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RIVERBED, BANKS AND BEYOND: AN EXAMINATION OF ROMAN INFRASTRUCTURE AND INTERVENTIONS IN RESPONSE TO HYDROLOGICAL RISK IN THE PO–VENETIAN PLAIN

by James Page[1]

Water poses a particular challenge to the cities and settlements of the Po–Venetian plain. The region has some of the highest levels of precipitation in Italy and is criss-crossed by dozens of rivers, including the Po, Adige and Tagliamento. Throughout history, there was considerable hydrological risk to the well-being of riparian communities from hazards such as flooding and lateral channel movement, yet local residents did not sit idly by. This article synthesizes the available evidence for Roman responses to hydrological risk in the Po–Venetian plain from the first century BC to the sixth century AD, examining their workings and the hazards they sought to counteract, integrating them into wider discussions on risk in the Roman world. The responses are divided into the categories of defensive works (embankments and dykes) and channel interventions (channel rectification, channel diversion and dredging). While the effectiveness of these methods is questioned, in particular their potential to cause unintended changes to the watercourse, the decision by riparian communities to undertake them suggests a degree of local success. Nevertheless, an examination of the archaeological and palaeoclimatic evidence suggests a discrepancy between peak intervention and peak risk, implying increasing vulnerability and risk acceptance amongst riparian communities during late antiquity.

L'acqua pone una particolare sfida alle città e agli insediamenti della pianura padano-veneta. La regione è caratterizzata da alcuni tra i più alti livelli di precipitazioni in Italia ed è attraversata da molti fiumi, tra cui il Po, l'Adige e il Tagliamento. Nel corso della storia, le comunità rivierasche hanno dovuto affrontare un notevole rischio idrologico legato a inondazioni e instabilità dei canali laterali. Gli abitanti dell'area non sono certamente rimasti a guardare. Questo articolo propone una sintesi delle evidenze disponibili relativamente alle risposte romane al rischio idrologico nella pianura padano-veneta dal I secolo a.C. al VI secolo d.C., esaminando il loro funzionamento e i pericoli che hanno cercato di contrastare, integrandole in più ampie discussioni sul rischio nel mondo romano. Le soluzioni individuate per arginare il rischio idrogeologico sono suddivise nelle categorie di opere difensive (argini e fossati) e interventi di canalizzazione (modifiche e deviazioni dei canali e dragaggio). Sebbene l'efficacia di questi metodi sia stata messa in dubbio, in particolare la loro possibilità di causare cambiamenti non intenzionali al corso d'acqua, la decisione delle comunità rivierasche di adottarli suggerisce un certo grado di successo

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locale. Tuttavia, un esame delle testimonianze archeologiche e paleoclimatiche suggerisce una discrepanza tra il picco di intervento e il picco di rischio, implicando una crescente vulnerabilità e un'accettazione del rischio tra le comunità rivierasche durante la tarda antichità.

INTRODUCTION

> Thus the river Po, swollen with brimming estuary, overflows its banks though defended by dykes, and oversets whole districts; if the earth anywhere gives way and collapses, unable to withstand the stream raging with its crest of waters, the whole river passes over and drowns plains which it never knew before; some owners their land deserts, while others gain new acres by the river's gift.[2]

The Po–Venetian plain was a significantly challenged part of the Italian peninsula when it came to water. The Po, Adige and East Alpine river systems flowed through the region, where their reputation for regular flooding, coupled with the waterlogged ground along their course, presented difficulties to those living in their vicinity.[3] While the rivers (and the rich alluvial soil they deposited) were responsible for much of the region's agricultural wealth, they were both a blessing and a curse.[4] Rivers might swell and break their banks, inundating the surrounding area and causing damage to life and property, while flooding and hydrological action might cause a river's channel to move, changing its course and altering the landscape in undesirable ways. In areas with a high water table, waterlogged ground was unsuitable for habitation and agriculture, and might serve as a breeding ground for disease. These hydrological processes and the risks they presented required human intervention to become manageable. In this respect, the above passage, written by the poet Lucan during the first century AD, is interesting. It highlights not only some of the challenges faced by those close to the river (flooding and the resulting channel movement) but also some of the solutions these communities utilized (such as dykes) in an attempt to overcome them.

