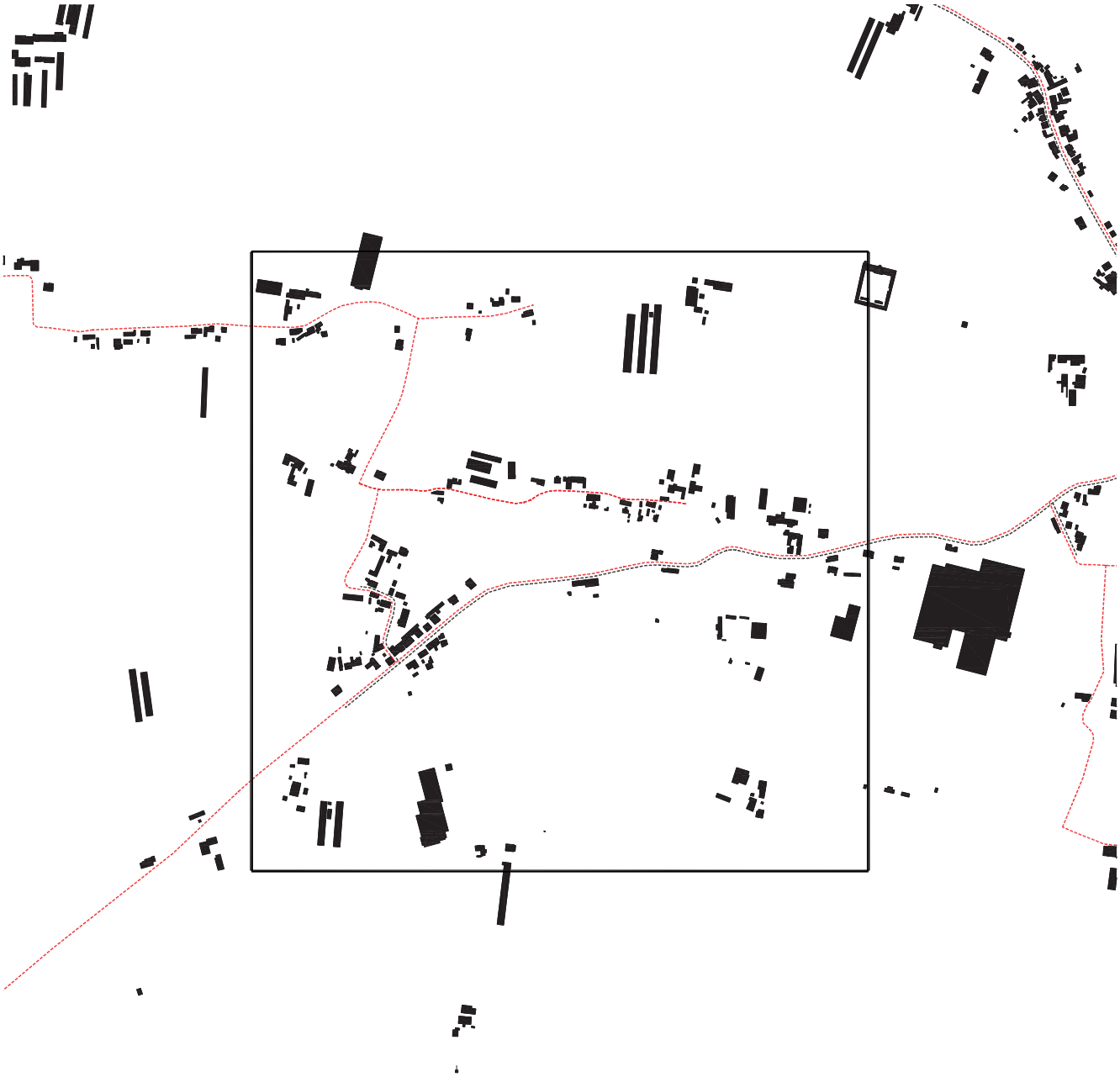


Figure 6.24. The route of the planned irrigation system Collettore Zeviano over the agricultural matrix of the Consorzio Valli Grandi e Medio Veronese waterboard. The map shows how the new system will connect with the existing N-S streams to feed them with irrigation water diverted from the Adige River. The extraction node in Sorio (black cross), the piped line of the Collettore Zeviano (red dotted line), the streams network managed by the waterboard (red lines), the case study area (yellow square). Source: Consorzio di Bonifica Veronese.

Figure 6.25. Drinking and waste water systems of 1955 (left) and 2007 (right) in the case study area. Drinking water piped network (red dotted lines), waste water piped network (black dotted lines).



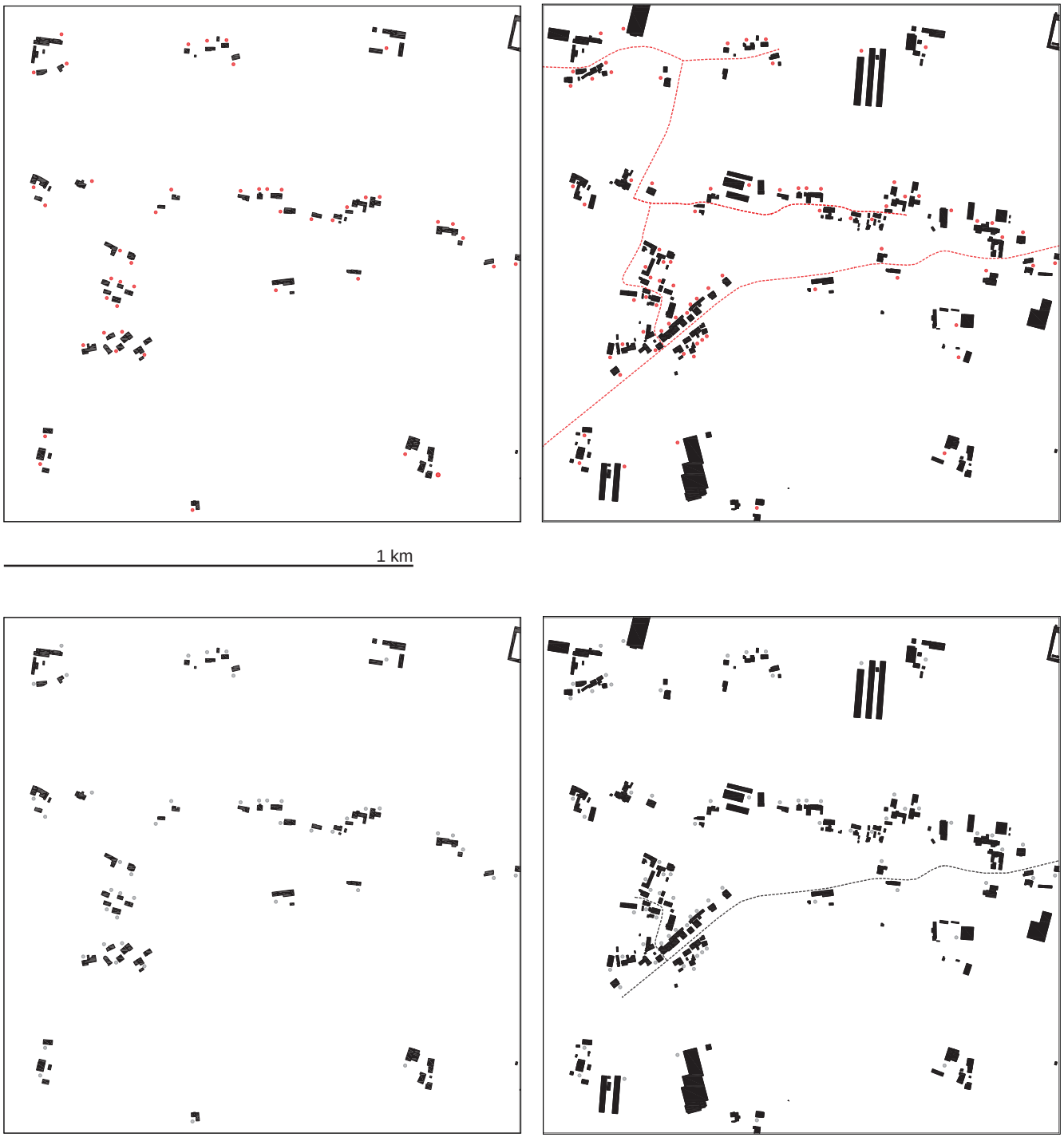


Figure 6.26.(top) The patterns of the drinking water system of 1955 (left) and 2007 (right) in the case study area. Piped network (red dotted lines), wells (red dots).

Figure 6.27.(bottom) The patterns of the waste water system of 1955 (left) and 2007 (right) in the case study area. Piped network (black dotted lines), individual treatment systems (grey dots),

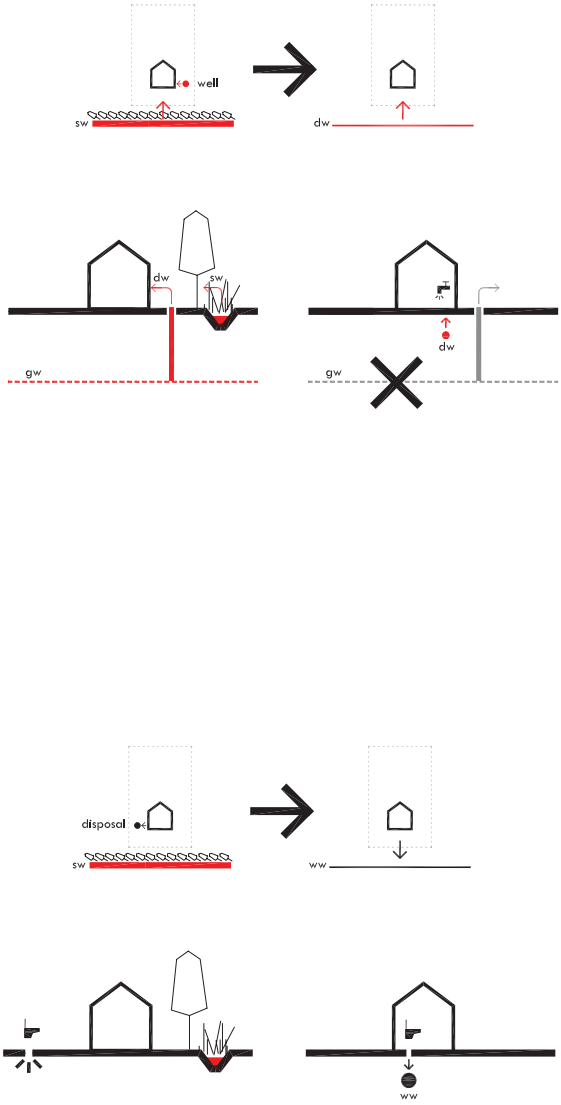


Figure 6.28.(top) Drinking water system models 1955-2007. Structures and processes of change. Piping.

Figure 6.29.(bottom) Waste water system models 1955-2007. Structures and processes of change. Piping.

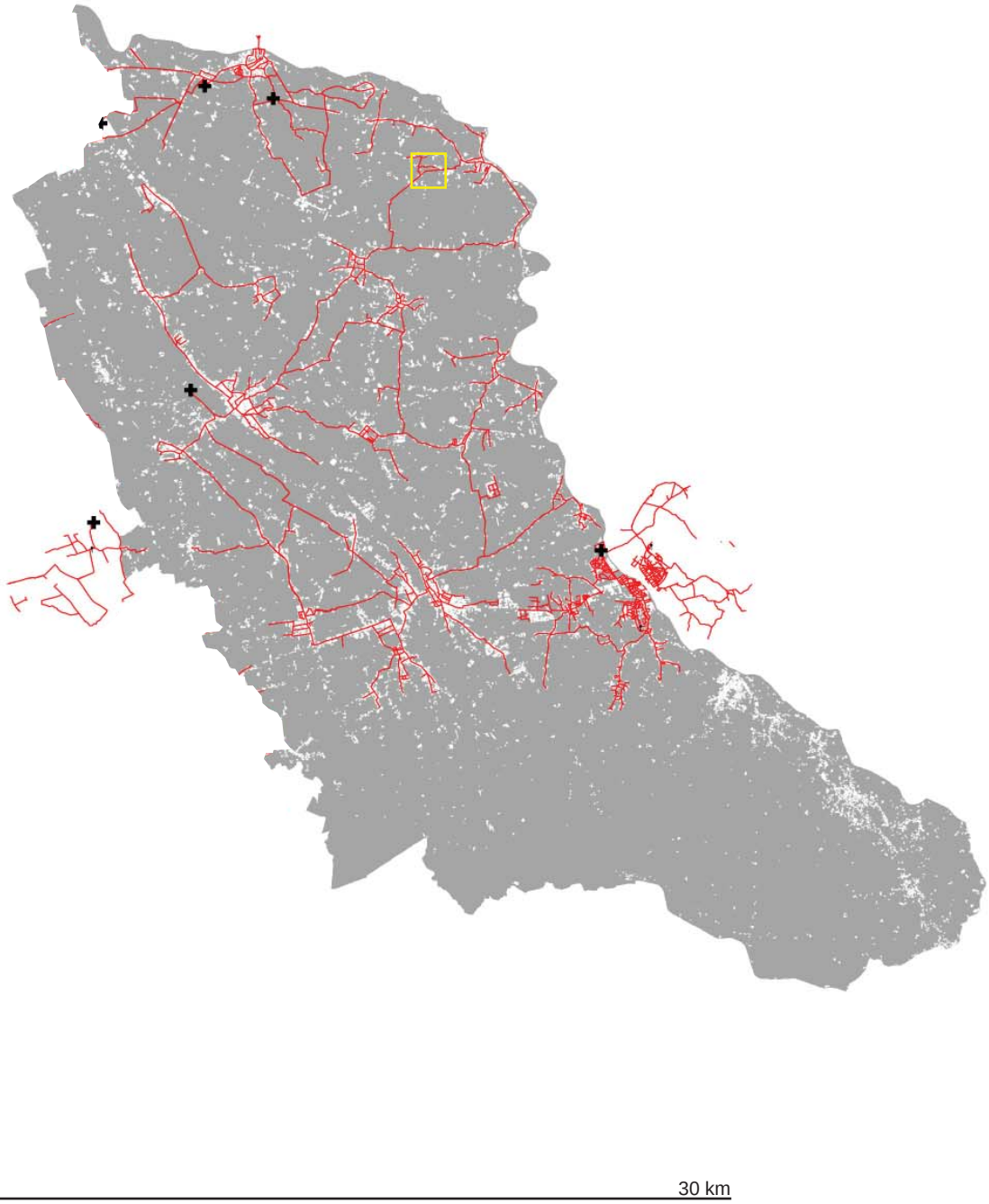


Figure 6.30. The centralized drinking water system and the built environment in the Consorzio Valli Grandi e Medio Veronese waterboard. Piped network (red lines), nodes of extraction (black crosses), case study area (yellow), built environment (white dots). The systems in the municipalities of the bottom-end part of the catchment (Badia Polesine, Castagnaro and Giacciano con Baruchella) are not represented.

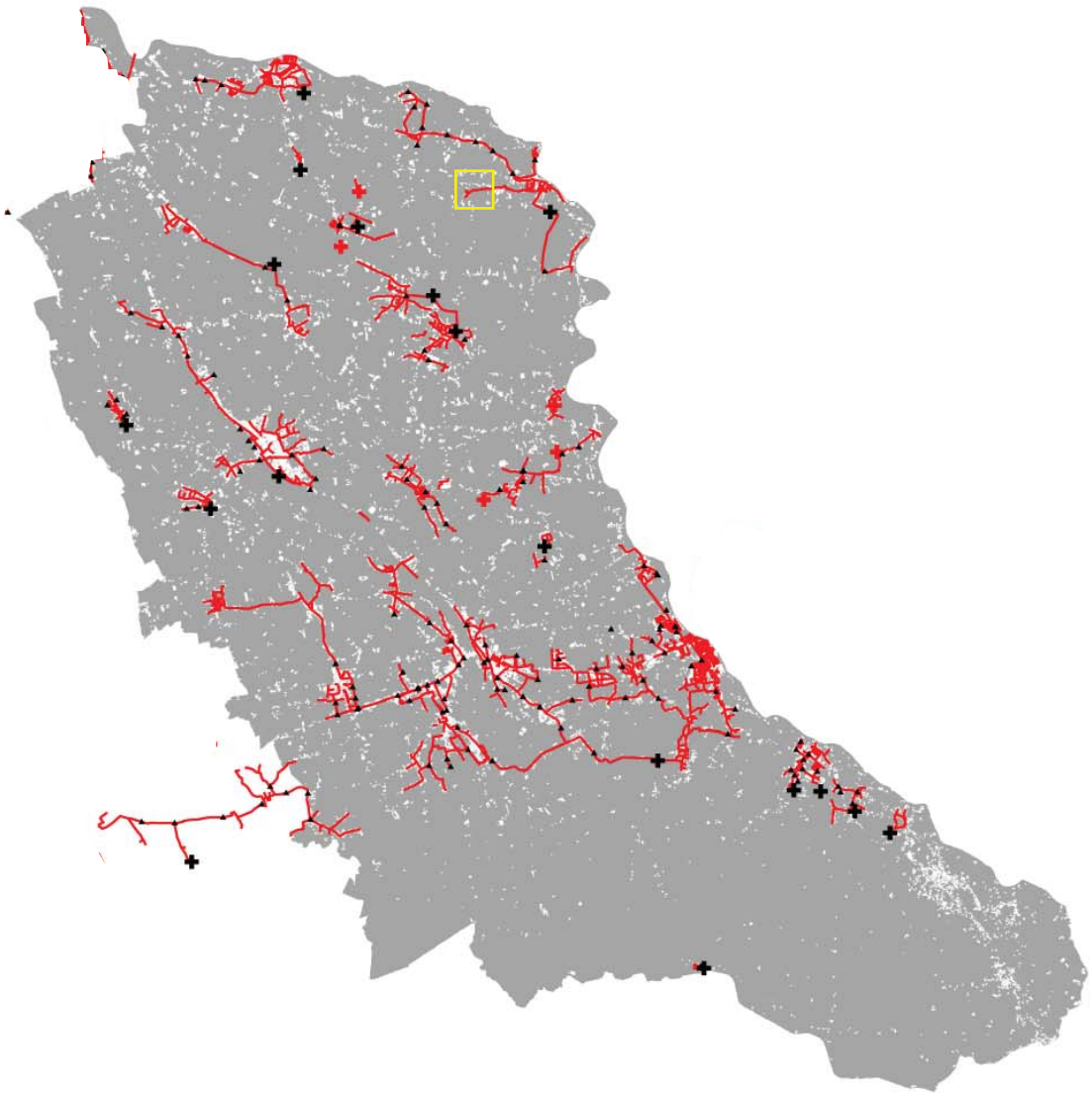


Figure 6.31. The centralized waste water system and the built environment in the Consorzio Valli Grandi e Medio Veronese waterboard. Piped network (red lines), lifting systems (small black triangles), treatment plants (black crosses), case study area (yellow), built environment (white dots). The systems in the municipalities of the bottom-end part of the catchment (Badia Polesine, Castagnaro and Giacciano con Baruchella) are not represented.

