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# 15 Human Impact on Hydrology

## Direct and Indirect Consequences of Medieval Urbanisation in Southern Germany

**Abstract:** It is the aim of this contribution to widen the perspective on urban water. Beyond the archaeological traces of water management related to towns, we need to take the ecological consequences of urbanisation into account. On the one hand, the urban infrastructure with water regulations, channels and sewers had direct consequences on the local hydrology; on the other hand, urbanisation had indirect consequences on the hydrology in more distant rural areas, too. These indirect consequences were probably a major factor of late medieval landscape changes, which were at the basis of the late medieval crisis. The article uses the situation in Southern Germany in order to sketch possible interrelations and demonstrate the perspective of human ecology.

It is the aim of this contribution to sketch some of the ecological aspects of urban water. There is a large body of research in both environmental history and archaeology.[1] There is, however, a fundamental problem, because basic categories, which are important for an understanding of ecological connections, are not present in the available sources. For example, the terms 'energy', 'climate' or 'water run-off' can neither be found in medieval texts nor can archaeologists excavate them. Dealing with aspects of environmental history or human ecology requires the acceptance of abstract categories and an open mind for hypotheses and interdisciplinary exchange. Otherwise, archaeologists, at least, will be stuck in a typology of sewers and water channels. For this reason, this article will not discuss the many observations on water usage within the town, but focus on a landscape perspective.

The interaction of towns and rivers has many dimensions,[2] and is characterized by complex interactions. I will use some examples from Southern Germany to provide at least a rough impression of this complexity. There are many towns in Southern Germany situated on large rivers, such as the Rhine or the Danube, going back to the Roman period or before, but the majority represents towns developing mainly in the High Middle Ages, most often also related to some rivers or creeks.

## Intended landscape modification during urbanisation

At first glance, it seems quite easy for archaeology, at least, to identify planned modifications of waterscapes. At Salzburg, for example, the builders of the 12$^{th}$-century Alm channel changed the local water courses by digging a tunnel below Hohensalzburg castle (Fig. 1). In this way the town was supplied with fresh water.[3] In many other towns, water courses were modified for mill races, the water supply of factories, or for flood fortification systems. In some cases, water courses were altered in order to construct navigable waterways or to prevent the risk of flooding.

However, in many cases it is quite difficult to trace anthropological changes to the landscape clearly. At Ulm (Fig. 2), for example, the river Blau passes the western bluff of the Weinhof

**1** Untermann 2009.
**2** Gunzelmann 2009.
**3** Zillner 1864.


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**Fig. 1:** Salzburg, the Alm channel below Hohensalzburg castle.