While the structures and practices used to control and alter hydrological processes in the Po–Venetian plain (embankments and dykes, channel rectification, diversion and dredging) are recorded in the region's archaeology and ancient literature, they have yet to be integrated into wider discussions on water management.[5] Indeed, research on water management in Italy beyond

[2] Lucan, *Pharsalia* 6.272–8. Abbreviations of classical authors and works follow *The Oxford Classical Dictionary*, eds S. Hornblower, A. Spawforth and E. Eidinow (Oxford University Press, fourth edition, 2012, and online). See the References for translations used.

[3] The Po alone has 141 tributaries and one of the highest discharge rates of any river located in the former Roman Empire, at 1,540 m^3/s (Gumiero *et al.*, 2009: 474–81).

[4] Plin., *HN* 3.117, commented that 'where [the Po] deposits its spoil it bestows bounteous fertility'.

[5] Fluvial hazards and risk in Italy have not been approached in the same way as in countries such as France, Germany and the Netherlands, where there exists an established tradition of scholarship concerning fluvial management and landscapes. See, for example, Allinne's (2005, 2007) work on

Rome and Ostia is often framed around the use of water as a resource either for extraction or for transportation — an exploitative rather than a reactionary angle.[6] This article aims to help address the imbalance by examining the strategies employed by the Romans in response to hydrological risk in the Po–Venetian plain between the first century BC and sixth century AD. Communities actively responded to the risks posed by rivers with considerable hydraulic infrastructure, which was used to counteract multiple types of hazard. It is impossible to know whether the Romans were aware of the potential drawbacks stemming from piecemeal interventions along the watercourse, yet while their effectiveness can be debated, the numerous examples present in the Po–Venetian plain suggest that riparian communities believed them to be worth undertaking.

HYDROLOGICAL CONTEXT AND RISK

Northern Italy is located in a transition zone between the wet, temperate climate of northern Europe and the drier, Mediterranean climate to the south. The region experiences some of the highest precipitation in Italy in the form of both rain and snow, and the high volume of water has resulted in the development of an extensive river network fed by runoff from mountains, springs and wetlands. These rivers are a defining feature of the landscape, and range in size from small, seasonal mountain torrents to larger streams and rivers with discharges of thousands of cubic metres per second, with the Po forming the centre of the network (Gumiero *et al.*, 2009: 474).[7] The Po basin alone has a watershed of some 74,000 km^2, draining the Southern Alps and Northern Apennines, alongside the Colline del Po, the Langhe and the Monferrato hills. The Po dominates the region, moving west–east across the plain before emptying into the Adriatic (Fig. 1). It has 141 tributaries of varying size, the largest being the Adda and the Oglio. Directly to the east and running parallel to the Po in its final stretches is the Adige, the second longest river in Italy and possessing a watershed of 12,100 km^2.[8] Beyond the basins of the Po and the Adige, the

urban responses to fluvial hazards in southern France; Franconi's (2014, 2016, 2017a, b) work on the Rhine which has highlighted the impact climate had on riparian systems, and the anthropogenic responses to try to counter it (often unsuccessfully); and Rieth's (1998) discussions on historical fluvial landscapes.

6 There are some notable exceptions, such as Arnaud-Fassetta *et al.*, 2010, and Keenan-Jones, 2013, but these remain a minority. For example, in his seminal text on fluvial environments in the Roman period, Campbell (2012: 317–19) talks about attempts in Rome to manage the Tiber, yet falls short of examining the evidence for managing hydrological risk on rivers beyond the capital. In the Po–Venetian plain, the main exploration of the region's rivers has been through their ability to provide transportation (e.g. Uggeri, 1987, 1990, 2016; Medas, 2003, 2018).

7 The modern mean annual discharge of the Po is 1,540 m^3/s, though the greatest recorded discharge is 10,300 m^3/s, observed at Pontelagoscuro during the 1951 flood.

8 It is possible that the Adige may in fact have been a tributary of the Po during antiquity (Calzolari, 2004: 19–20). The Adige is recorded as a tributary in several ancient sources,