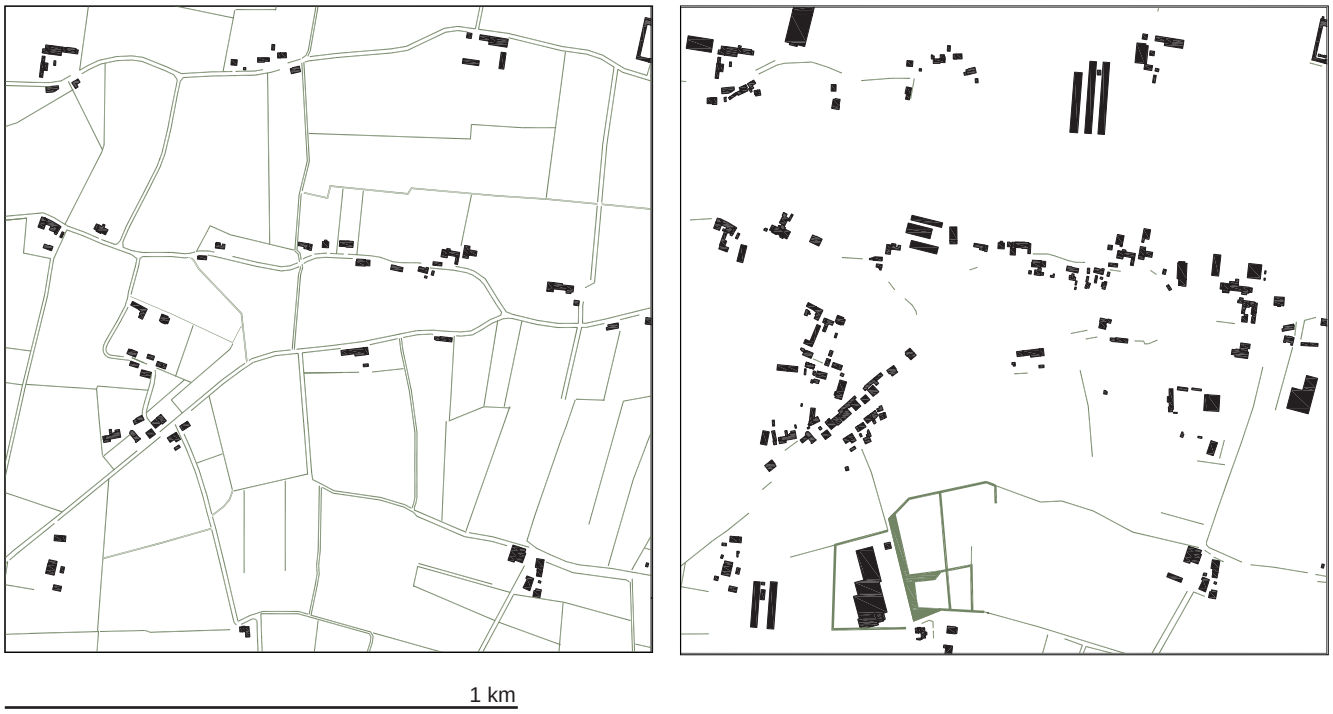
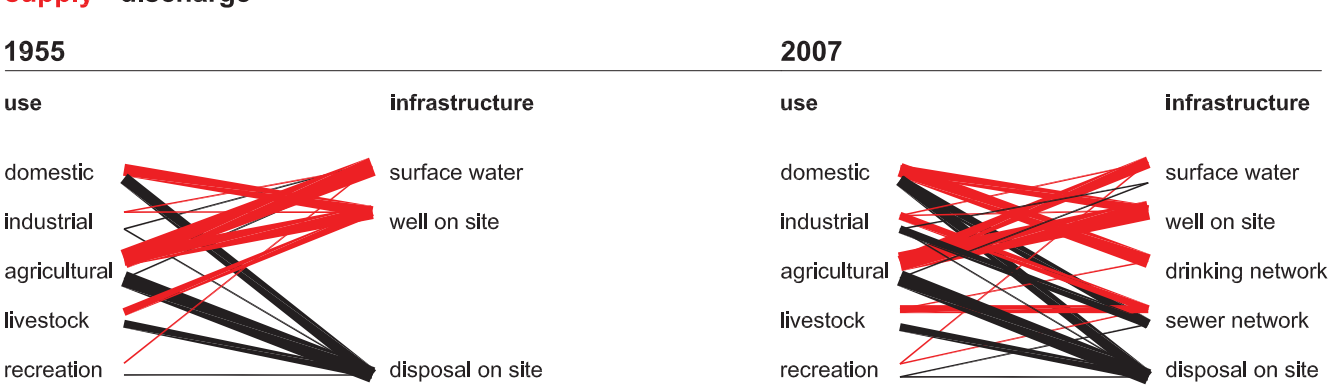


Figure 6.32. The patterns of the green corridors of 1955 (left) and 2007 (right) in the case study area. The micro-corridors of the mixed farming system spread throughout the framed landscape in 1955 are not represented.

Figure 6.33. The patterns of the accessibility of 1955 (left) and 2007 (right) in the case study area. Spaces of public access (black), spaces of private access (grey).



Water System in the *Città Diffusa*

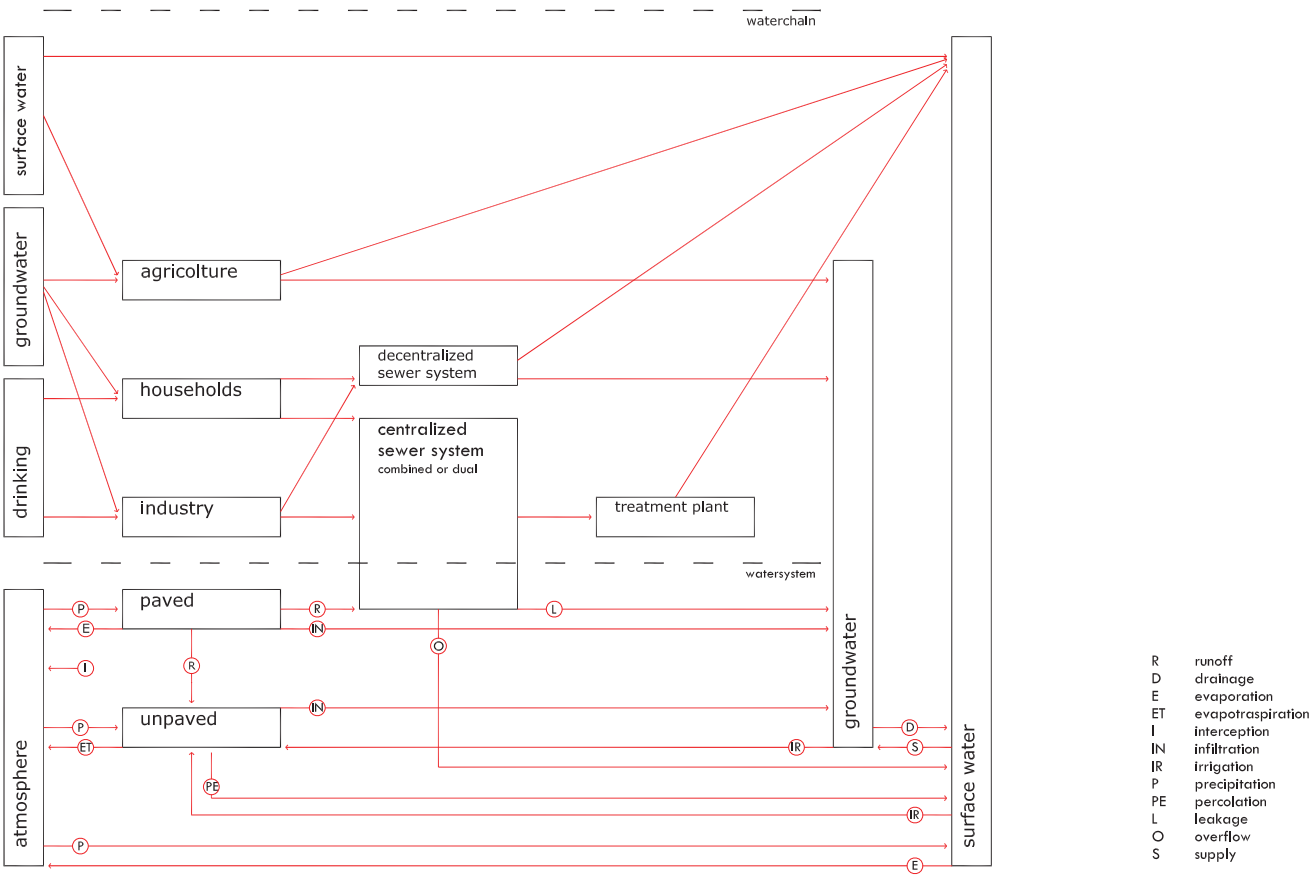
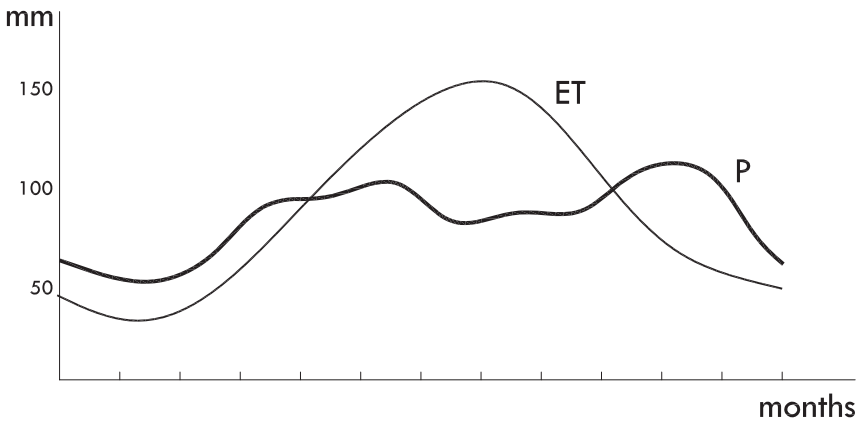


Figure 6.34.(top) Water uses and infrastructures of 1955 and 2007 in the Veneto *Città Diffusa*. According to Marsalek et al. (2008: 26) the water demand transformation has been estimated by disaggregating the total delivery of water to the area into a number of classes of water use and determining separate average rates for each class. The qualitative analysis of the demand makes use of investigations conducted on the case study area.

Figure 6.35.(bottom) The complex water system of the Veneto *Città Diffusa*. Adapted and based on the studies of van der Toorn Vrijthff and van de Ven, 2008: 11.

Chapter 7

Landscape and water strategies



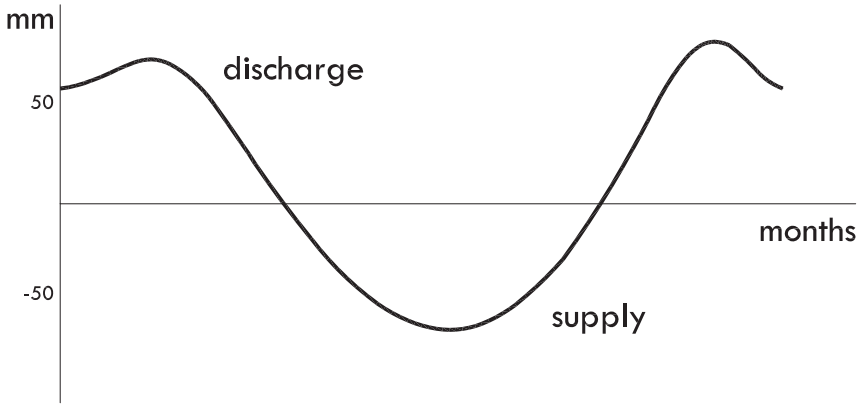


Figure 7.1.(top) Rhythm of precipitation (P) and evapotranspiration (ET) during the year. Data set from: Chiaudani, 2008: 59; Bixio et al., 2010: 195.

Figure 7.2.(bottom) Rhythm of supply and discharge during the year. Data set from Chiaudani (2008: 59) and Bixio et al. (2010: 195).

Figure 7.3. Pilot projects in the Veneto. Top. Pilot Project Cava Merotto, 2008. Project proposal and realization. Source: Viganò et al. (2009). Bottom. Pilot Project Vallevecchia, plan and realization, 2000. Source: Veneto Agricoltura.

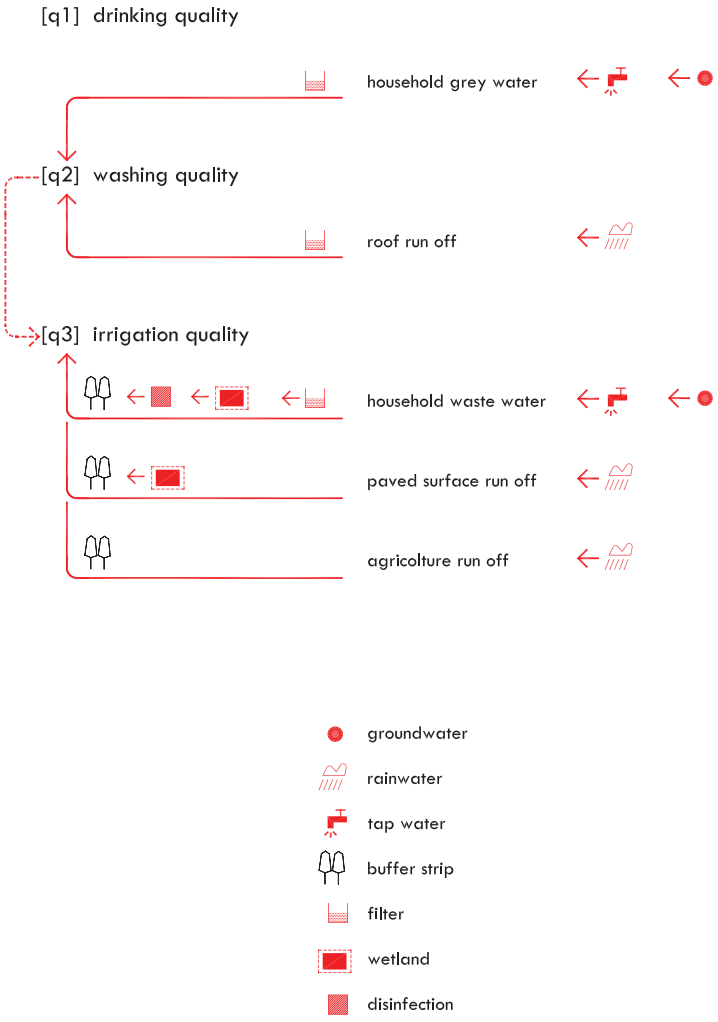


Figure 7.4. Water recycling in low plain contexts. Water runs “from clean to polluted”. Accordingly, each water flow requires a specific recycling process. The diagram addresses different water flow qualities with specific recycling processes and related technical devices and/or landscape elements. For example, wastewater from households can be recycled for irrigation use, requiring a filter and a sedimentation tank for primary treatment, a wetland for secondary treatment, a system for disinfection and a forested buffer strip for tertiary treatment.

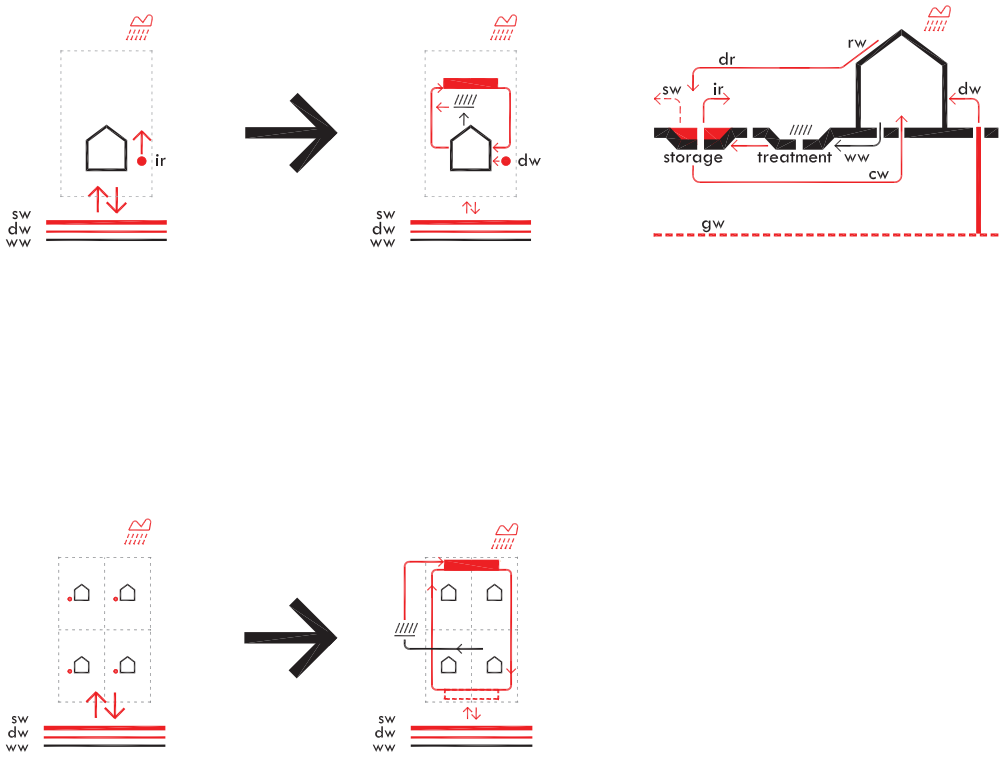


Figure 7.5.(top) Residential dwelling lot guiding model. Cleaning water (cw), drainage (dr), drinking water (dw), groundwater (gw), irrigation (ir), rainwater (rw), surface water (sw), waste water (ww).