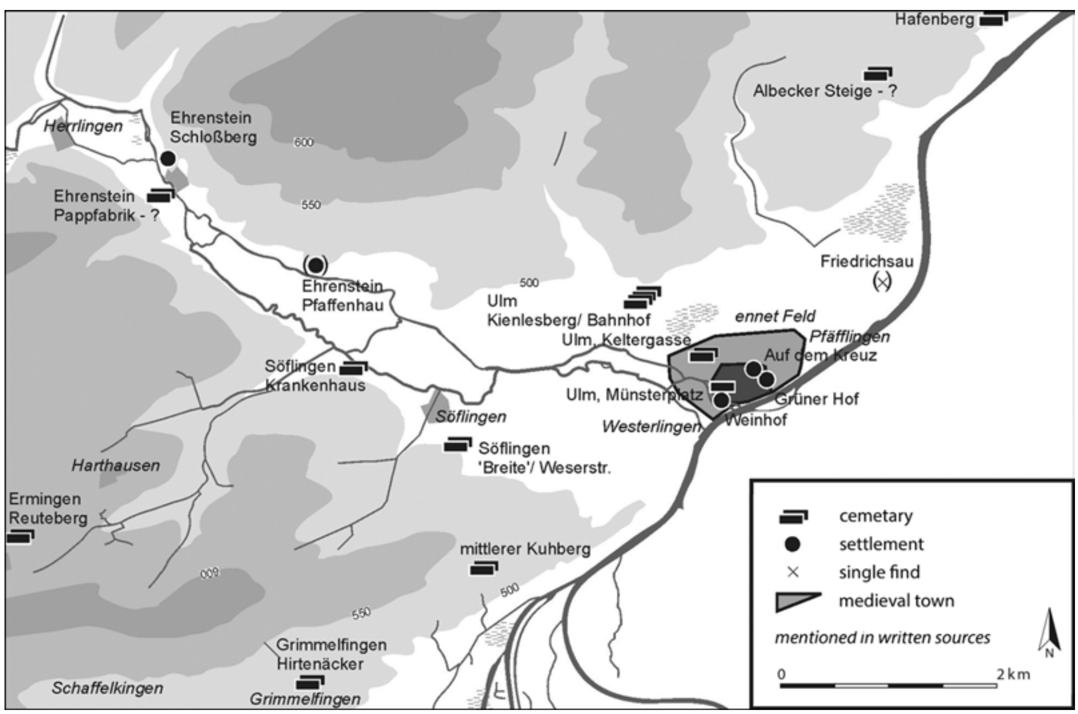


**Fig. 2:** Map of Ulm.

hill, where the early medieval palatium was situated. North of the town, which extends over a low ridge, there is an old river course of the Blau, still visible in 19th century maps. Occasional finds of prehistoric sherds show that there was fluvial sedimentation north of the later town at least up to pre-Roman times. However, because systematic research is lacking, we do not know when the current course of the river Blau was established and whether this happened by natural causes or by human intent. Possibly the Blau was regulated in order to establish proper locations for milling and handicrafts.[4]

4 Schmid 2007, 7.

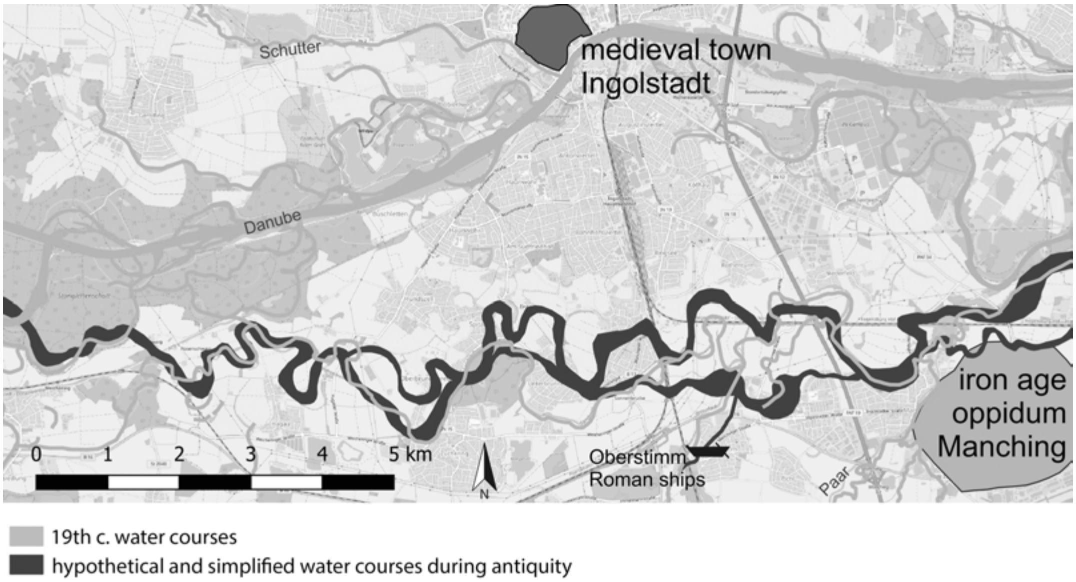


**Fig. 3:** Map of the Danube near Ingolstadt.

The Danube valley close to Ingolstadt was characterized by a meandering river course which entailed a large number of backwaters (Fig. 3).[5] Ingolstadt was mentioned at the beginning of the 9th century for the first time. It was situated on a low terrace to the north, close to the mouth of the Schutter brook. The situation provided locations for mills, but also direct access to the Danube river as an important line of transport. However, in Roman and early medieval times the course of the Danube was some kilometres south of Ingolstadt. In pre-Roman times, the oppidum of Manching[6] was located opposite the later town on the southern bank, probably also because the Danube was used as an important transportation route. This southern Danube course was navigable in Roman times, as the ships discovered in Oberstimm[7] show. Close to the Iron Age oppidum of Manching, water courses of the Danube were still active even in the Late Middle Ages.[8] It is an interesting question as to whether these changes of the regional hydrology were the result of natural floods or of artificial water channelling. However, within the southern part of the town of Ingolstadt, urban archaeology shows some intentional changes of water courses by land filling and bank stabilisation.[9]

Both examples lack detailed modern geoarchaeological data for verifying the medieval topography and landscape changes. Relevant information comes from river sediments, which are not protected as archaeological sites, because their anthropological character is often hardly obvious. Furthermore, the redirection of river systems may have taken place far away from the towns themselves and are thus outside the remit of urban archaeology.

Excavations at the Donaumarkt in Regensburg between 2009 and 2015 allow the reconstruction of the development of an urban quarter at the waterfront.[10] They showed the change from a floodplain situation, to some harbour and canal constructions and to a landfill in the 12th/13th centuries, which provided the ground for urban stone architecture. Over the centuries, there have been many floods and their sediments are partially visible in the archaeological record[11] (Fig. 4). A flood in 1304 caused basic changes to the northern waterfront opposite the city. The

**5** Schmidt – Riedel 2008, fig. 206.
**6** Guichard et al. 2000.
**7** Bockius 2002.
**8** Schramedei – Brunnacker 1992, 427.
**9** Arauner 2008.
**10** Nießen – Wollenberg 2019.
**11** Codreanu-Windauer et al. 2008.