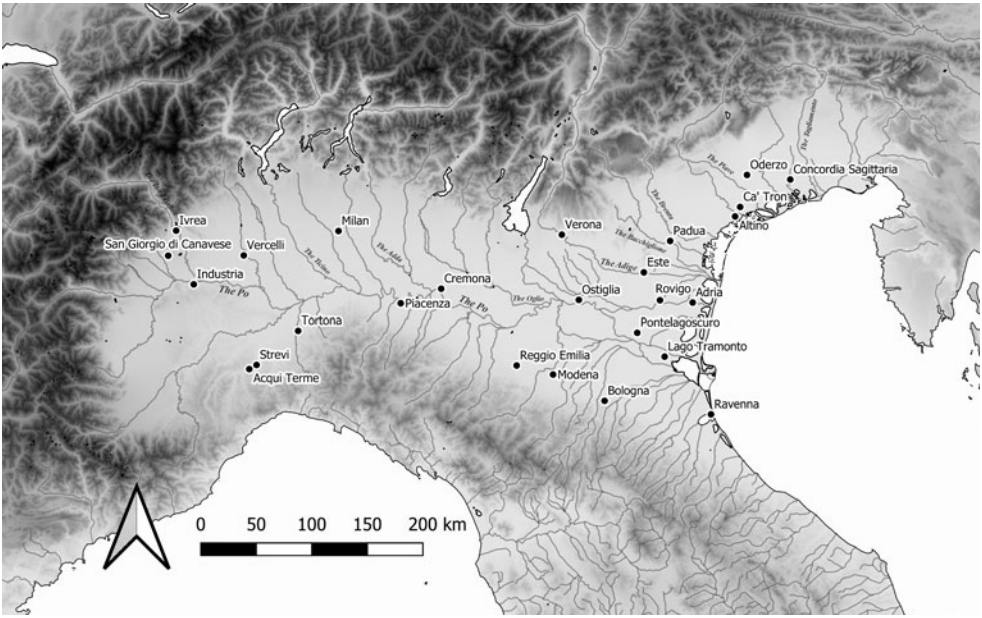

Fig. 1. Map of the Po–Venetian plain with rivers and places mentioned in the article.

eastern Italian Alps feed rivers such as the Bacchilgione, Brenta and Tagliamento that drain south into the Adriatic.

Complex processes drive fluvial systems, not all of which are fully understood. River conditions are not constant but rather exist in a continuum, constantly evolving as they move from source to sea. Fluvial conditions and hydrodynamics are likely to be very different upstream and downstream of any given point on a river (Vannote *et al.*, 1980). The morphology of the river channel itself can be determined by a variety of factors, including slope, bed composition, water and sediment discharge, tributary input and human intervention (Negri *et al.*, 2004; Lanzoni, Luchi and Bolla Pittaluga, 2015: 95). The Po has a very shallow gradient (at times less than 1 per cent in its lower reaches) and, as a result, the river's sediment load, rather than its velocity, is one of the driving variables in determining its geomorphology (Mozzi, Piovan and Corrò, 2020: 81). Sediment levels within a river channel need to be carefully balanced in order to retain equilibrium between erosion and deposition (Bridge, 2003: 199–211; Colombo and Filippi, 2010: 331–2). The complex parameters governing this are unique to each river, with the uncontrolled removal of sediment or sediment sources often having unforeseen consequences.[9]

including Plin., *HN* 3.121; Serv., *Aen.* 9.676; and Sid. Apoll., *Epist.* 1.5.4. Several possible palaeochannels of the Adige have been identified, and it seems likely that a branch of the river entered the Po near Rovigo (Uggeri, 2016: 85).

9 For example, the widespread extraction of large quantities of gravel and sand from the bed of the Po during the 1970s and 80s led to the severe incision of the river channel and the degradation of the river's delta (Marchetti, 2002; Surian and Rinaldi, 2003).

In northern Italy, the transition of rivers from the Alps and Apennines to the Po–Venetian plain is dominated by alluvial fans dating from the late Pleistocene and early Holocene (Fontana, Mozzi and Bondesan, 2008; Fontana, Mozzi and Marchetti, 2014; Cremaschi, Storchi and Perego, 2018). The aggradation of these fans ended in the middle Holocene, after which the rivers and streams began to entrench. Beyond the fans, rivers are flanked by fluvial ridges interspersed by crevasse splays, deposits of sediment marking where these ridges or artificial dykes failed along the course (Castaldini *et al.*, 2019: 784–5).[10] Depressed areas of back-swamp are located behind the fluvial ridges, characterized by poorly drained, waterlogged soils of fine sediment and clay (Brandolini and Cremaschi, 2018: 3).[11] In the areas closest to the Adriatic coast, the height of the land falls below sea level in several areas, resulting in areas of brackish standing water and marsh, alongside the formation of lagoons.