Figure 7.6.(bottom) Circulation model. Drinking water (dw), surface water (sw), waste water (ww). Elaboration based on: Tjallingii (1996: 208).

Chapter 8

Scenarios of integration and decentralization

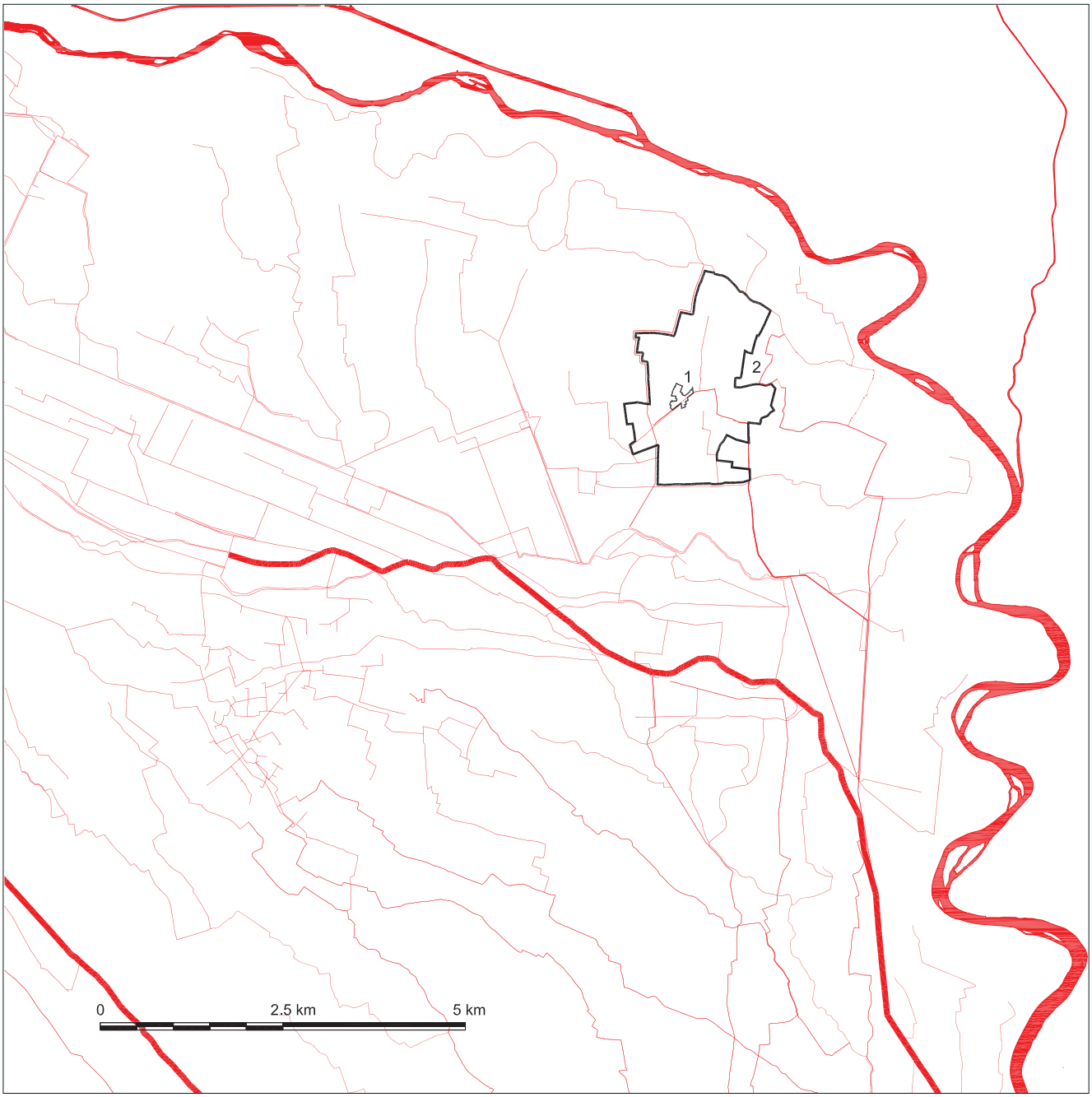
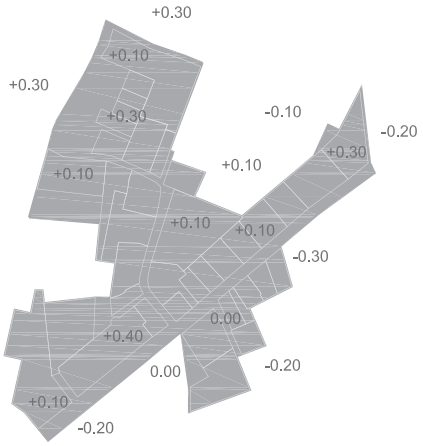


Figure 8.1. The case study areas: the Ponzilovo settlement area (1) and the Saccaro catchment basin (2). Source for the photos: Telespazio 2007 (Ponzilovo) and Regione Veneto 2006 (Saccaro catchment).

1.

2.



1.

2.

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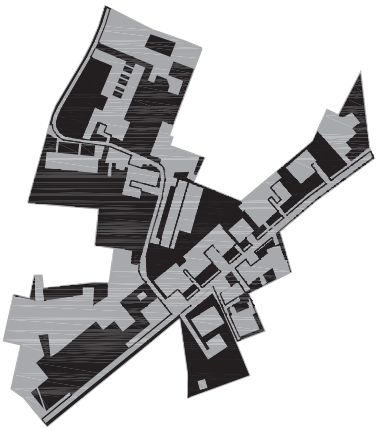


4.

Figure 8.2. Ponzilovo settlement area. Relief (1). Land cover: paved areas (white) (2), semi-paved areas (dark-grey) (3), gardens (black) (4).

Figure 8.3.(top) Ponzilovo settlement area, groundwater direction and wells.

Figure 8.4.(bottom) Ponzilovo settlement area, drainage system.

Figure 8.5.(top) Ponzilovo settlement area, drinking water piped service.

Figure 8.6.(bottom) Ponzilovo settlement area, wastewater piped service.

Figure 8.7.(top) The household selected. M. Ranzato photo.

Figure 8.8.(bottom) The residential dwelling lot framed in the settlement area of Ponzilovo. Source: Telespazio 2007.

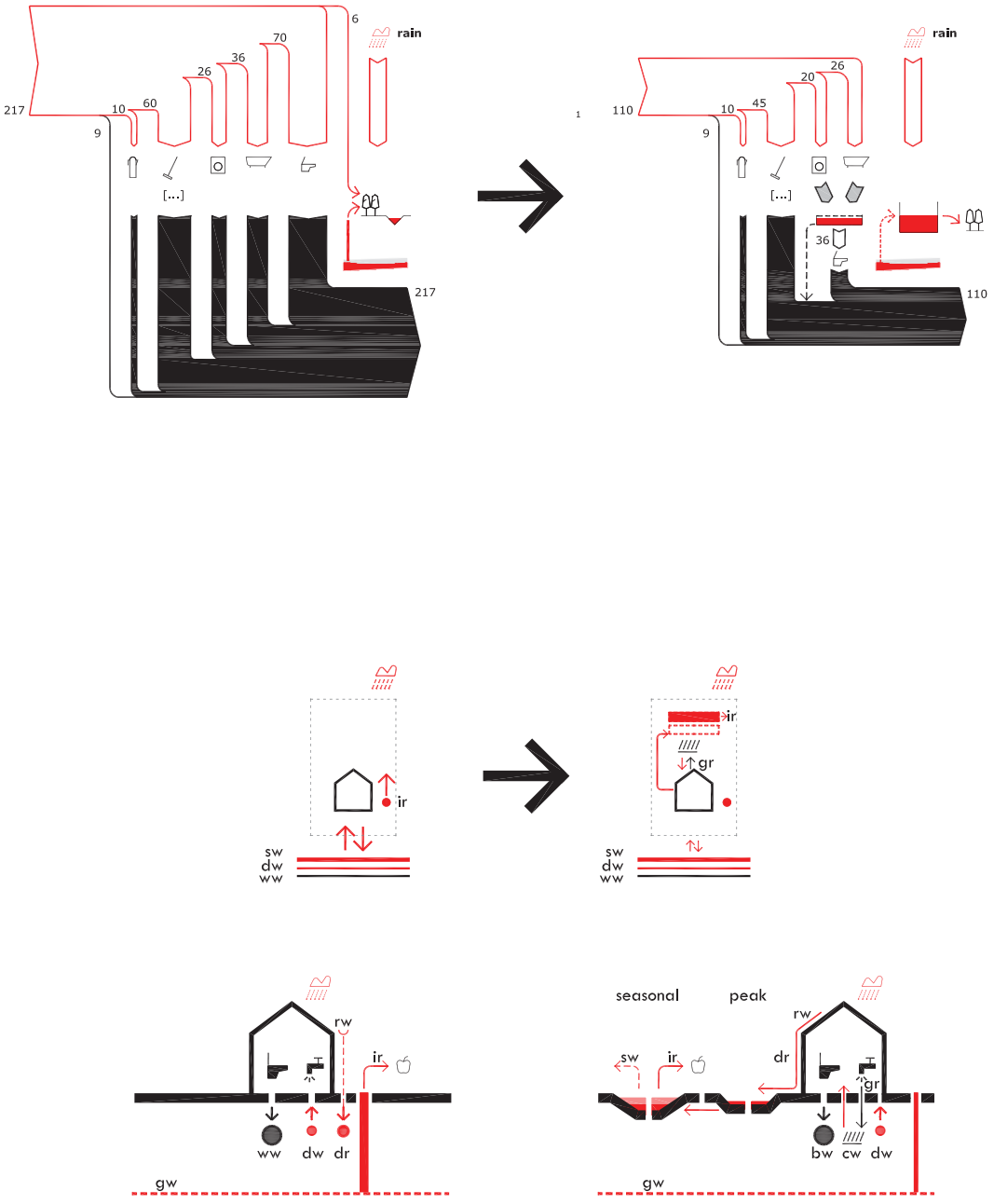


Figure 8.9.(top) From a high water consumption household to a water saving household. Elaboration based on Schuetze et al. (2008: 101).

Figure 8.10.(bottom) Guiding model for existing dwelling lots, result of the learning process. Cleaning water (*cw*), drainage (*dr*), drinking water (*dw*), grey water (*gr*), groundwater (*gw*), irrigation (*ir*), rainwater (*rw*), surface water (*sw*), waste water (*ww*).

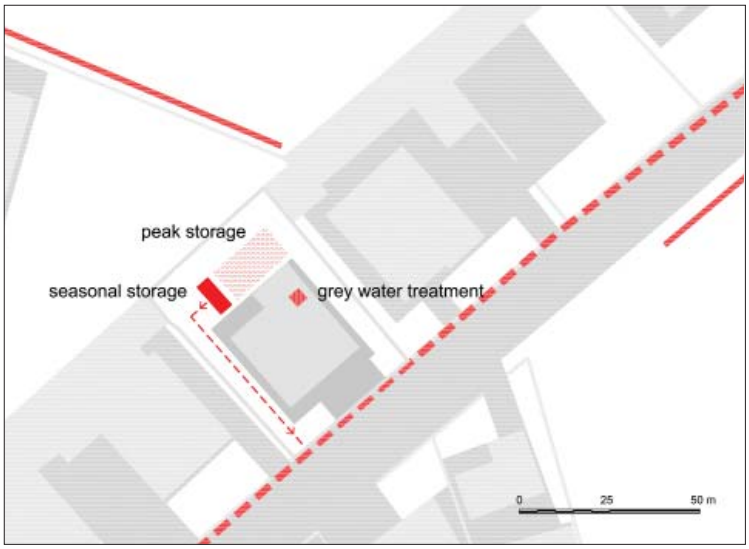
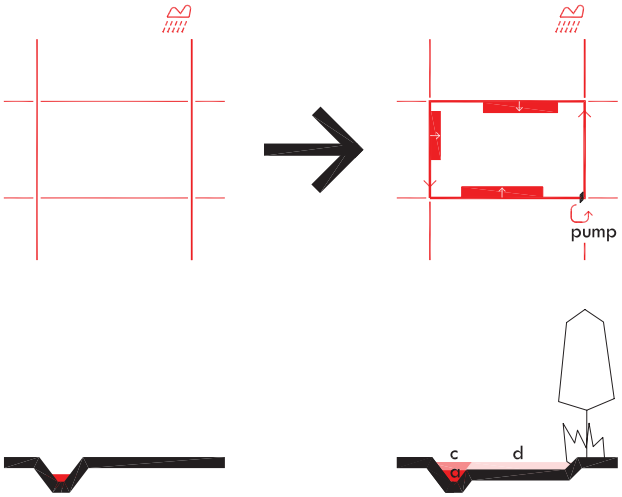


Figure 8.11.(top) Household storage strategy. The image exhibits how the water system has been designed. Grey waters are treated onsite by an indoor grey water treatment device, much like an activated sludge facility. Treated grey waters are reused for flushing toilets. Rainwater from the roof and the paved surfaces is buffered in a rainwater garden located in the back of the lot. After a storm, the rainwater buffered is delivered to the nearby open air tank, which functions as seasonal storage. Excesses of water are released via pipe line to the existing drainage system.

Figure 8.12.(bottom) Household storage strategy at a wider-angle view.



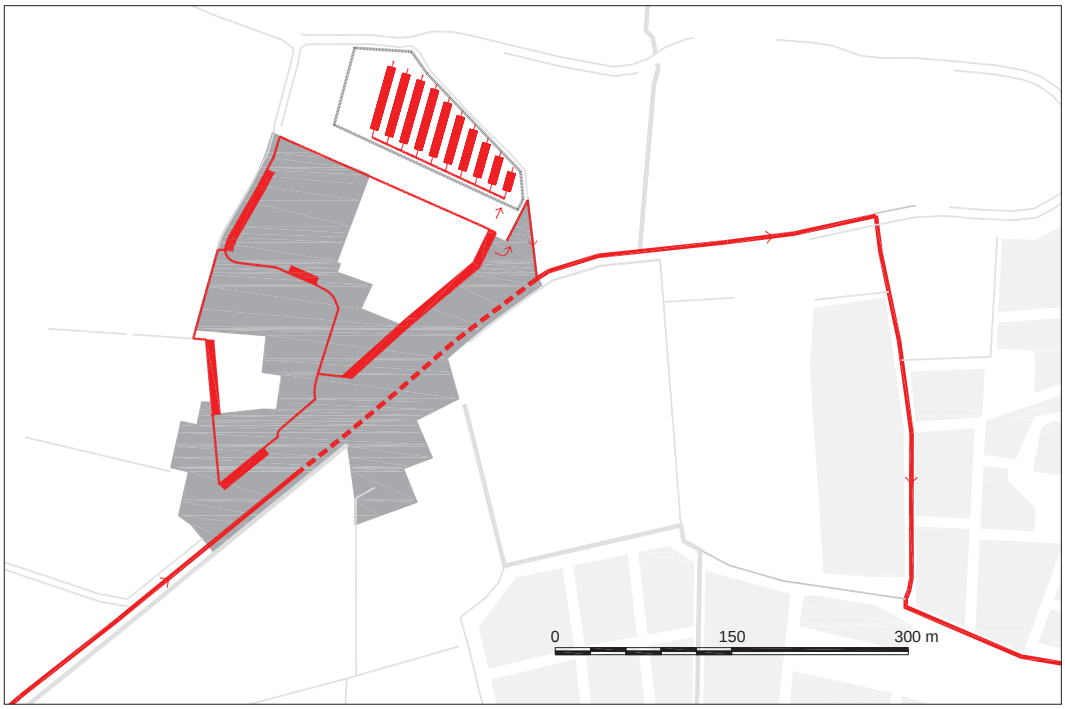
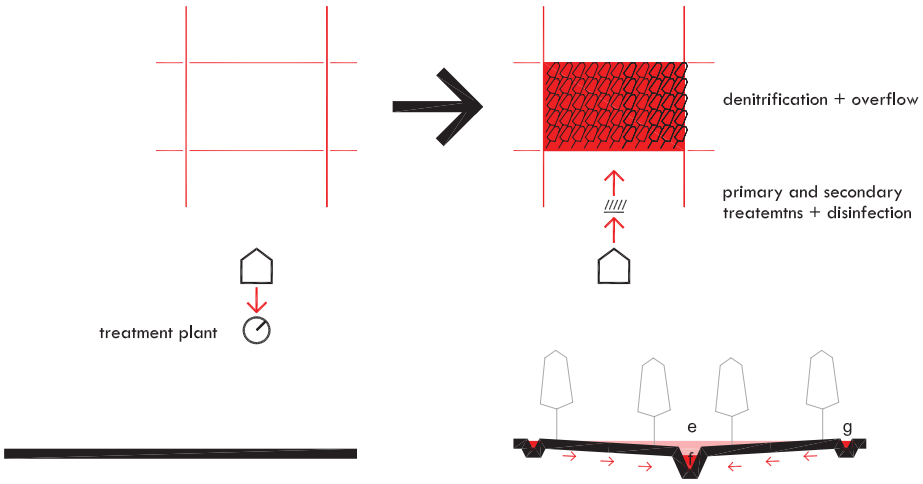


Figure 8.13.(top) A version of the guiding model for the field system. Accordingly, ditches are adapted to have more room for water.

Figure 8.14.(bottom) Neighbourhood level, peak storage.