**Fig. 4:** Regensburg, sediments at the excavation of the 'Donaumarkt'.

main course of the Danube now used a riverbed close to the northern flank of the valley, causing the Regensburg town council to redirect the river back to the city. The northern bank was only partially under the town's control and therefore a long debate over the legal rights on the river started with the Bavarian duke.[12]

At Bamberg, which was situated at the foot of the old Babenburg castle within a riverine landscape of water channels and islands, we can also trace changes of urban water.[13] Within the Staufian period, the riverside opposite to the castle was fortified by a new town wall; this affected also the topography. An old river channel, where many subfossil trees had been deposited, mainly in the Roman period, was first transformed into a small ditch and later filled in completely (Fig. 5). Ground water level was rising during the Late Middle Ages, as indicated by soil marks.[14] During later centuries, the hydrological topography was adapted to the multiple uses of urban water as a waterway and as an energy source, but also as a water supply for tanneries and sewers.[15]

Today there is plenty of evidence of medieval construction in connection with water during the first millennium in Central and Western Europe, primarily coming from an archaeological interest in long-distance trade. What we can learn from this research is that altering hydrological landscapes was common practice already in the first millennium.[16] Environmental history provides a broad record of water regulation in various landscapes, but only in a few cases has archaeological evidence of this been identified.[17]

Topographies of urban water thus need to be thoroughly researched in order to identify possible landscape modifications in the course of urban development.

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**12** Knoll 2013, 298.
**13** Gunzelmann 2009.
**14** Schöpplein 2016, 51 f. 54 f.
**15** Hanemann – Dengler-Schreiber 2009.
**16** Kröger et al. 2017; Werther – Kröger 2017.
**17** Castanet 2011; compare the ongoing research project at Heidelberg University: Land unter? – Hochwasser und Hochwasserschutzmaßnahmen am Oberrhein zwischen dem frühen und hohen Mittelalter <https://www.geog.uni-heidelberg.de/geomorph/land_unter.html> (23. 04. 2019).

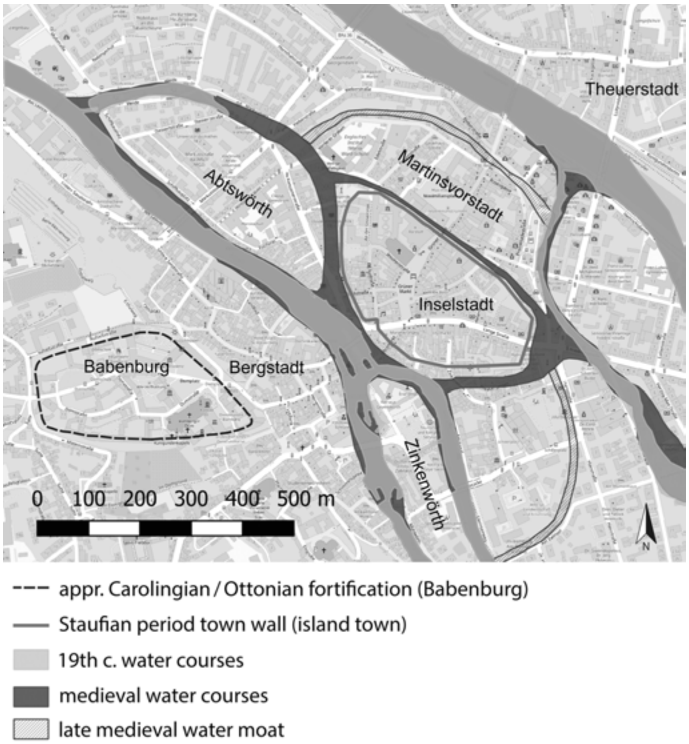


**Fig. 5:** Hydrotopography of Bamberg.

## Changing role of waters affects urban design

In the course of time, the importance of rivers and watercourses for transportation and travelling changed. With flat boats, even rather small creeks were navigable. Transportation by waterways was much more effective than transportation on land.[18] There are some indications that inland navigation was important in the Early Middle Ages. On the river Main, for example, a line of fortified sites seems to have controlled and supported water transportation on the river. In 796, a channel was constructed, or at least attempted, in order to connect the Danube river system and the Rhine/Main river system: the Fossa Carolina.[19]