As it enters the plain, the Po exhibits a gravel-bed morphology, which transitions to a sand-bed morphology between the confluences of the rivers Ticino and Trebbia (Lanzoni, Luchi and Bolla Pittaluga, 2015: 95). The upper reaches of the Po contain braided systems consisting of multiple intersecting channels (anabranches) separated by sandbars, while in the middle and lower river single-thread meanders form the dominant channel morphology (Colombo and Filippi, 2010: 333). The erosion of sediment from the banks (and its accompanying deposition) causes the channel to move both laterally and longitudinally (Seminara, 2006: 274).[12] Bank erosion is normally a gradual and continuous process, but avulsion (often instigated by flooding or downstream blockages) can cause the river channel to move its path rapidly to a new, more favourable course (Bridge, 2003: ch. 8). Adjacent to the Po basin, the geomorphology of the Adige exhibits similar characteristics to the Po in its lower course (Piovan, Mozzi and Zecchin, 2012: 429–32). The eastern Italian Alps feed rivers such as the Bacchilgione, Brenta and Tagliamento that drain south into the Adriatic across the Venetian plain, and although some of these rivers possess similar characteristics to those of the Po plain, several watercourses present significantly different geomorphology. Most notable of these is the Tagliamento, where braiding forms the dominant channel morphology.[13] This morphology is highly unstable, with periods of high flow leading to rapid changes in channel path, alongside sandbar formation and destruction (Surian and Fontana, 2017: 158–9). During low flows, the majority of the channel remains dry, with water contained within the anabranches.

[10] Inactive fluvial ridges and crevasse splays are also present along the course of palaeochannels across the Po–Venetian plain.

[11] Many of these were either drained or partially drained between the second century BC and first century AD, but would reactivate as Roman land reclamation schemes began to fail during late antiquity.

[12] The Po itself has migrated north by approximately 50 km over the past three millennia (Bridge, 2003: 310–11).

[13] Significant braiding is also seen in the middle Brenta and Piave rivers, alongside the Torrente Meduna (Carton *et al.*, 2009; Picco *et al.*, 2013).

As the rivers of the Po–Venetian plain are fed by tributaries from both the Alps and the Apennines, the fluvial network is influenced by several discharge regimes. The first is Alpine, which is driven by temperature and results in maximum discharge occurring during the spring and summer from snowmelt, coupled with a dry winter period characterized by low flow due to water being locked up as snow and ice (Nelson, 1970: 155; Gumiero *et al.*, 2009: 480; Vezzoli *et al.*, 2015: 347).[14] The second is located in the pre-Alpine areas and Apennines and is driven by precipitation with two maxima, one in spring/summer, and the other in autumn, with low flows during the summer and the potential for drought in severe cases (Gumiero *et al.*, 2009: 481). Seasonal flooding is a common occurrence on the rivers across the region in the spring and autumn, but it is when high water levels from the Alpine and Apennine tributaries coincide that exceptional flooding occurs in the middle and lower Po (Marchi, Roth and Siccardi, 1995: 477; Camuffo and Enzi, 1996).[15]

The hydrological forces present in the Po–Venetian plain ensure that its riparian environments are in a constant state of flux. Water level, sedimentation and the velocity of its rivers change with the seasons and, in turn, alter the wider landscape.[16] The waterways of the Roman period were probably very different from the modern waterscape, with a combination of anthropogenic and environmental processes contributing to their evolution.[17] Indeed, riparian systems are highly susceptible to even minor variations in temperature and precipitation, which in turn impact on their behaviour. An increase of 1°C can reduce river flow by between 5 and 15 per cent due to decreased precipitation and evapotranspiration (Klostermann, 2001: 37–8; Bravard, 2008: 55; Franconi, 2013: 709). This increases the threat of winter flooding and summer drought. Alternatively, a decrease of 1°C will increase precipitation throughout the year, increasing the risk of flooding year-round and reducing the likelihood of summer droughts. Consequently, even small changes to the region's hydrology had the potential to alter the characteristics and behaviour of its fluvial systems, presenting new and evolving risks to those living in riparian environments.

[14] It should be noted that the large glacial lakes located in the Southern Alps also help to regulate this regime.

[15] The upper Po runs from its source on the Pian del Re to the river's confluence with the Dora Baltea. The middle Po runs from the Dora Baltea to its confluence with the Oglio. The lower Po runs from the Oglio to the Adriatic.

[16] See Franconi, 2017a, for a discussion on researching fluvial environments during the Roman period.