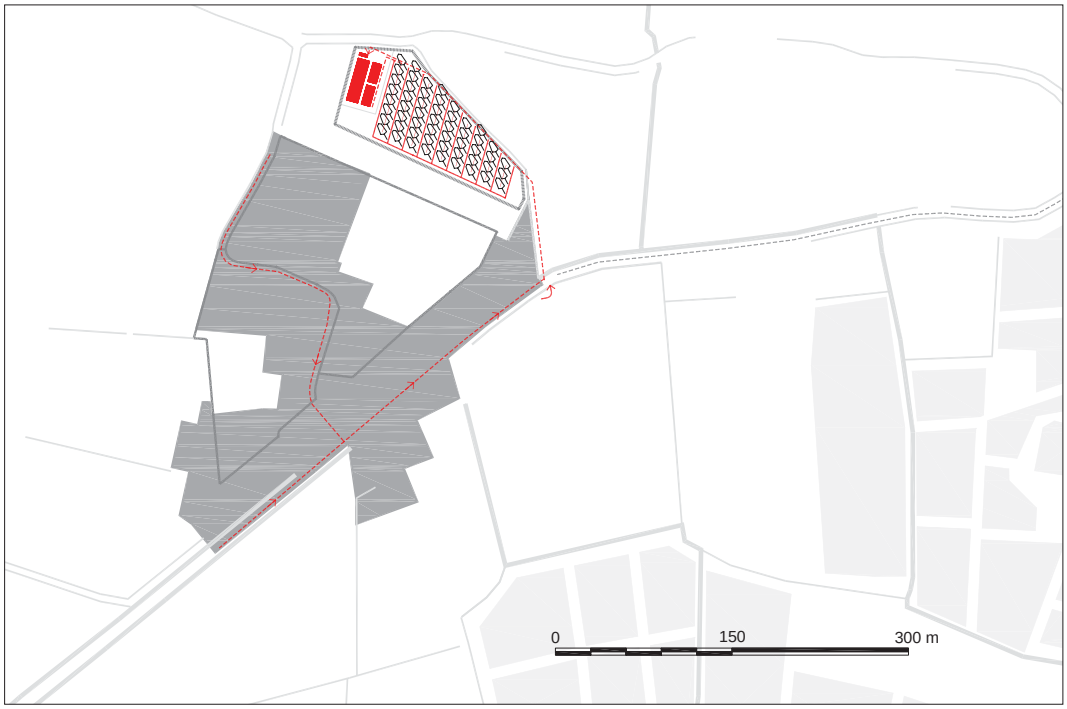
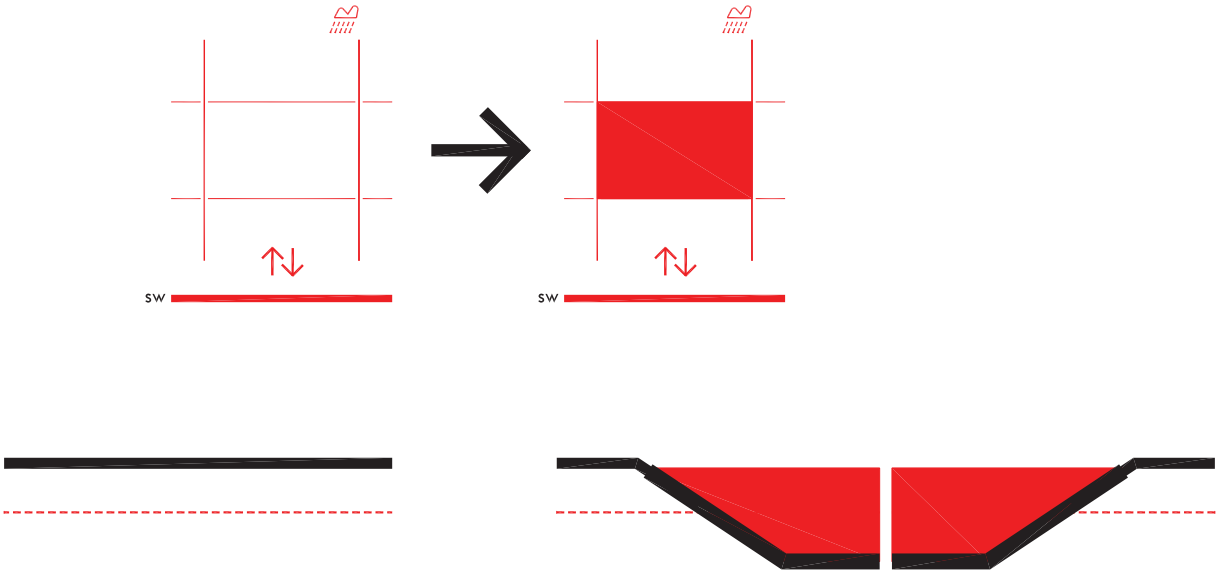


Figure 8.15.(top) A version of the guiding model for the field system. Accordingly, a nearby agricultural field arranged to perform a tertiary treatment, accommodates overflow in its lower parts.

Figure 8.16.(bottom) Neighbourhood level, purification system.



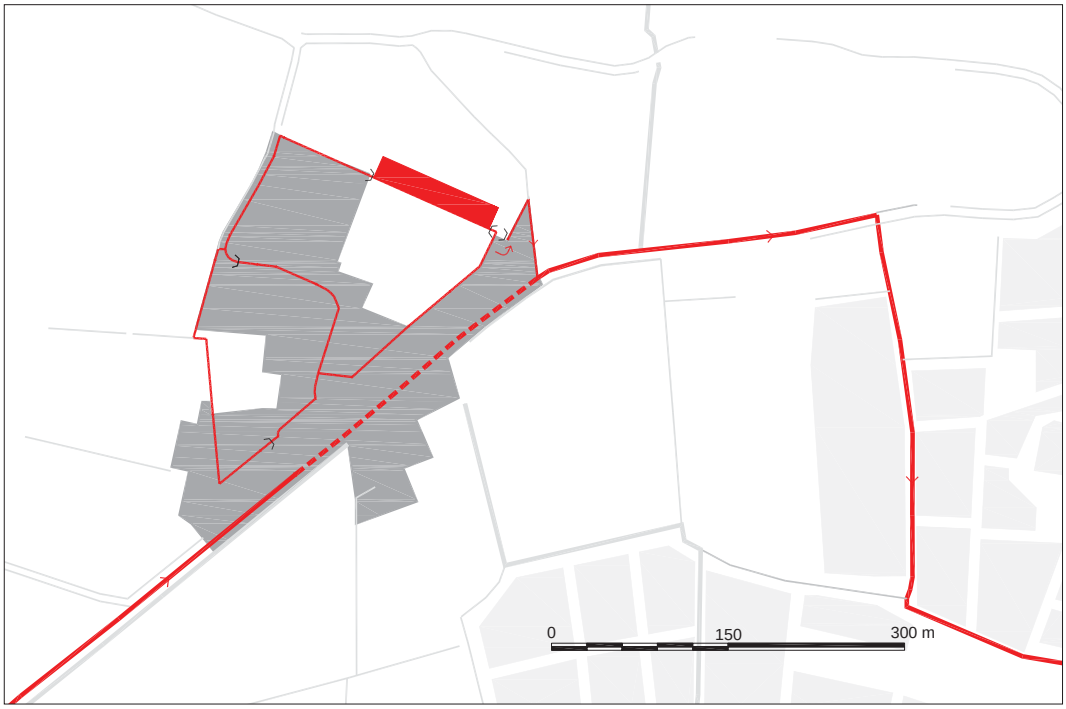


Figure 8.17.(top) A version of the guiding model for the field system. Accordingly, part of a neighbour agricultural field is deepened to perform a permanent retention pond.

Figure 8.18.(bottom) Neighbourhood level, seasonal storage (*version a*).

Figure 8.19.(top) Neighbourhood level, the storage strategy as a whole.

Figure 8.20.(bottom) Neighbourhood level, new shared public spaces.

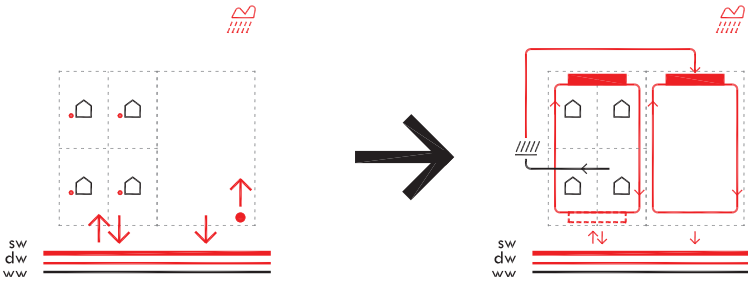
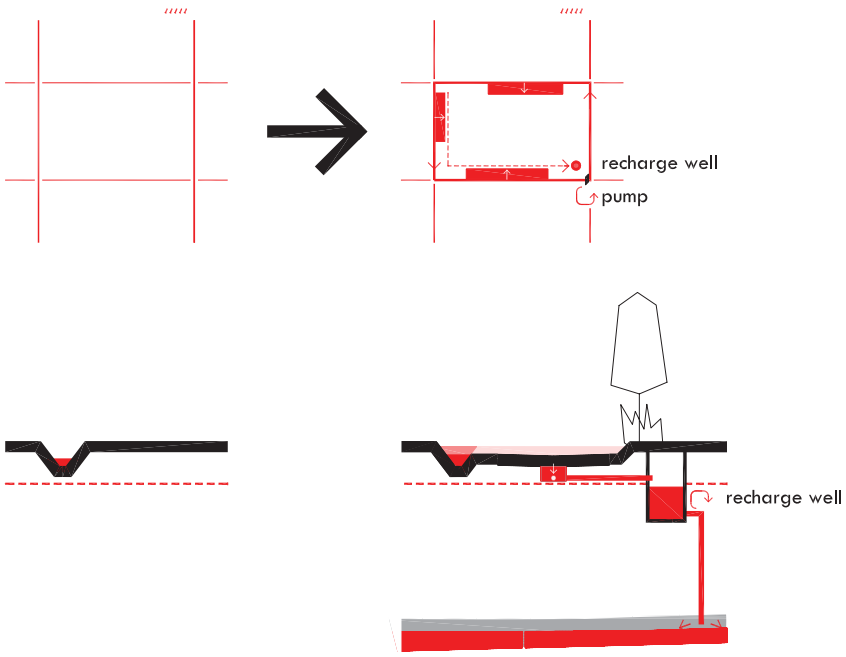


Figure 8.21. Guiding model networks of storage systems, results of the learning process.



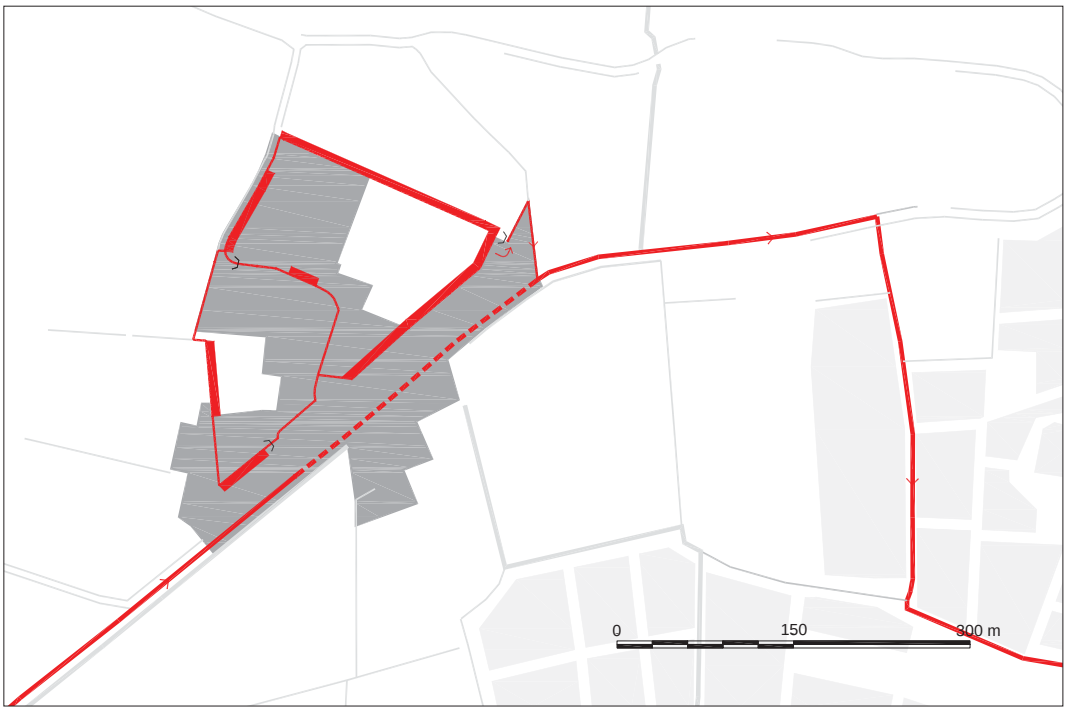


Figure 8.22.(top) A version of the guiding model for the field system. Accordingly, ditches are adapted to have more room for water and perform infiltration to a pipe network connected to a tank and a recharge well.

Figure 8.23.(bottom) Neighbourhood level, subsurface storage option, peak storage.

Figure 8.24. Neighbourhood level, subsurface storage option, aquifer recharge system.

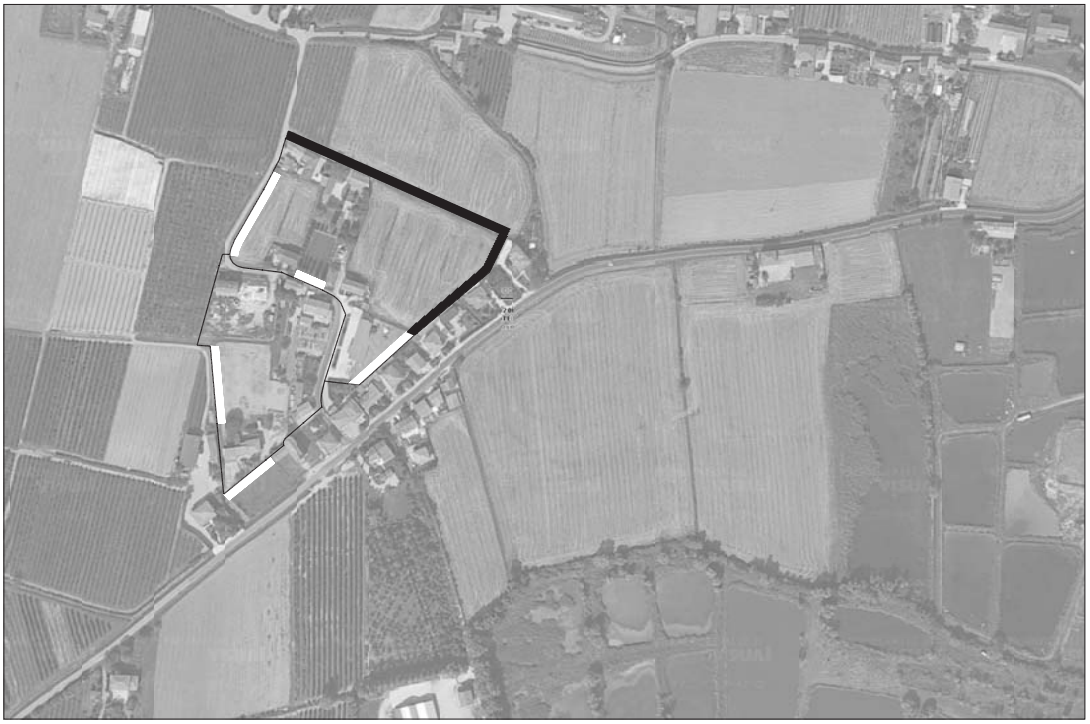


Figure 8.25.(top) Neighbourhood level, subsurface storage option, the storage strategy as a whole.

Figure 8.26.(bottom) Neighbourhood level, subsurface storage option, new shared public spaces.

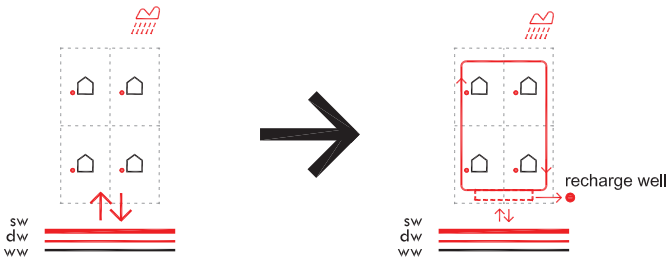


Figure 8.27. Subsurface storage circulation model, result of the learning process.