In the High Middle Ages, during the Staufian period, land transportation gained in importance.[20] The famous Tabula Peutingeriana was copied during the 13th century from a late antique map showing the Roman roads. There were also some attempts, at least in Italy, to renew the obligations of adjoining owners to take on the maintenance and repair of roads.[21] It is still a question in research as to whether there were also technical innovations in land traffic, for example, the cambered wheel, the horse collar, or horseshoes. Dating innovations is a problem.[22] Horseshoes can be found in rather large quantities at medieval sites, whereas wooden wheels and horse collars made of wood and leather are rarely preserved. A correlation of these innovation with 13th century's changes needs to be researched. There are also very few dated medieval bridges to help to clearly define periods of intense bridge construction activities. In central Europe, there are at least some bridges dating to the Staufian period, some in rural contexts, some close to towns (Fig. 6). For example, the bridge across the river Neckar at Neckar-

**18** Eckoldt 1984.
**19** Ettel et al. 2014; Schmidt et al. 2018; Werther – Kröger 2017.
**20** Szabó 1999.
**21** Szabó 1977.
**22** Cf. Schreg 2003; Schreg 2013b.

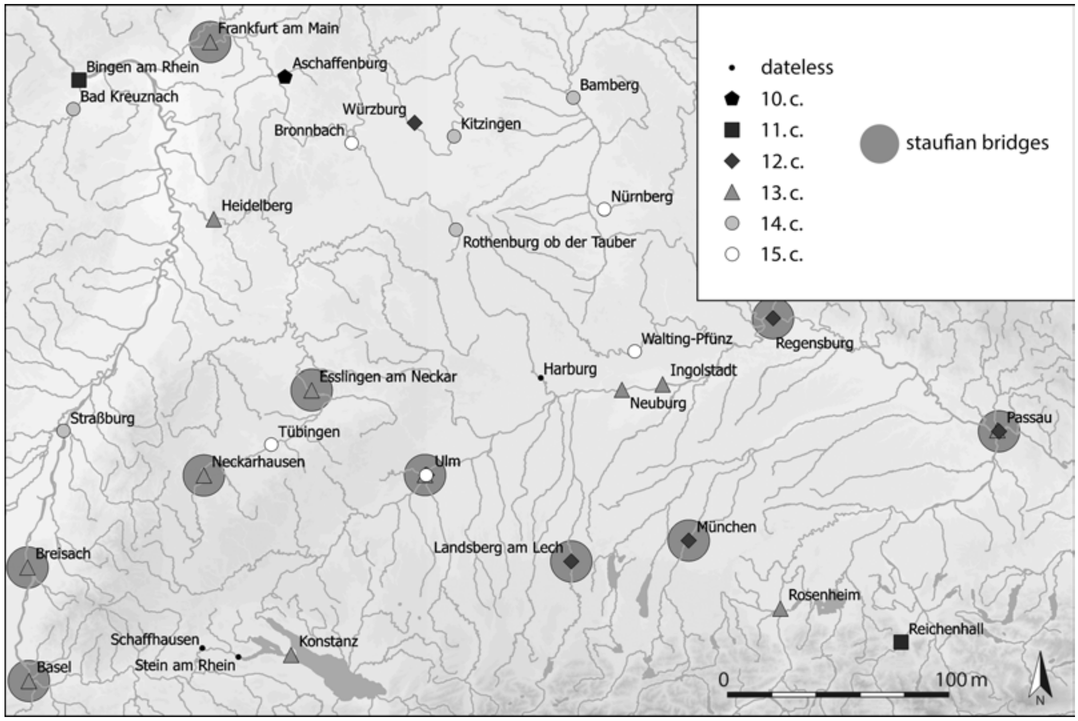


**Fig. 6:** Map of medieval bridges in Southern Germany.

**Fig. 7:** Neckarhausen, bridge built 1257.

hausen, close to Horb and still standing, has been dendrochronologically dated to 1257[23] (Fig. 7), while the bridge across the Danube at Regensburg was already constructed in the first half of the 12th century.[24]

River crossings were interesting locations for the founding of towns. They were important strategic points in the territorial politics of noble families. In Southern Bavaria, for example, the old Roman road between Salzburg and Augsburg crosses the Inn and the Isar. At both rivers, the road was relocated to new bridges and towns or markets. Munich was founded as a town by the Dukes of Bavaria trying to establish a market and toll station in competition with the previous Isar crossing at Oberföhring, some kilometres downstream.[25] In the 13th century, the old Roman bridge, the Pons Aeni, at modern-day Pfaffenhofen was replaced by one at Rosen-

**23** Ungerer-Heuck 1989.
**24** Knoll 2013, 294–297.
**25** Schwarz 1989, 180 f.; Päffgen 2013, 149–156.

**Fig. 8:** Tübingen and the Neckar River from south. Close to the Stiftskirche are the buildings of the university. Left of the Neckar bridge, timber rafts are visible.

heim, where a castle and a market were established to control the river crossing. In 1276 the bridge is mentioned for the first time.[26]

Within the close surroundings of towns, transportation of consumer goods towards the town increased. With some possible exceptions in specific topographical situations, such as in delta areas or coastal lowlands,[27] this traffic relied on roads and streets, and only to a lesser degree on local waterways. This is especially true for landscapes in Southern Germany, where most agrarian production areas were not close to water courses.