[17] Too often, studies have assumed parity between ancient and modern river conditions, forgetting the heavy modifications to river courses made by humanity during the nineteenth and twentieth centuries. These have significantly changed the character of most waterways (Cioc, 2002; Marchetti, 2002; Nienhuis, 2008). For discussions on the role of archaeologists, hydrologists and palaeoclimatologists in recreating ancient fluvial environments, see Edgeworth, 2011; Macklin, Lewin and Woodward, 2012; Izdebski *et al.*, 2016.

The application of palaeoclimatic data can help recreate former riparian environments, and the publication of several major studies in northern Europe over the past decade offers an unprecedented reconstruction of weather conditions during the Roman period.[18] Unfortunately, palaeoclimatic data exist at a much lower level of resolution for Italy; however, several recent studies suggest there was significant regional variation (Labuhn *et al.*, 2016: 74–81; Finné, *et al.*, 2019: 858–9; Bini *et al.*, 2020: 791). For example, Apennine speleothems suggest pronounced dry periods during the first and second centuries AD for central Italy, in contrast to the supposed uniform wetness suggested by the narrative of the Roman Climatic Optimum (Bini *et al.*, 2020: 800).[19] From the third century onwards, northern Italy seems to have become increasingly wet, an outlook supported by local excavation and geomorphological research that point to increasing hydrological instability in the region (Labuhn *et al.*, 2016: 74–81).[20] Stratigraphic cores taken from Bologna, Modena and Reggio Emilia document a series of large flood deposits between the first and sixth centuries AD (Cremonini, Labate and Curina, 2013: 170–3; Cremaschi, Storchi and Perego, 2017: 59–60; Bosi *et al.*, 2018: 4–5).[21] The cores suggest that from the third century AD onwards, flooding led to a large increase in land elevation in some areas of the plain from sediment deposition. In Modena's hinterland, pollen analysis undertaken on samples from the cores produced evidence that flooding also changed the landscape around the city. After a major flood during the third century AD, evidence for taxa associated with stagnant water was predominant, suggesting the creation of wetlands (Bosi *et al.*, 2018: 11–12). This new, waterlogged environment would persist until at least the end of the sixth century. At Acqui Terme in Piedmont, increased flooding and sodden ground saw the abandonment of the areas closest to the watercourse, and relocation to higher levels, in the late third to early fourth century AD (Crosetto, 2013a: 76–7).[22] In the Venetian plain, flooding and sediment deposition contributed to the decline of cities such as Este, Altino, Adria and Concordia Sagittaria during this period, where the combination of external socio-economic pressures and severe flood damage, followed by the silting-up or movement of economically important river

[18] Shindell *et al.*, 2003; Büntgen *et al.*, 2011; McCormick *et al.*, 2012; Sigl *et al.*, 2015; Harper, 2017: 44–5; Harper and McCormick, 2018: 33–9. These are complemented by more targeted studies that can reconstruct local climate in detail.

[19] The narrative of the Roman Climatic Optimum has been strongly challenged by Haldon *et al.*, 2018.

[20] Speleothem analysis from Renella cave in the Apuan Alps also points to a significant increase in flooding in northern and central Italy during the sixth century AD (Zanchetta *et al.*, 2021).

[21] The floods here are considered exceptional events, as opposed to the smaller annual floods common in the region.

[22] A similar outcome can be seen at the fort site of Oedenburg in France, where the lowest-lying parts of the adjacent *vicus* were abandoned in the fourth century, probably as a result of the rising water table and subsequent increased risk of flooding (Ollive, 2007: 651–2). See also Ollive *et al.*, 2006, 2008.

channels, proved a fatal combination (Boscolo, 2015: 340–2; Brogiolo, 2015: 58–9; Fontana, Frassine and Ronchi, 2020).