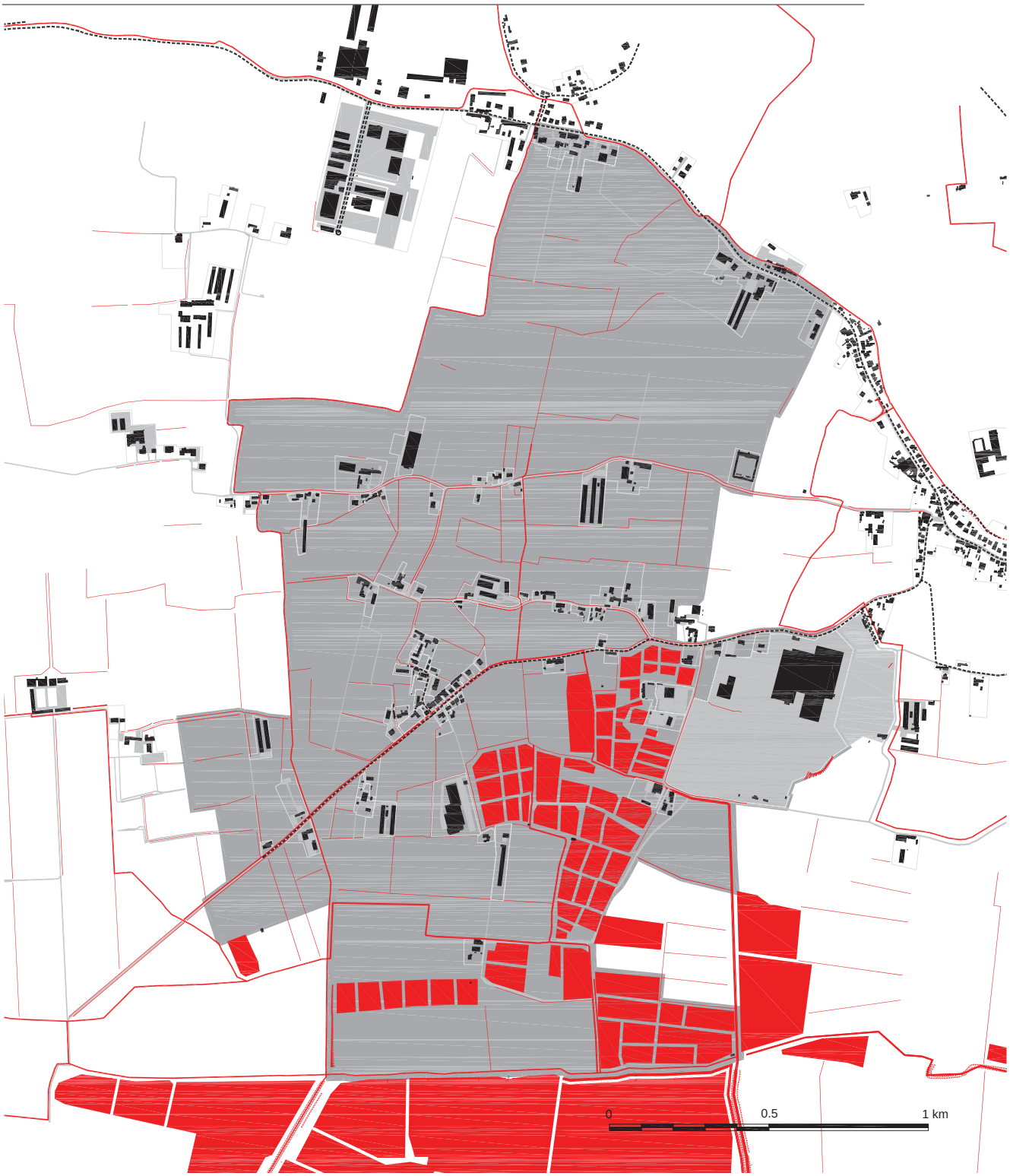
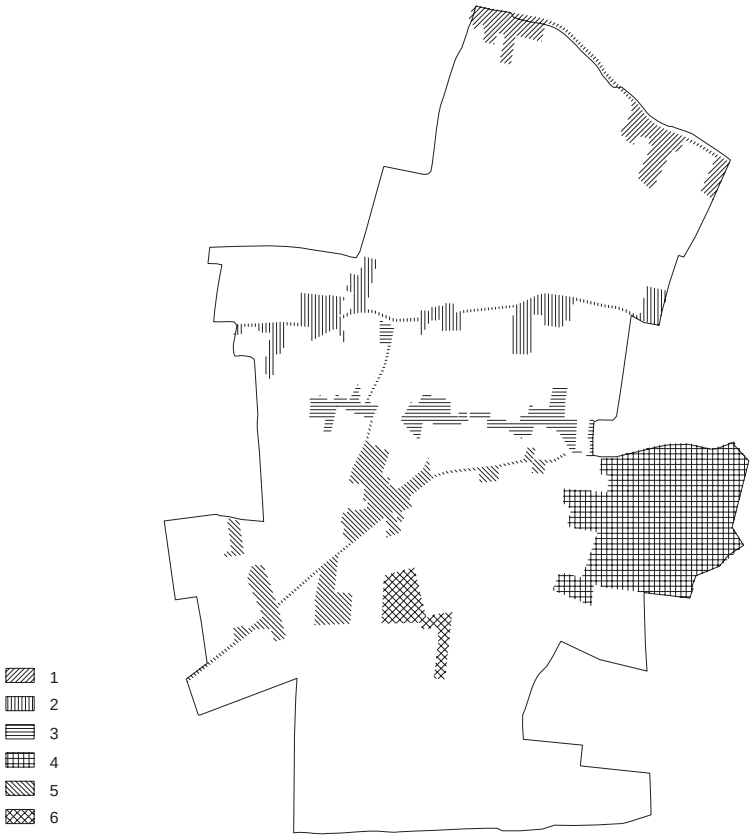


Figure 8.28. The Saccaro catchment area.

1 km



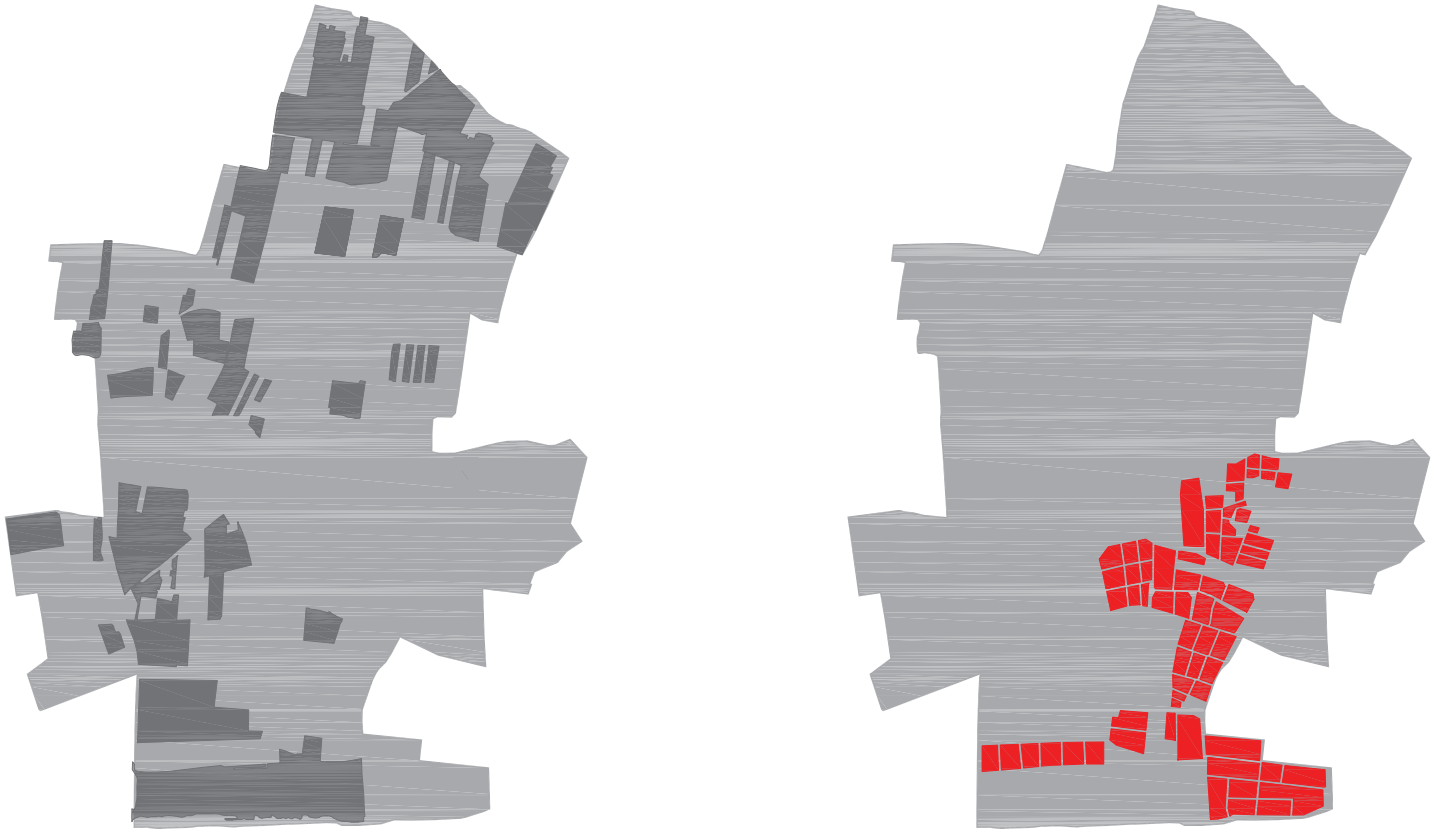


Figure 8.29.(top) Saccaro catchment area, land cover. From left to right: covered areas, arable lands, orchards and forests, water expanses (former clay pits).

Figure 8.30.(bottom) Saccaro catchment area, design zones. Each zone includes settlements with shared infrastructures. Zones are treated as manageable units which seem to offer promising combinations for the future.

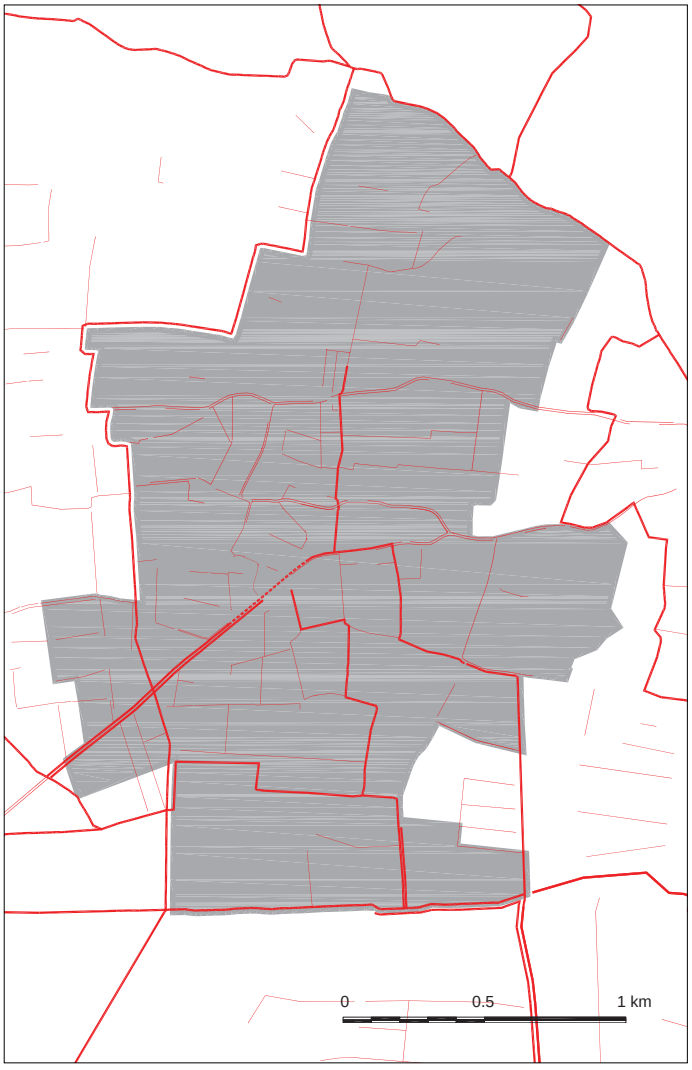


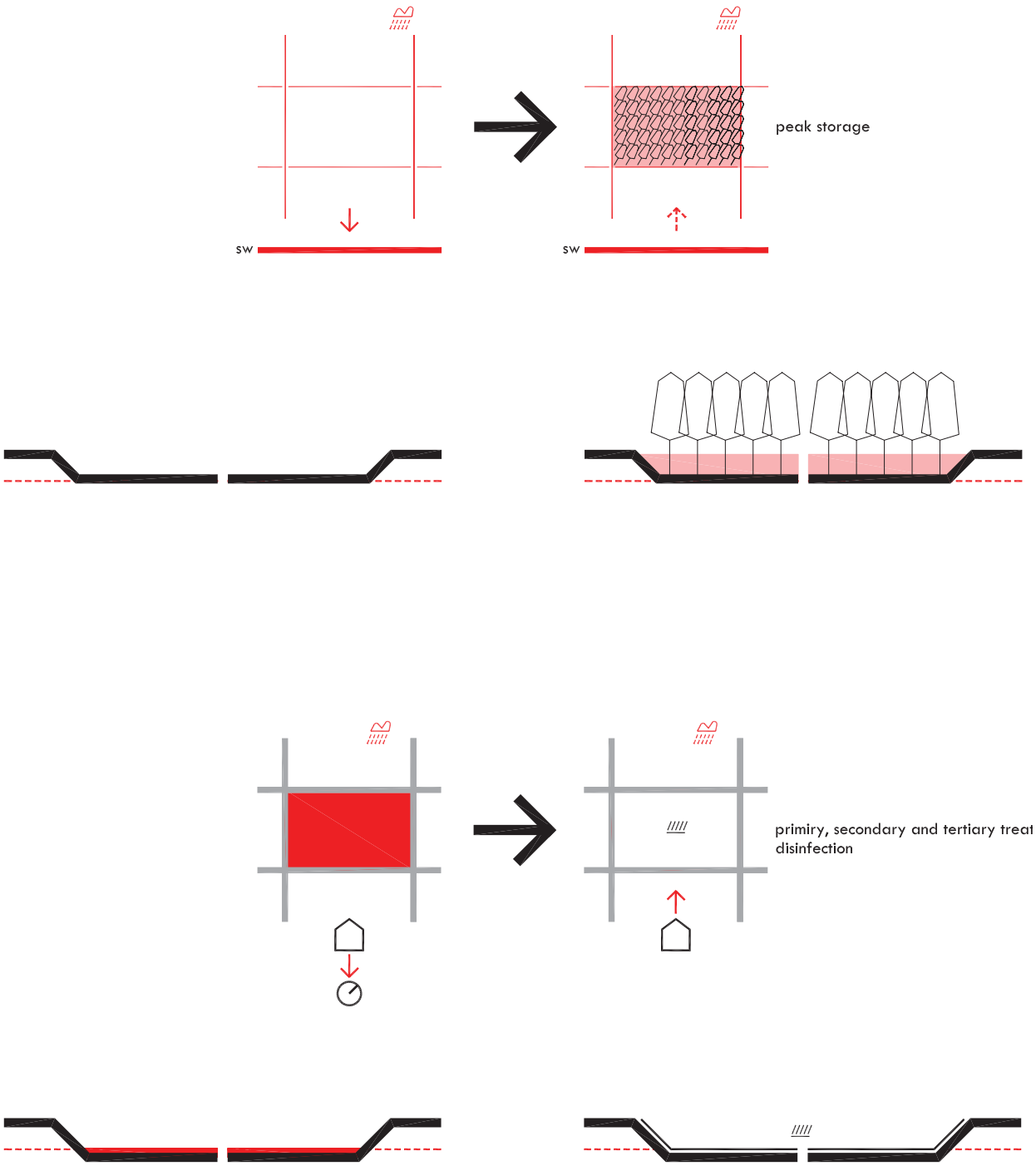
Figure 8.31. Saccaro catchment area, drainage water system.

Figure 8.32. Saccaro catchment area, drinking water network (1) and wastewater network (2).

1.

2.

Figure 8.33.(top) A version of the guiding model for the excavation site system. A filled up former clay pit or a very



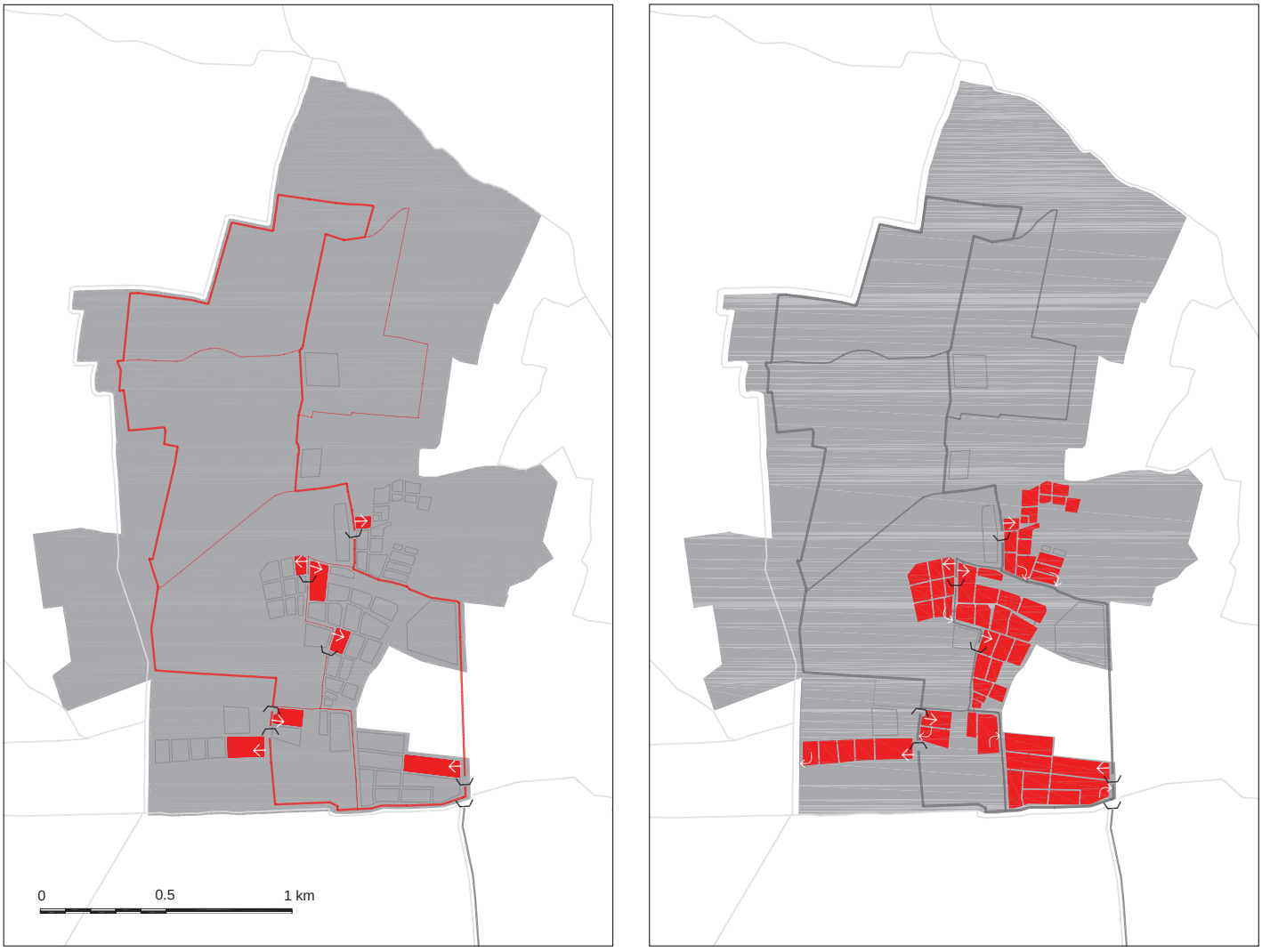
shallow clay pit transformed in an hygrophilous forest (*agro forest*). In case of heavy storms waters from the surface water network expand into.

Figure 8.34.(bottom) A version of the guiding model for the excavation site system. A filled up former clay pit or a shallow clay pit is recovered in a wastewater purification system complete of wetlands to perform secondary and tertiary treatments, and other devices for primary treatment and disinfection.

1.

2.

Figure 8.35. Catchment area level, peak storage (1) and waste water purification system (2).



1. 2.

Figure 8.36. Catchment area level, surface water purification system (1) and seasonal storage (2).