However, the transportation of firewood and timber, often over long distances, was carried out by floating or drifting. The supply of towns with timber therefore affected urban architecture and topography. Market places for timber can often be found at a situation easily accessible from the river, close to a town gate, sometimes outside the oldest urban centre within an area of later urban expansion.

The importance of timber rafting is visible in the town of Tübingen and its surroundings. The nearby Schönbuch forest has been intensively used at least since the 10$^{th}$/11$^{th}$ centuries, when iron production and pottery kilns needed large quantities of firewood. It is not possible to calculate how much forest has been cleared. In the Late Middle Ages, however, some areas were left in the neighbourhood of Bebenhausen monastery, where a hermitage was founded. In other parts, however, clearing caused soil erosion and gullying in the 14$^{th}$ century. In the 15$^{th}$ century, there was even a glass factory in the Schönbuch forest, requiring wood for energy and potash.[28]

Timber for house construction in Tübingen was thus rare. When Herzog Eberhard von Württemberg intended to establish the University of Tübingen in 1477, he first had to solve the problem of timber supply. He signed a treaty with neighbouring territories to open the Neckar River for floating. Buildings such as the Stiftskirche and the first university building (Fig. 8) were built with long tree trunks, imported from the Black Forest on the Neckar river. Researchers have discovered the holes for joining together the single logs to large rafts in many late medieval and early modern buildings. The treaty of 1475 was not the first one related to rafting on the Neckar

**26** Schwarz 1989, 71 f.
**27** E. g. Gawronski – Veerkamp 2017.
**28** Schreg 2018.

River, but the huge building programme established timber rafting on the Neckar even downstream of Tübingen. The availability of long logs triggered changes in the regional church architecture, when the basilica type was replaced by hall churches requiring bigger roof constructions.[29]

## Unintended effects of urbanisation on hydrology and landscape

To illustrate the possible interactions between urbanisation and hydrology, the Swabian Alb provides a valuable example, even if many questions are still open. The Swabian Alb is a karst landscape, where there was travertine formation, especially in the valleys along the northern bluff during the Holocene. Travertine deposits often were several tens of metres thick and they formed terraces, swamps and even lakes within the valleys (Fig. 9). In prehistoric times and even in the Middle Ages, many valleys remained hardly usable. The old traffic routes could not use the lower gradient in the valleys, but had to surmount the steep slopes on the bluff of the Alb directly.[30] This situation explains why archaeological sites, such as the late Iron Age oppidum at Heidengraben[31] or the migration period hillfort at Runder Berg, both close to Urach, were situated at what are today rather remote places.