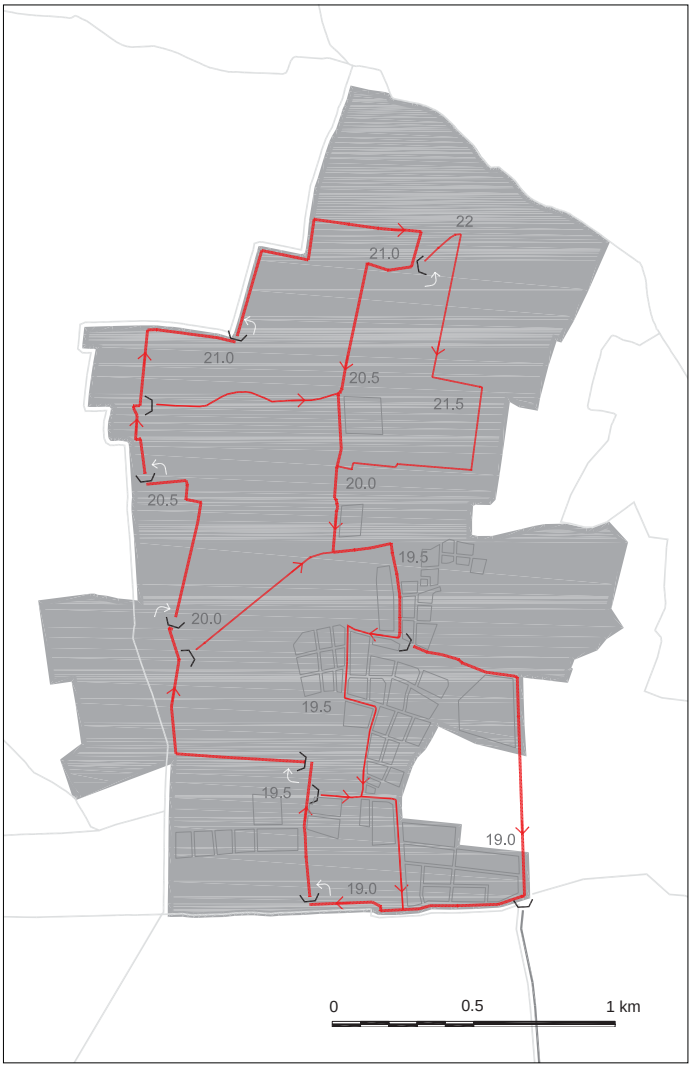


Figure 8.37. Catchment area level, circulation system.

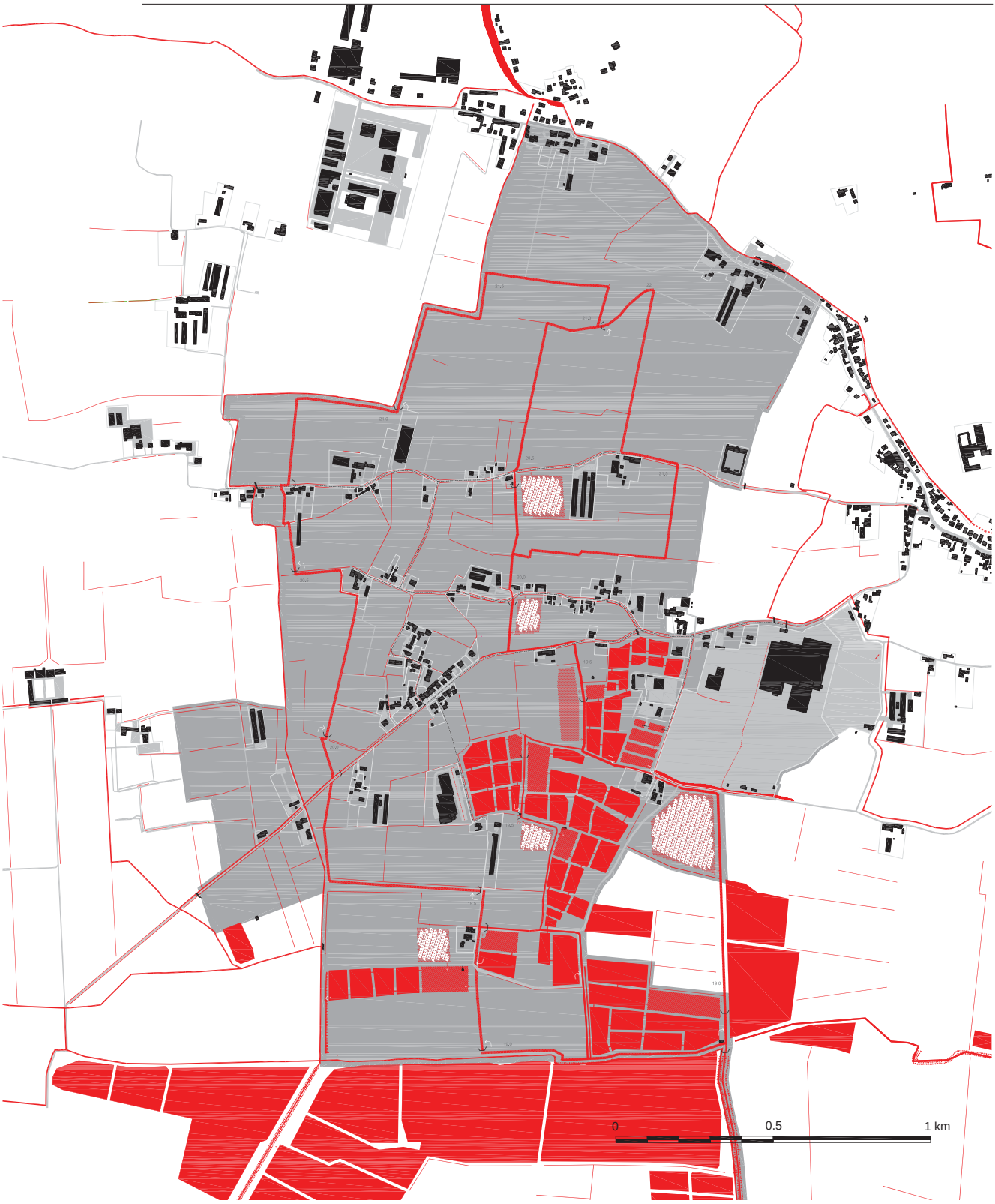


Figure 8.38. Catchment area level, the storage strategy as a whole.

Figure 8.39. Catchment area level, new shared public spaces.

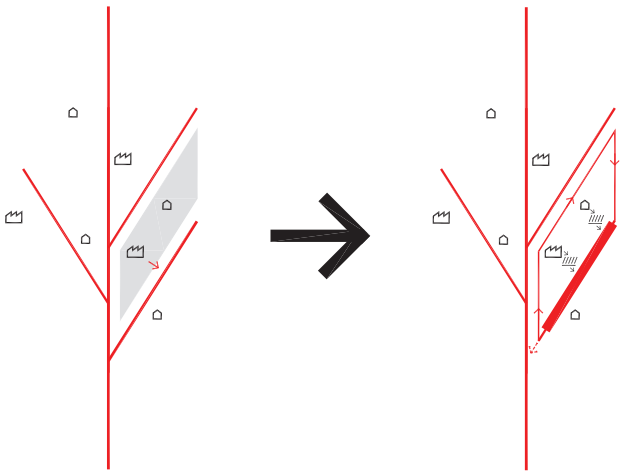
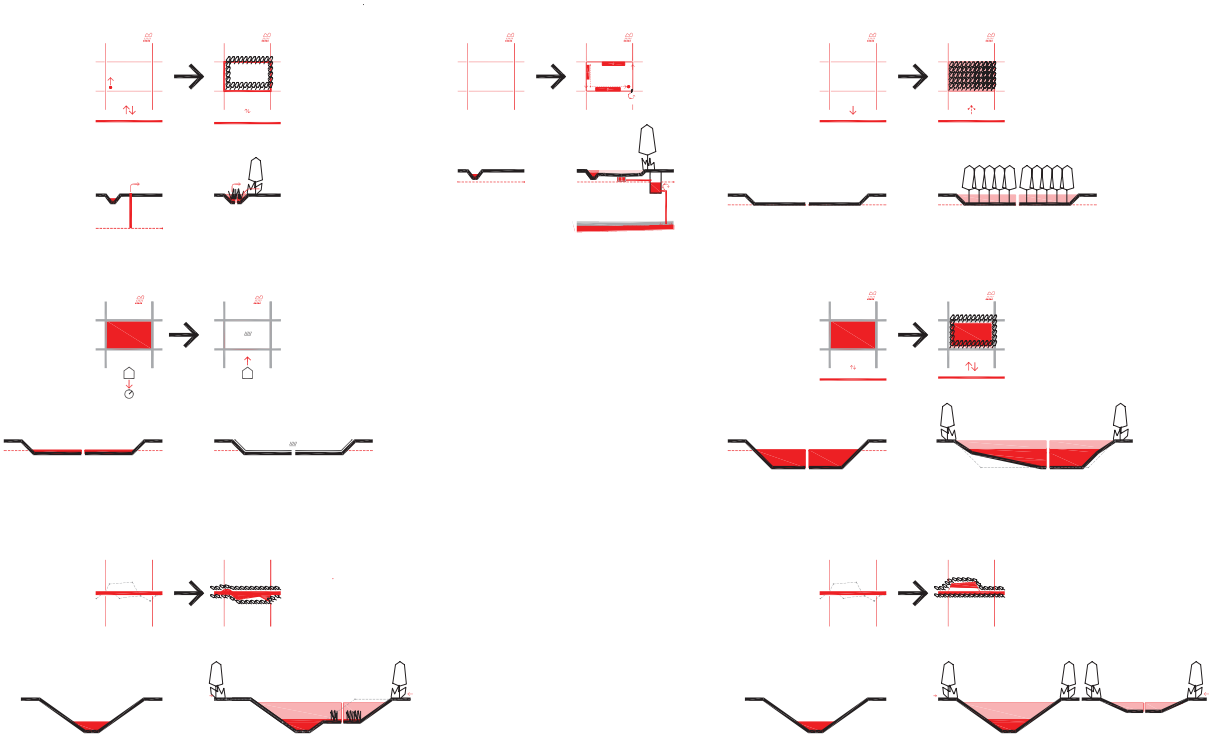


Figure 8.40. Circulation model for catchment areas, result of the learning process. In the model, peak storage, seasonal storage and the purification system for surface waters are gathered in one storage element. A multifunctional quarry area is a good example of such storage facilities.

Chapter 9

Conclusions

small

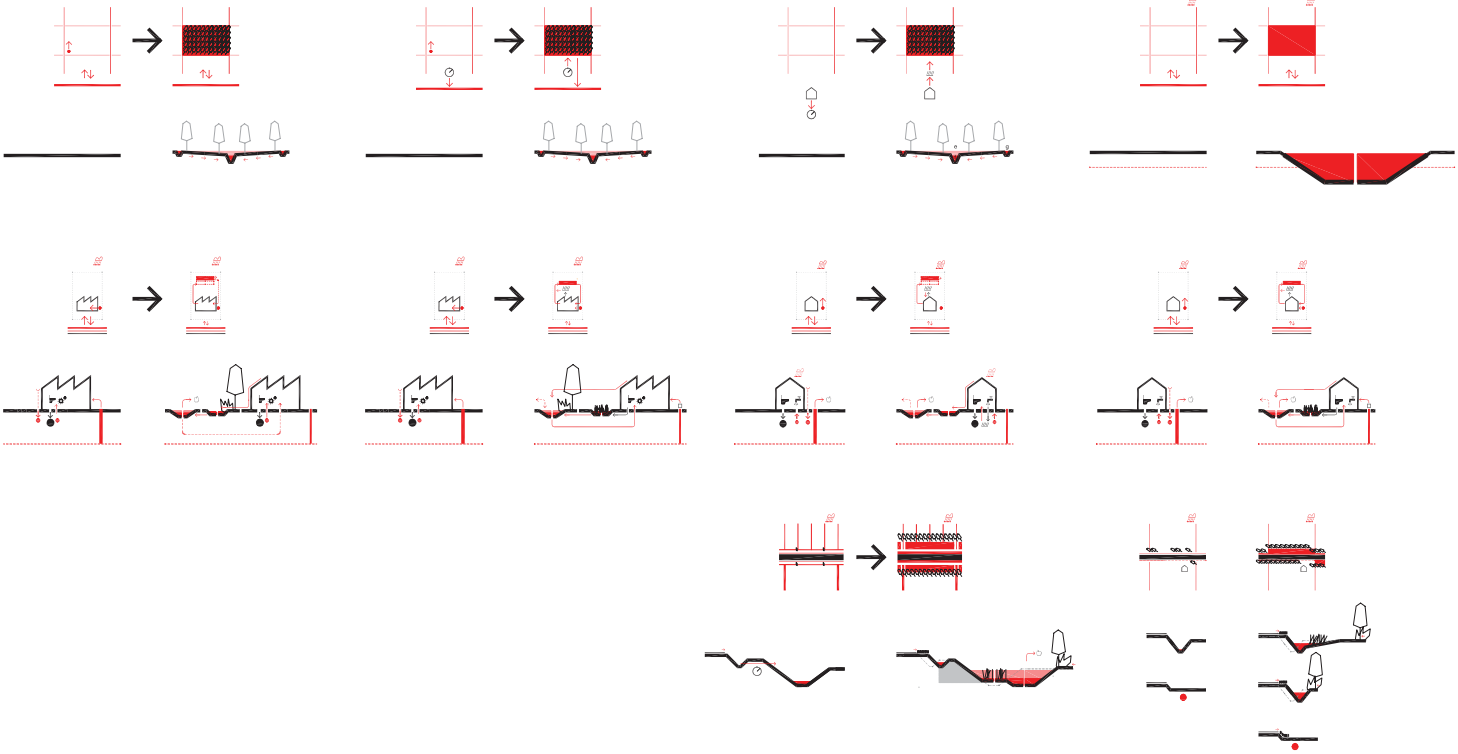


medium

large

extra large

Figure 9.1. The toolbox of guiding models for different levels of integrated management of water in the low plains of the Veneto *Città Diffusa*.



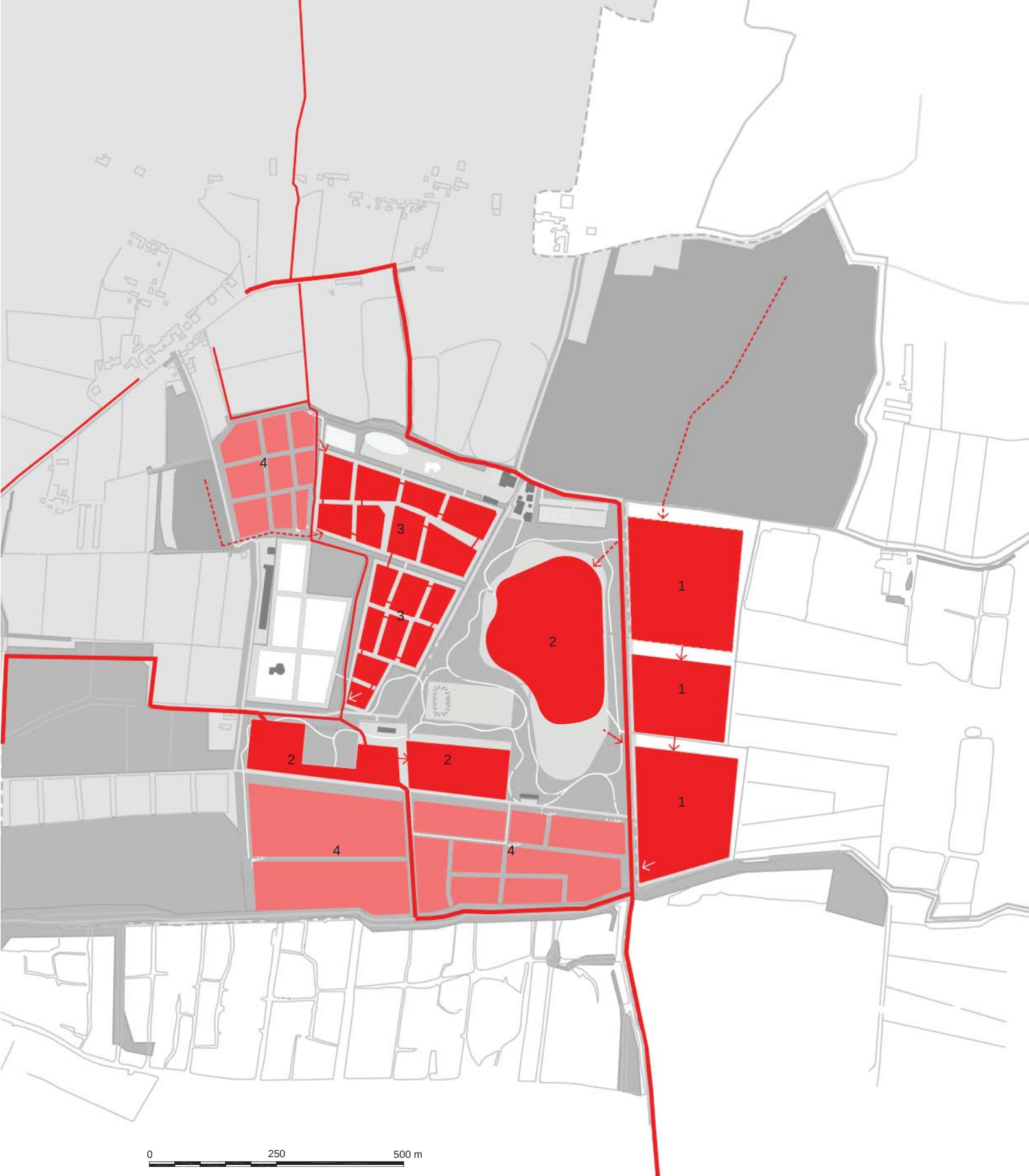


Figure 9.2. The water system of the park designed by the Consorzio di Bonifica Veronese water board to recover one of the main excavation sites of Ronco all'Adige. The main components are the lakes with peak storage and the seasonal storage functions (1), the lakes for recreation that also perform bioremediation (2), the ponds of the agricultural laboratory for aqua farming or seasonal storage combined with solar fields (3), the reservoir (4).