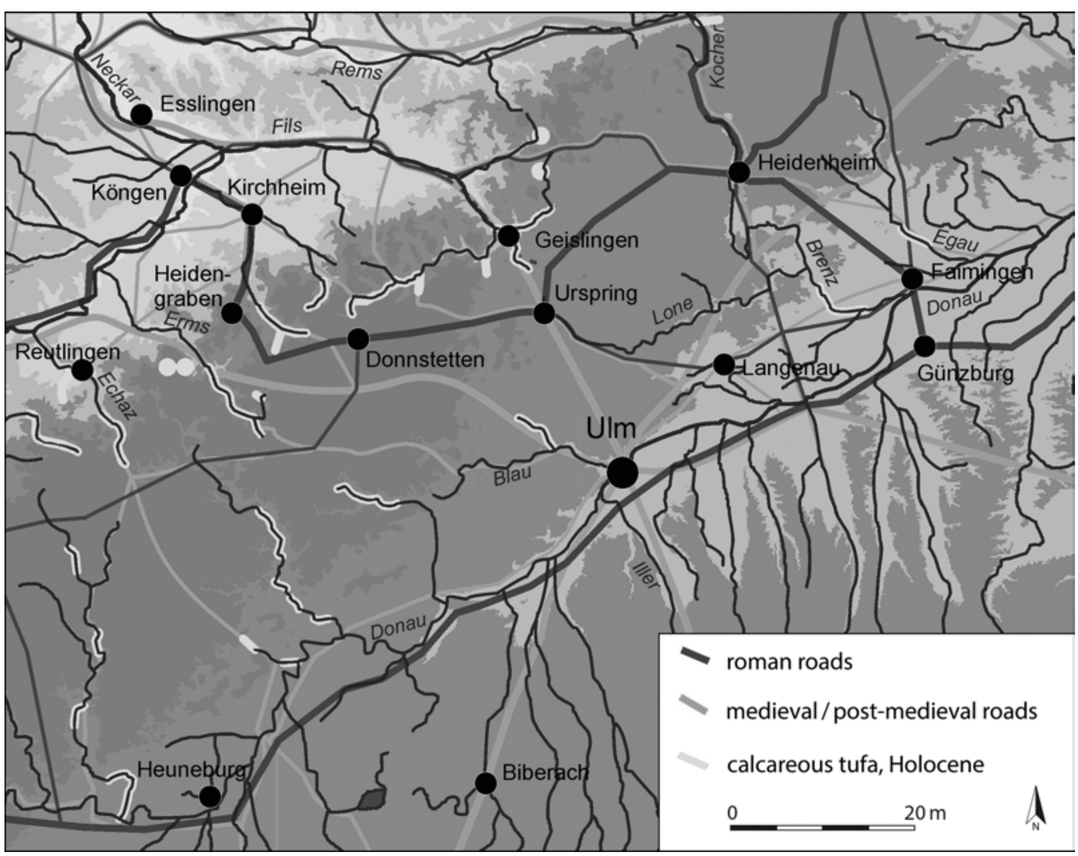


**Fig. 9:** Roman and medieval traffic lines in the karst landscape of the Swabian Alb. Holocene travertine blocked many valleys at the northern bluff of the Alb.

29 Marstaller 2009; Marstaller 2012.
30 Schreg 2009d; Schreg 2009e.
31 Stegmaier – Wahr 2009.

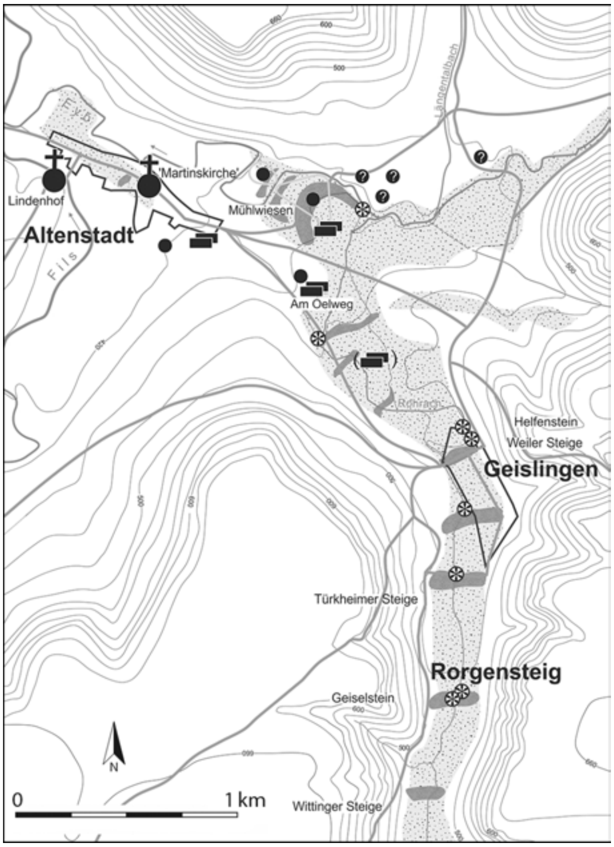


**Fig. 10:** Map of Geislingen with travertine terraces, roads, mills, and the late medieval town.

In most valleys, late medieval towns can be found, such as Geislingen, Urach or Pfullingen. The exact chronology of valley drainage and founding of the towns is still unclear. It is thus not certain whether water management in the Alb valleys was a consequence or a precondition for urban development.

At Geislingen an der Steige, we may assume that the end of travertine deposition already predated the development of the town.[32] The town itself, along with the earlier settlements in the Geislingen basin, was situated at the rim of travertine terraces providing rather dry ground, on the one hand, and ideal locations for milling, on the other. Whereas the town was founded sometime in the later 13$^{th}$ century, the early medieval village of Geislingen, some kilometres to the northwest, was already related to a road crossing the Swabian Alb. In any case, there are Merovingian cemeteries with precious grave goods. In 1237, Emperor Frederic II signed a charter *apud Giselingen*, when he was on his way from Vienna to Speyer, travelling through Ulm and Geislingen. It is not sure whether at that time the town of Geislingen already existed. There was probably already an access yard, some mills and probably some other small-scale settlements, as indicated by high medieval pottery sherds. Certainly, by then there was some settlement activity in the Rohrach valley, which today has given way to the road and the railway (Fig. 10). Oral tradition, at least, remembered the landscape of the Rohrach valley as characterized by lakes, where one of the children of a local noble family was said to have drowned. Excavations within the town of Geislingen have revealed the remains of fences, representing a first phase of occupation, maybe the remains of pre-urban land use for husbandry in a rather wet area.[33]

However, mills, water regulation, irrigated meadows, flooded urban fortification ditches and the channelling of the Rohrach, flowing partially through the town, were important factors