Appendix A

Guiding models

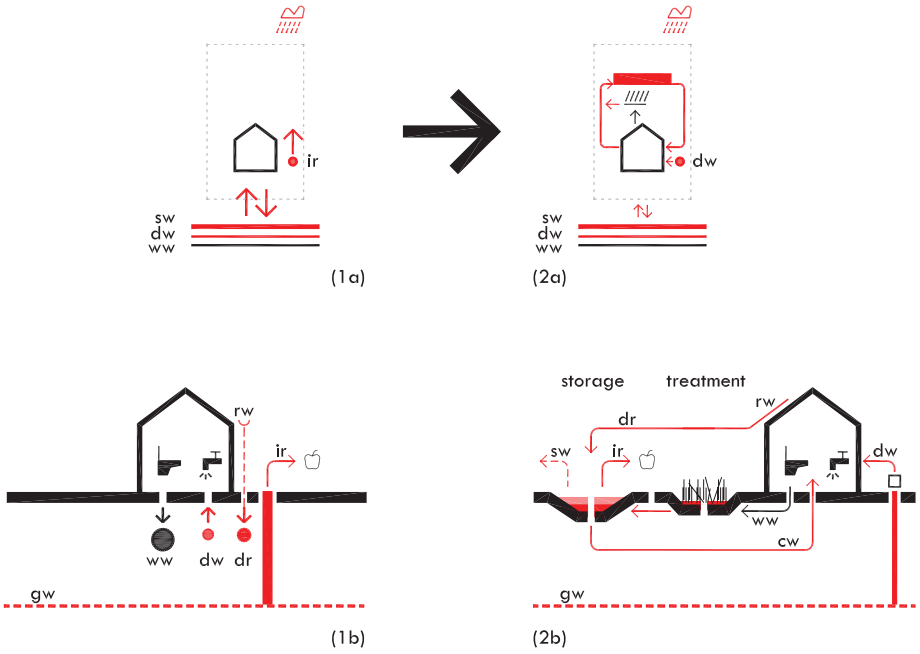


Figure A.1. Resilient dwelling lot guiding model.

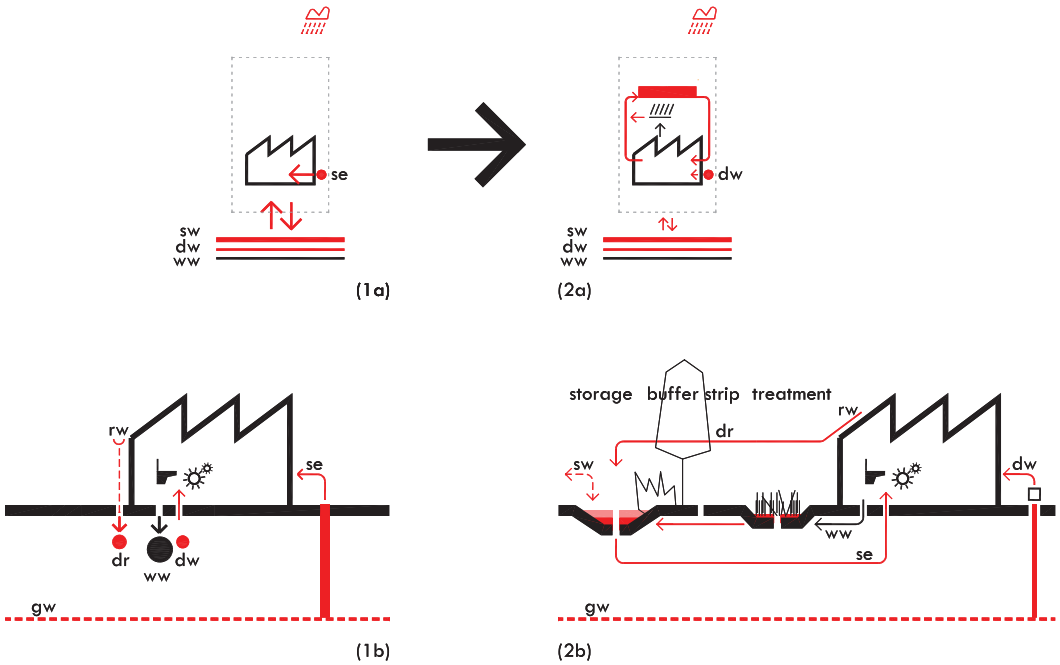


Figure A.2. Resilient dwelling lot guiding model.

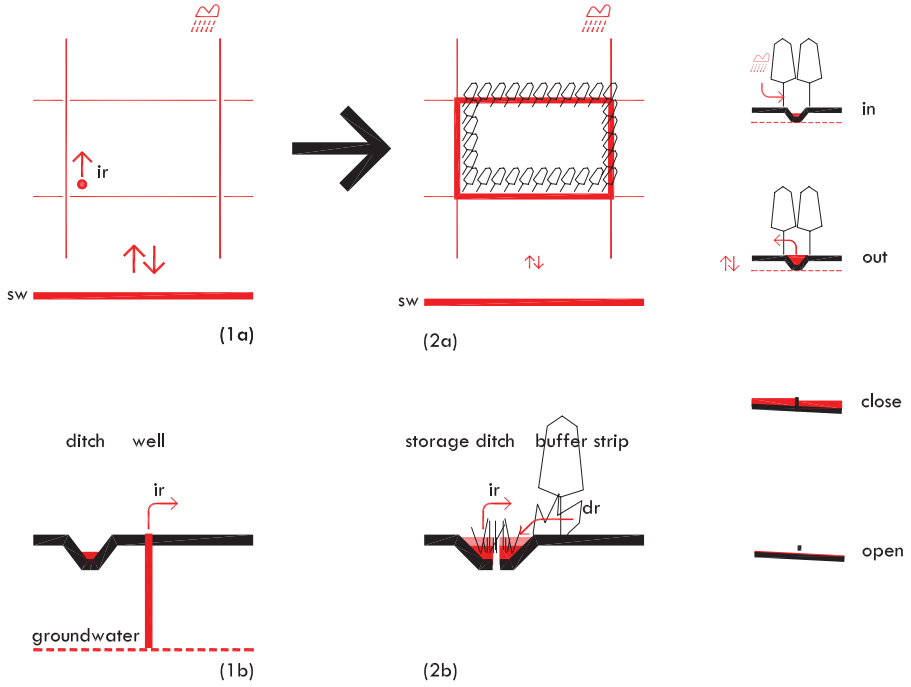


Figure A.3. Resilient agricultural field guiding model.

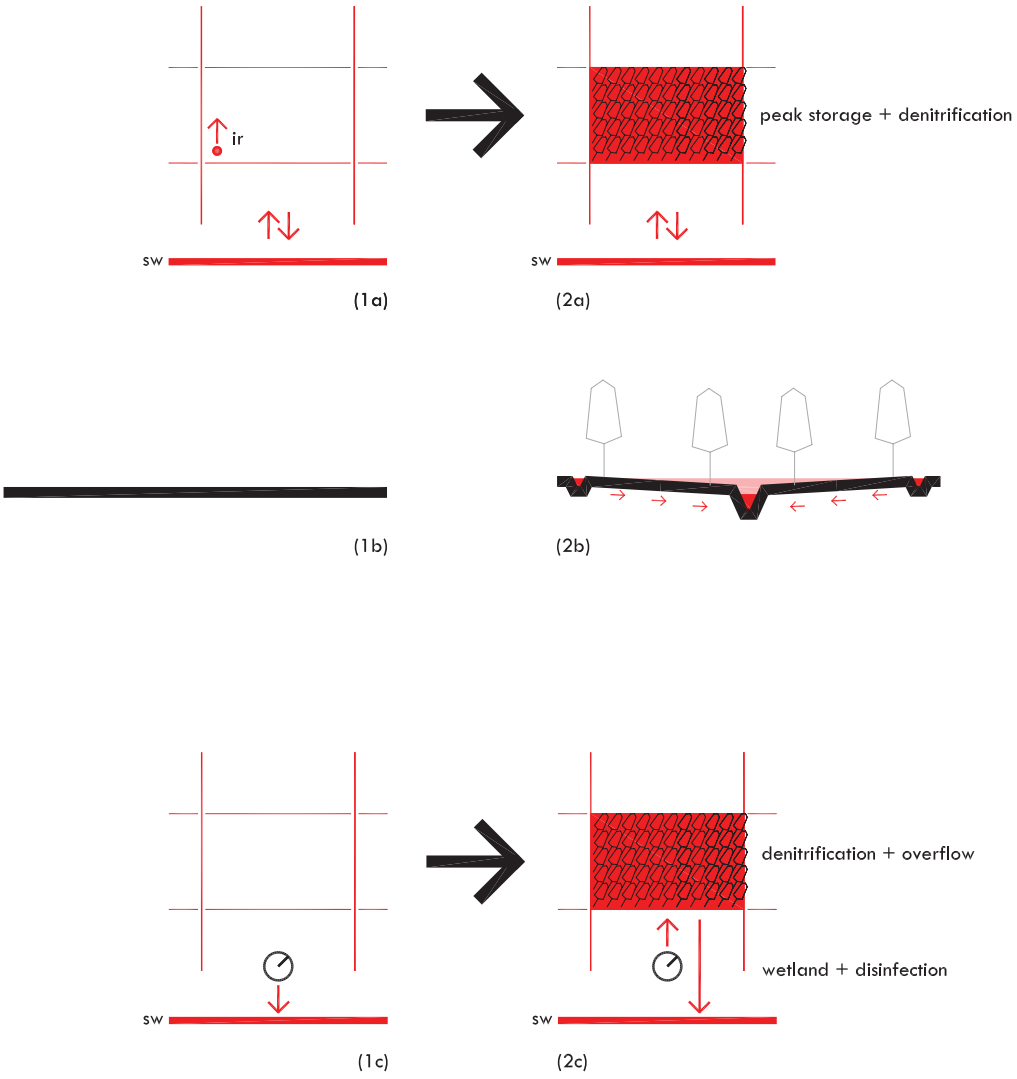


Figure A.4. Forested buffer strip guiding model.

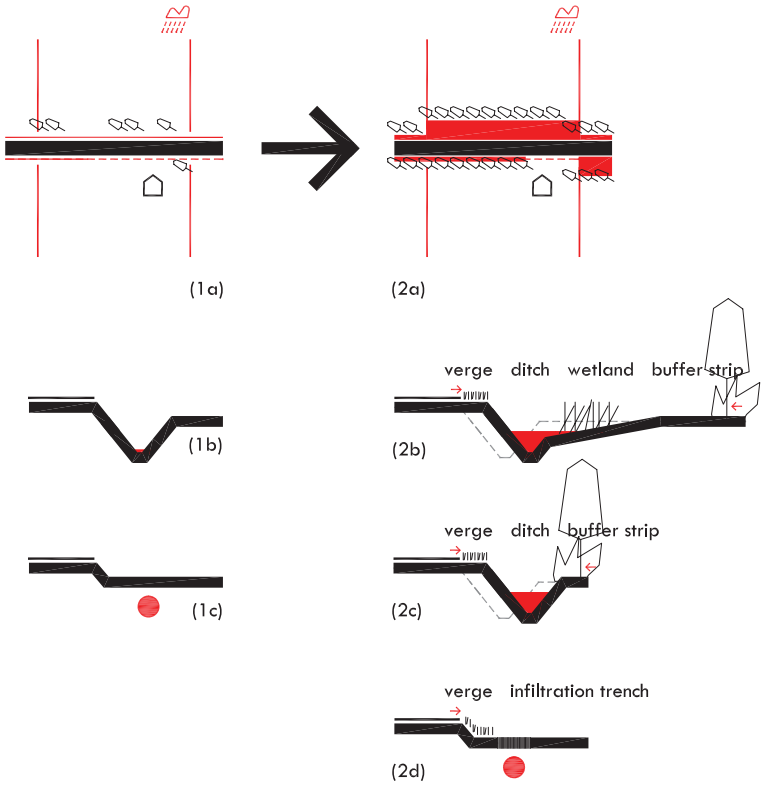


Figure A.5. Resilient road strip guiding model.

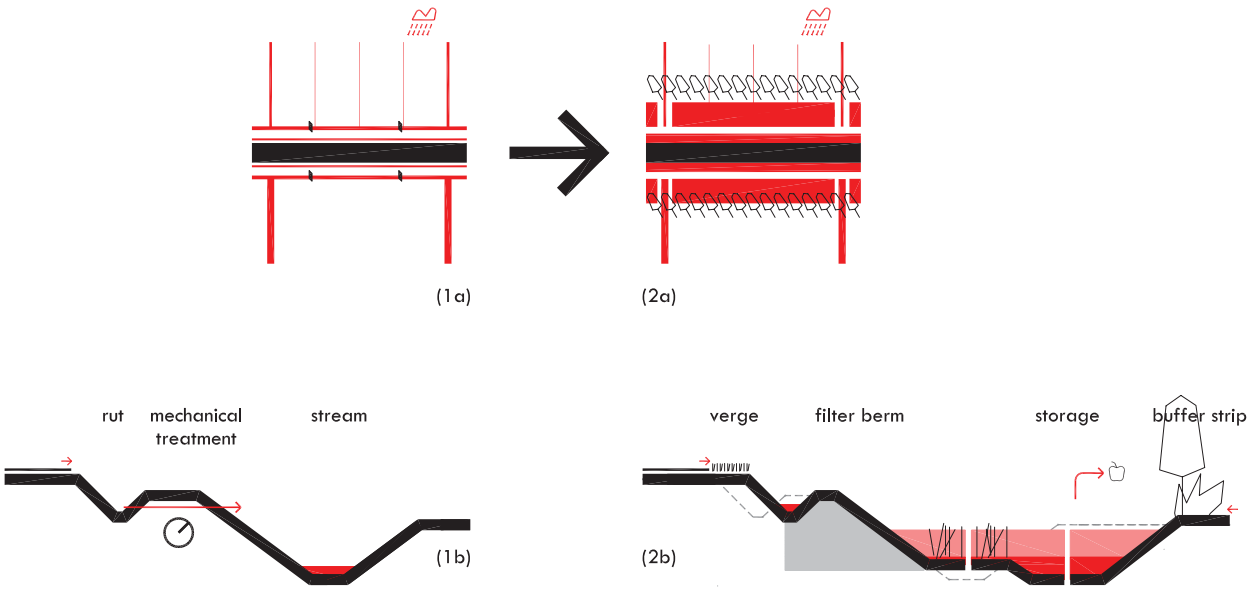


Figure A.6. Resilient highway corridor guiding model.

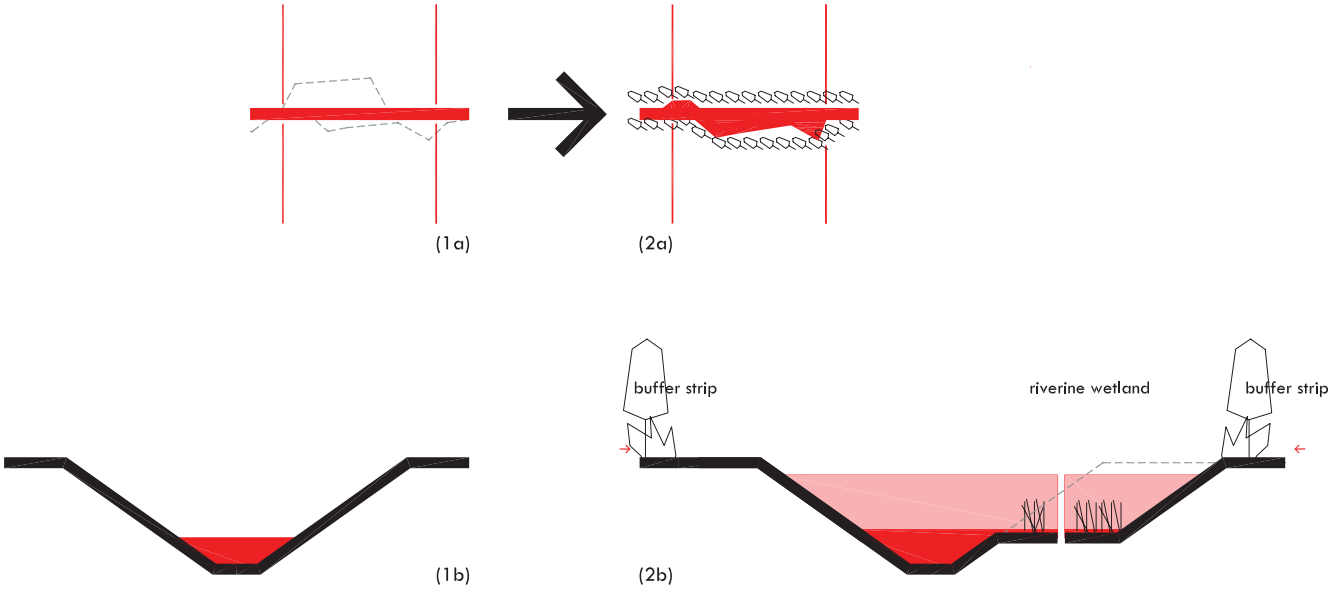
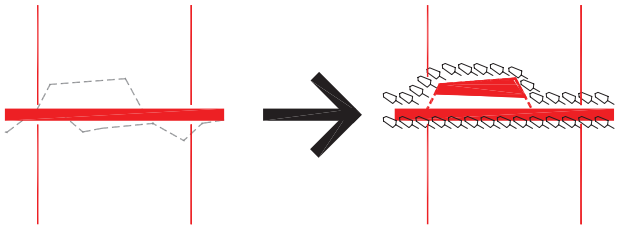
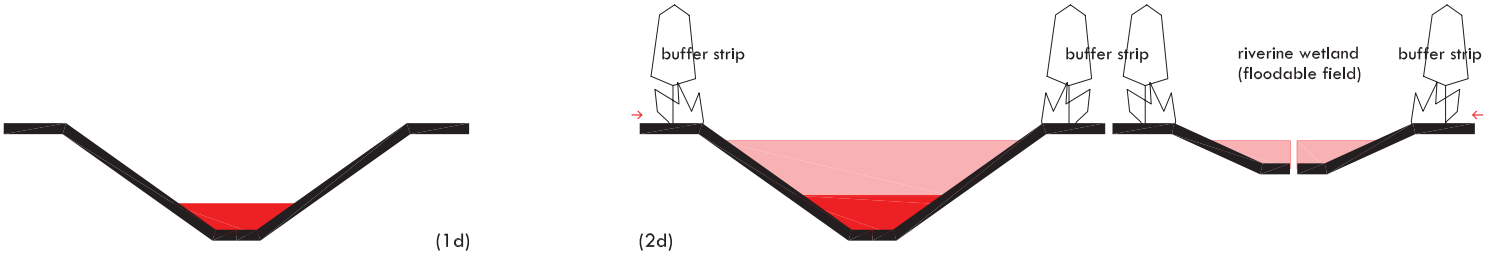


Figure A.7. Resilient stream corridor guiding models. The widening of the cross section (left), the adding of a by-pass (right).