**32** Schreg 2009b.
**33** Lang – Schreg 1997.

in the cessation of travertine formation. The deposition of travertine depends on oxygen transfer to the calcareous water. When water courses were regulated, limescale became increasingly rare. The reduced travertine formation probably opened the Geislinger Steige, crossing the Rohrach valley, already prior to the founding of the town. Whereas the Roman roads bypassed the Rohrach valley for large distances, the Geislinger Steige became an important route during the Early Middle Ages, altering the main lines of traffic in such a way that the topographical situation of Ulm gained in importance.[34]

## Urban water and big history

The example of the karst landscape of the Swabian Alb referred to a specific regional phenomenon of the interaction between urbanisation and hydrology. However, there is a more general interdependence between urbanisation and hydrology, which was probably, in some ways, valid for the majority of old agrarian landscapes in Central Europe. Urban water is not only related to specific urban infrastructure, but is also part of wider ecological changes and possibly also a factor in the late medieval crisis.

### Beyond urban water: indirect consequences of urbanisation on the hydrology of more distant rural landscapes

The typical medieval village in most parts of southern Germany developed only in the 10th to 13th centuries. Within this complex process, urbanisation was certainly an important factor, even if we still do not understand the interrelation in all details.[35] The discovery of medieval settlement areas outside the later villages – abandoned in Southwestern Germany in the 12th/13th centuries, in Southern Bavaria probably already in the 10th/11th centuries – give a clear indication of basic changes of rural settlement structures.[36] It becomes clear, however, that the medieval village formation was a long lasting, complex process with many regional differences. The background of these changes within the rural settlement pattern is characterised by social and economic changes, such as the restructuring of the aristocracy (rise of the gentry, establishment of castles), urbanisation, and the intensification of land use. Marginal landscapes, such as the low mountain ranges of the Palatinate Forest, the Black Forest, the Spessart region and the Bayerische Wald (Bavarian Forest) gained in economic importance. There is increasing evidence of early medieval activities causing soil erosion by local clearings, as these mountainous landscapes became more and more important as energy sources for firewood and watermills. Within the old agrarian landscapes, we may presume that the establishment of regulated three-field crop rotation (*Dreizelgen* or *geregelte Dreifelderwirtschaft*) was a major element in village formation. Whereas a simple crop rotation was already known, the innovation of the High Middle Ages was compulsory crop rotation (*Flurzwang*), which required an equally distributed landholding over the three areas of crop rotation. Regulations were controlled by the farmers' community (*Markgenossenschaft*/*Gemeinde*) which now evolved, partly in imitation of urban administration.

**34** Schreg 2009a, 86–89.
**35** Schreg 2013a.
**36** Schreg 2006, 323–328; Schreg 2009c.

But with regard to our topic of urban waters, the ecological consequences are far more important than the social ones. Prior to the introduction of regulated crop rotation, there was a small landscape mosaic of enclosed plots cultivated individually by farmers. Settlements themselves often shifted over small distances, enabling an alternating land use so as to prevent soil degradation. The introduction of the open field system saw the removal of field walls and hedges, which in general had been necessary because of the grazing during fallow periods. But the cooperation and coordination of crop rotation superseded the enclosure of every single field, because within regulated crop rotation, herds belonging to different owners were kept together in the larger field blocks. This removal of hedges changed the microclimate by increasing heath emission over large grain fields, by increased evaporation, and by increasing water run-off. Thus, a transformation of the rural landscape triggered by the growth of towns had far-reaching effects, among others on the hydrology. Geo-archaeological research has yielded some evidence for increased soil erosion, resulting not only in gullying, but also in changes in the valleys. The sedimentation of alluvial clay reduced stream velocity, enlarged the meandering of creeks and rivers, and raised the ground water level in the valleys and the drier situations on the surrounding slopes.

## Increasing risks by hydrological changes

The high medieval landscape changes, for which urbanisation was one factor among others, resulted in some risks for the local society.[37] The increasing exposure of an open landscape with fewer hedges to soil erosion and the changing microclimate were accompanied by some disturbances of the biotopes of small animals like rodents or birds. At the same time, yields of agrarian land may have declined, rather than increased, because the gain of land by the introduction of the open field system may have been offset by the losses caused by the more permanent cultivation of single land plots. We need to remember that the formation of the village marks the end of a shifting settlement system, which may have contributed to sustainable soil management through the alteration of land use by settlement activities, gardens, agrarian fields and sometimes maybe even wood-cutting. Within the open field system, husbandry meant that herds were held in common and therefore the risk of animal diseases became more serious. Looking at the 14$^{th}$ century, just a few generations after these fundamental changes within the agrarian landscape, we can, in fact, see an increase in animal diseases, soil erosion and the subsequent abandonment of many rural settlements. This even raises the question of whether the outbreak of the Black Death may have had an anthropogenic component, as the extreme weather of 1342 including the flood around St Mary Magdalene's day in July may have had some consequences for rodent populations, including the rats, which were an important reservoir of *Yersinia pestis*.[38] New studies show that there was a genetic mutation of this pathogen shortly before 1349 and that the introduction of *Yersinia pestis* may have been more complex than hitherto assumed.[39]