(1c) (2c)


buffer strip
buffer strip
riverine wetland
(floodable field)
buffer strip

(1d) (2d)

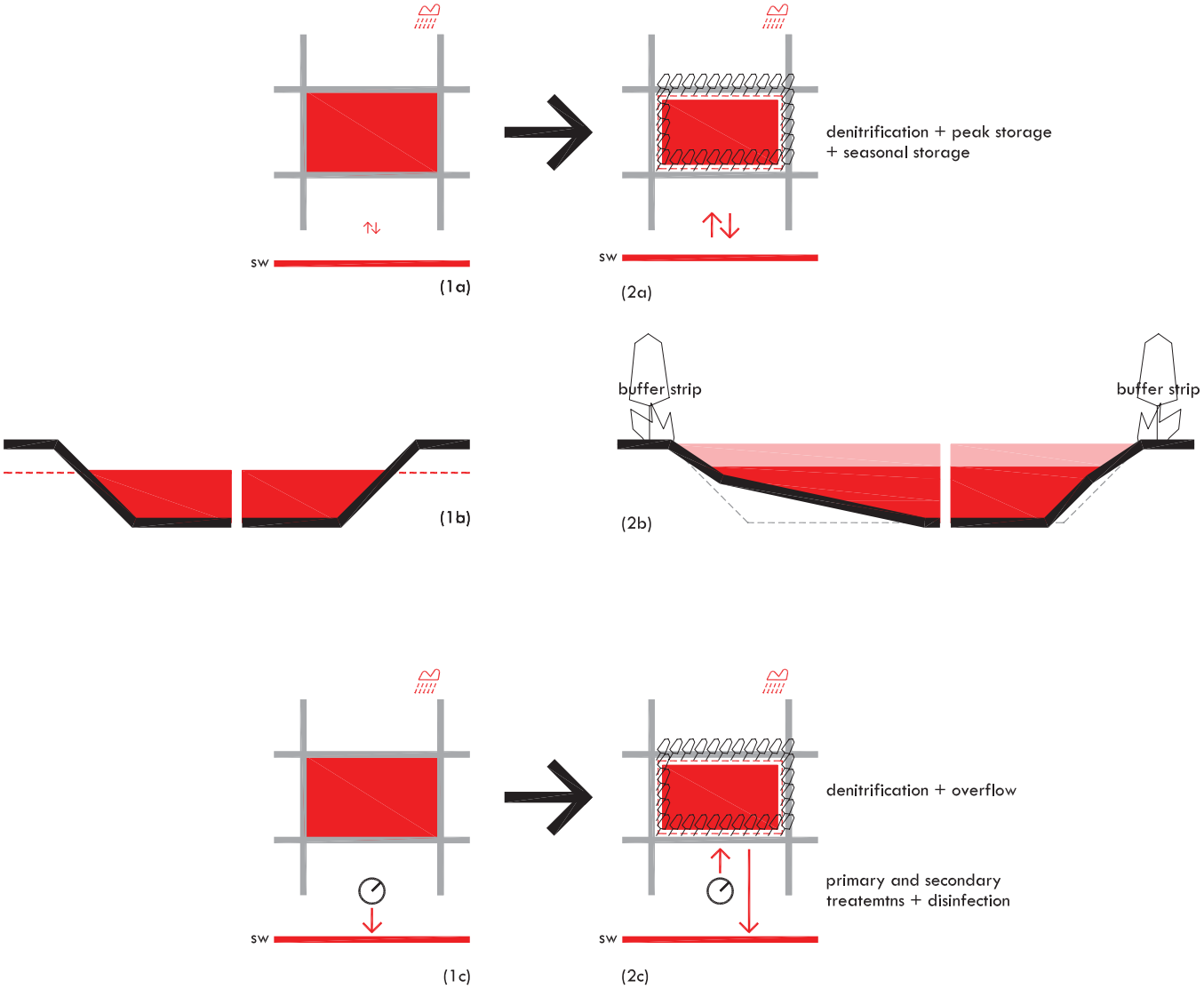


Figure A.8. Resilient quarry area guiding model.

Appendix B

Rhythms computation

P d [h]	P h [mm]	INT m [mm/h]	DIS in [l/s]	R c	DIS sto [l/s]	DIS out [l/s]	VOL in [m3]	VOL out [m3]	VOL sto [m3]
0,08	19	226	375	73	324	51	423	15	408
0,14	24	170	488	95	437	51	570	27	544
0,17	27	156	528	103	477	51	623	31	592
0,25	32	128	636	124	585	51	764	46	717
0,36	38	105	759	148	707	51	924	67	857
0,42	41	98	704	137	653	51	995	77	918
0,50	45	89	641	125	589	51	1092	93	999
0,58	48	82	591	115	540	51	1181	108	1073
0,67	51	77	552	107	500	51	1264	123	1140
0,75	54	72	519	101	468	51	1341	139	1202
0,83	57	68	491	96	440	51	1414	154	1260
0,92	60	65	468	91	416	51	1484	170	1314
1	56	56	400	78	349	51	1383	185	1198
2	65	32	233	45	182	51	1626	370	1255
3	71	24	170	33	118	51	1787	555	1232
3	71	24	170	33	118	51	1787	555	1232
4	75	19	136	26	84	51	1911	740	1171
5	79	16	114	22	62	51	2014	925	1088
6	82	14	99	19	47	51	2102	1110	991
7	85	12	88	17	36	51	2179	1295	884
8	88	11	79	15	27	51	2249	1481	769
9	90	10	72	14	21	51	2313	1666	647
10	92	9	66	13	15	51	2371	1851	521
11	94	9	62	12	10	51	2426	2036	390
12	96	8	57	11	6	51	2476	2221	256
13	98	8	54	11	3	51	2524	2406	118
14	99	7	51	10	0	51	2591	2591	0
15	101	7	48	9	0	51	2776	2776	0

VOL sto max [m3]
1314

P d = duration of precipitation
P h = precipitation height
INT m = medium intensity
DIS in = discharge in

R c = runoff coefficient
DIS sto = discharge stored
DIS out = discharge out
VOL in = volume in

VOL out = volume out
VOL sto = volume stored

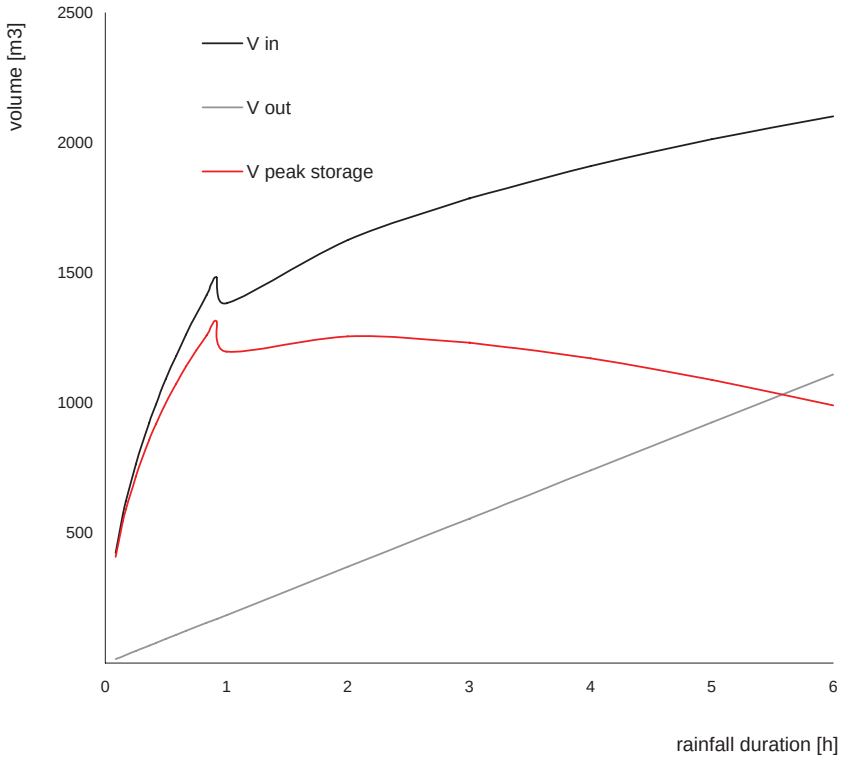


Figure B.1. Model and peak rainfall curve, ARI 50 years.

P d [h]	P h [mm]	INT m [mm/h]	DIS in [l/s]	R c	DIS sto [l/s]	DIS out [l/s]	VOL in [m3]	VOL out [m3]	VOL sto [m3]
0,08	14	165	274	53	223	51	293	15	277
0,14	18	123	352	68	300	51	394	27	367
0,17	19	112	379	74	328	51	430	31	399
0,25	23	91	451	88	400	51	525	46	479
0,36	27	74	533	104	481	51	632	67	565
0,42	29	68	493	96	441	51	679	77	602
0,50	31	62	446	87	394	51	743	93	651
0,58	33	57	410	80	358	51	802	108	694
0,67	35	53	381	74	329	51	856	123	733
0,75	37	50	357	69	306	51	907	139	768
0,83	39	47	337	66	286	51	954	154	800
0,92	41	44	320	62	268	51	999	170	830
1	38	38	272	53	221	51	926	185	741
2	44	22	158	31	107	51	1092	370	722
3	48	16	115	22	64	51	1204	555	649
3	48	16	115	22	64	51	1204	555	649
4	51	13	92	18	40	51	1291	740	551
5	53	11	77	15	26	51	1363	925	438
6	56	9	67	13	15	51	1425	1110	315
7	57	8	59	11	8	51	1480	1295	185
8	59	7	53	10	2	51	1530	1481	50
9	61	7	49	9	0	51	1666	1666	0
10	62	6	45	9	0	51	1851	1851	0
11	63	6	41	8	0	51	2036	2036	0
12	65	5	39	8	0	51	2221	2221	0
13	66	5	36	7	0	51	2406	2406	0
14	67	5	34	7	0	51	2591	2591	0
15	68	5	32	6	0	51	2776	2776	0

VOL sto max [m3]
830

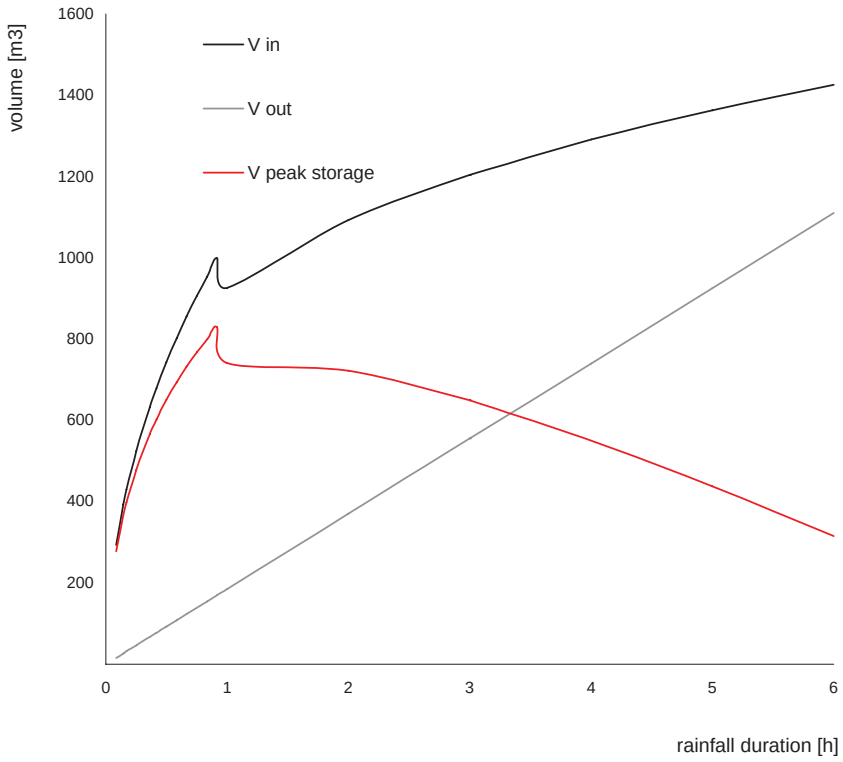


Figure B.2. Model and peak rainfall curve, ARI 5 years.

	WW in [m3]
January	583
February	526
March	583
April	564
May	583
June	564
July	583
August	583
September	564
October	583
November	564
December	583

	E [mm]
January	21,5
February	53,7
March	82,5
April	106,8
May	129,2
June	133,5
July	134
August	118
September	90
October	66,7
November	44,3
December	36,5
total	1016,7

	January	February	March	April	May	June	July	August	September	October	November	December
1993	0	7,8	44	59,2	36,4	32,2	55,2	26,6	124,8	131,4	39,6	27
1994	35	24,4	2,2	92,2	38,6	26,8	70,6	52,4	110,4	55,2	51	41,2
1995	24,4	77,4	22,8	53	150,8	154,8	33	72,2	52	6	22,2	93
1996	92,8	40,6	10,4	73	71,6	25,2	30	96,2	64,2	111,8	92,8	148,6
1997	63,4	2,6	18	34	26	112,4	75,6	30,2	36	10,8	69,8	113,2
1998	47	6,6	6,2	85,4	58,6	46,4	23	21,2	88,2	62,4	14,4	4,6
1999	21,2	4,6	39,2	96,8	47,8	140	61	56,6	123,2	94	63,2	31
2000	n.a	2	41,2	33,4	48,2	84,8	22,6	27,8	36,4	98,6	117,4	8
2001	50,6	8,8	114,6	51	74	45,8	74	67,4	95,8	89,8	55,4	0,6
2002	27,6	70,4	13,8	124,2	99	45,8	130,2	180	82,4	72,6	76	96,4
2003	23,2	3,4	7	84	15,2	27,2	13,4	8,8	24	75,8	102,6	55,6
2004	36	124,8	88	118	105,6	55,8	63,4	20,2	120,8	107,4	106,8	63,4
2005	5	9,4	6	103,8	107,2	8	41,2	158,2	65,8	182,8	87,6	55,4
2006	21,2	46,4	32	31,6	46,4	19,8	57,6	134,4	133,8	18	36,4	37,4
2007	15,8	61,8	110	1	59,4	66,4	152	60,4	75,8	51,6	51,8	7,2
2008	37,8	22,6	21,6	79,4	70,6	178,6	39,4	19,6	38,6	31,8	99	134,8
average	31,4	32,1	36,1	70	66	66,9	50,3	64,5	79,5	75	67,9	57,3

Figure B.3.(top left) Monthly volume of treated wastewater.

Figure B.4.(top right) Average monthly evaporation.

Figure B.5.(bottom) Average monthly precipitation.

	P [mm]	ET [mm]	PE n [mm]	PE a [mm]	PE tot [mm]	ET net [mm]	IR u [mm]	IR u hyp [mm]	IR out [m3]
January	31,4	13,8	17,6	28	46	0	28	0	0
February	32,1	27,4	4,7	37	41	0	37	0	0
March	36,1	61,6	0	46	46	25,5	71	0	0
April	70	86,7	0	44	44	16,7	61	31	607
May	66	127,6	0	46	46	61,6	107	107	2139
June	66,9	144,8	0	44	44	77,9	122	122	2434
July	50,3	154,4	0	46	46	104,1	150	150	2985
August	64,5	132,7	0	46	46	68,2	114	114	2270
September	79,5	86,4	0	44	44	6,9	51	26	507
October	75	45,7	29,3	17	46	0	17	0	0
November	67,9	19,4	48,5	-4	44	0	-4	0	0
December	57,3	11,5	45,8	0	46	0	0	0	0
total	697	912	145,9	394	540	360,9	755	550	10942

	P [mm]	X [m2]	R in [m3]
January	31,40	20000	628
February	32,10	20000	642
March	36,10	20000	722
April	70,00	20000	1400
May	66,00	20000	1320
June	66,90	20000	1338
July	50,30	20000	1006
August	64,50	20000	1290
September	79,50	20000	1590
October	75,00	20000	1500
November	67,90	20000	1358
December	57,30	20000	1146
total			13940

Figure B.6.(top) Irrigation demand.

Figure B.7.(bottom) Run off volume.

	R in [m3]	WW in [m3]	P in [m3]	EV out [m3]	IR out [m3]	STO net [m3]	STO tot [m3]	STO d [m]	Y [m2]	X [m2]
January	628	0	69	47	0	667	4943	2,25	19900	2200
February	642	0	71	118	0	652	5595	2,54		
March	722	0	79	182	0	666	6261	2,85		
April	1400	0	154	235	303	756	7017	3,19		
May	1320	0	145	284	2139	-954	6063	2,76		
June	1338	0	147	294	2434	-1267	4796	2,18		
July	1006	0	111	295	2985	-2208	2588	1,18		
August	1290	0	142	260	2270	-1130	1458	0,66		
September	1590	0	175	198	254	1067	0	0,00		
October	1500	0	165	147	0	1564	1564	0,71		
November	1358	0	149	97	0	1465	3029	1,38		
December	1146	0	126	80	0	1247	4276	1,94		

DR out [m3]
2295

	R in [m3]	WW in [m3]	P in [m3]	EV out [m3]	IR out [m3]	IR out (K) [m3]	STO net [m3]	STO tot [m3]	STO d [m]	Y [m2]	K [m2]	X [m2]
January	628	583	104	71	0	0	1269	7410	2,25	19900	25000	3300
February	642	526	106	177	0	0	1184	8594	2,60			
March	722	583	119	272	0	0	1221	9815	2,97			
April	1400	564	231	352	607	0	1302	11117	3,37			
May	1320	583	218	426	2139	250	-689	10428	3,16			
June	1338	564	221	441	2434	2000	-2789	7639	2,31			
July	1006	583	166	442	2985	3500	-5239	2399	0,73			
August	1290	583	213	389	2270	1750	-2372	27	0,01			
September	1590	564	262	297	507	0	1624	0	0,00			
October	1500	583	248	220	0	0	2179	2179	0,66			
November	1358	564	224	146	0	0	2082	4262	1,29			
December	1146	583	189	120	0	0	1880	6141	1,86			

DR out [m3]
1305

Figure B.8.(top) Model employed for the computation of the *seasonal storage version a.*

Figure B.9.(bottom) Model employed for the computation of the *seasonal storage version b.*