There is a lot of speculation in this scenario by now, and we are far from a consistent picture of all the interconnections of the late medieval crisis. We need to verify or falsify the hypothesis of these long-term consequences of high medieval landscape changes by establishing more facts: 1) on the history of *Yersinia pestis*, because genetics indicate its presence in Europe already in the 6$^{th}$ century. This raises the question if the 1347 outbreak spreading from the east interacted with plague germs present in central Europe before 1347, 2) on the changes of biodiversity and the living conditions of small animals, 3) on the physical outline of fields and field

**37** Schreg 2013a.
**38** Schreg 2019.
**39** Bos et al. 2011; Namouchi et al. 2018.

**Tab. 1:** Consequences of urbanisation in the Late High and Late Middle Ages related to hydrology.

| **Economic and social consequences** | **Ecological consequences** |
|---|---|
| local<br>– more intensified and more diverse use of watersheds<br>– increasing water management<br>– Water construction<br>∘ milling and industrial channels<br>∘ flood protection<br>∘ fortification (moats)<br>∘ fresh water channels<br>∘ waterways and harbours<br>∘ …<br>– conflicts of interest related to<br>∘ drinking water vs. industrial water<br>∘ river transportation vs. land transportation (bridges)<br>∘ river transportation vs. fishing<br>∘ milling and water distribution<br>regional<br>– increasing demand for products of rural landscapes<br>– village formation<br>– intensified agriculture<br>increasing need of energy<br>– increasing construction of water mills<br>supra-regional<br>– market economy<br>– specialised production<br>– growth of forest-based economy (e. g. glass production, charcoal burning etc.) | local<br>– changing hydrology (raising or sinking ground water levels)<br>– effects on biodiversity<br>regional<br>– intensified agriculture<br>∘ removal of field walls and hedges<br>∘ open fields<br>∘ fewer long-term fallow periods<br>– changing microclimate (heath emission/ Albedo effect)<br>– increased water run-off<br>– soil erosion<br>– reduced biodiversity<br>– declining yields<br>changed metabolic cycles<br>– problems in manuring the agrarian fields (only solved by the introduction of dung manuring in the $14^{th}$ c.)<br>supra-regional<br>– changing hydrology<br>∘ landscape changes, e. g. in valleys<br>– new risks<br>∘ floods<br>∘ epidemics |

boundaries, and 4) on the hydrology and soil erosion. We need a precise chronology of these assumed changes, as this is a precondition for any correlation with urbanisation, for example.[40]

## Catastrophic flood events – long-term consequences of urban water?

An important part of the late medieval crisis mainly in the $14^{th}$ century was climate change. At that time, the beginnings of the Little Ice Age caused falling temperatures connected with extreme weather events. There is some chance that anthropogenic factors were involved also at that time, but at the global level this climate change was triggered by natural factors. The risks for human life, however, were dependent on cultural factors, such as land management strategies and settlement patterns.

In July 1342, at the time around St Mary Magdalene's day there was one of the heaviest rains causing floods and soil erosion, labelled by modern research as a millennium event.[41] We have written evidence, for example, from Mainz, Frankfurt, Würzburg, Bamberg and Regens-

**40** Schreg 2013a.
**41** Bork et al. 2011; Bauch 2014; Herget – Zbinden 2017.

burg of high water levels within the towns. At the site of Regensburg, where the Danube bridge had been destroyed, there is a thick layer of river deposits dating back to the 14th century.

Though the flood of St Mary Magdalene was by far the most severe one, there were other inundations during the 14th century. At the deserted town of Münster in the southern Black Forest, archaeological excavations also showed thick water-transported deposits dating to the 14th century. According to the current state of research, the Upper Rhine and the Southern Black Forest were outside the catchment of the flood of St Mary Magdalene.[42] There is, however, evidence from Esslingen, where written sources report of a landslide within the fortification walls in the summer of 1342. A vineyard glided off and damaged one of the urban monasteries.[43]

It is quite hard to link archaeological traces to one specific event. For this reason, the dating of soil erosion by radiocarbon dates in the Schönbuch forest to the 14th century cannot be linked to events of the summer of 1342, but is nevertheless a document for the clearance of forests discussed above.

## Conclusions

Looking at urban waters requires a perspective going beyond infrastructures. It is interesting to see the interrelation between urbanisation and landscape changes. The urban needs for food, energy and water had far-reaching effects, especially on the hydrology, which was, in turn, an important factor for late medieval landscape changes. In order to understand the complete picture, we need the perspective of human ecosystems, which allows us to address the right questions and to develop appropriate research strategies.

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**42** Jenisch 2019.
**43** Schreg 2013c.

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