The above examples show that hydrological risk had the potential to cause substantial and, at times, permanent damage to riparian settlement in the Po–Venetian plain. Over the past two decades, hydrological risk, defined by Blouin (2014: 16) as 'the product of a natural hazard … and a human vulnerability', has been increasingly recognized as a concern for fluvial communities during the Roman period.[23] In this case, the hazards originated from the hydrological processes of the Po, Adige and East Alpine river networks, with the vulnerability stemming from the presence of human settlement and activity on and alongside these fluvial systems. Although fluvial hazards presented a clear risk for those living along the watercourses of the Po–Venetian plain, riparian communities did not sit idly by. Using a combination of defensive works and channel interventions, they sought to address a series of hazards and processes that included flooding, lateral channel movement, and sedimentation. The responses and strategies employed by communities to counteract these processes can be broadly separated into two categories: defensive works and channel interventions.[24]

DEFENSIVE WORKS

Physical additions to the fluvial environment in the form of embankments and dykes are a blunt form of water management, their core function to provide a separation between water and a protected area of land. The terms embankment and dyke can cover a wide variety of structures, not all of which serve the same purpose. In this article, embankment will be taken to mean structures lining the riverbank, while dyke will refer to raised structures built above the level of the riverbank. Embankments and dykes represent one of the most accessible and effective responses to the risk of flooding and channel movement and, as such, are a common management strategy (Allinne, 2007: 76). Although little input was theoretically needed beyond their initial construction, the materials used and their level of maintenance (especially in the wake of damage) had a major impact on their longevity and effectiveness.[25]

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23 The ability of communities to recognize and respond to fluvial risk has been highlighted across the Roman world. For further discussions on the concept of risk see Allinne, 2007: 79–82; Arnaud-Fassetta *et al.*, 2010: 109–14; Leveau, 2017: 61–3.

24 While drainage works formed a key component of water management in northern Italy, they have been discussed elsewhere. For discussions on drainage channels and ditches within northern Italy see Botazzi, 1992; Calzolari, 1995; Ortalli, 1995. For discussions on the workings of amphora-based drainage schemes and their distribution within northern Italy, see Cipriano and Mazzochin, 1998; Antico Gallina, 2011, 2014.

25 This is in comparison to channel interventions, which needed repeated execution to be effective.

EMBANKMENTS

Embankments represent one of the most recognizable pieces of infrastructure in the fluvial environment. They generally consist of a durable barrier that separates the riverbank from the water, protecting it from erosion and undermining. These structures rarely extend in height above the top of the riverbank, a feature often seen in urban embankments where the area immediately behind the structure might serve as a landing stage and loading area (Allinne, 2007: 72–3). Embankments may also be linked to land consolidation efforts that raise the ground level behind them. This is seen at Oderzo in the Veneto, where the riverbank was consolidated with a combination of land reclamation using recycled amphorae, and then with a masonry embankment, its foundations piled deep into the river clay (Tirelli, 1987: 81; Cipriano and Sandrini, 2001: 289).[26]

Embankments existed in both urban and rural contexts, although they performed separate functions in these locations. Urban embankments are known across the cities of the Po–Venetian plain and were primarily constructed on a foundation of timber piles, with the main structure formed of a concrete core faced in stone (Fig. 2).[27] These embankments served a double purpose both as defences against fluvial hazards and as wharfing for the loading and unloading of river vessels.[28] In addition to protecting and consolidating the waterfront, another common use of urban embankments was to insulate bankside infrastructure, such as bridges, from the threat of undercutting by the river.[29] Evidence for this exists in Padua, where excavation unearthed a stretch of wooden embankment below the city walls that protected them from being undercut by the river Brenta (Fig. 3). The structure was initially constructed in the early first century AD, replacing an earlier Iron Age embankment that had suffered from severe erosion (Balista and Ruta Serafini, 1993: 98–101). However, by the second century AD the Roman embankment was already in need of repair due to increased undermining by the river. The last of these repairs included reusing planks from a river vessel to shore up the structure (Beltrame, 2001: 442–3). A similar situation exists at Ivrea, where the first-century AD stone embankment that formed the docks of the town was extended further upstream to encompass the foundations of a bridge, protecting them from being undercut by the river (Finocchi, 1980: 89–90; Cera, 1995: 186; Brecciaroli Taborelli, 2007: 133).

[26] See n. 24 for further information on amphora reclamation deposits.

[27] The best-documented examples come from Ivrea (Finocchi, 1980: 89–90; Brecciaroli Taborelli, 2007: 133); Milan (Caporusso, 1990: 94; 1991: 245) and Oderzo (Tirelli, 1987: 81; Cipriano and Sandrini, 2001: 289).

[28] For example, the existence of wharfing along large stretches of the Tiber in Rome has been confirmed, but it is unknown whether these were also intended to act as flood defences or whether this was an unintended secondary function (Aldrete, 2007: 193–6).

[29] This was especially important in regions characterized by loose, sandy soil that enabled swift channel erosion and movement.

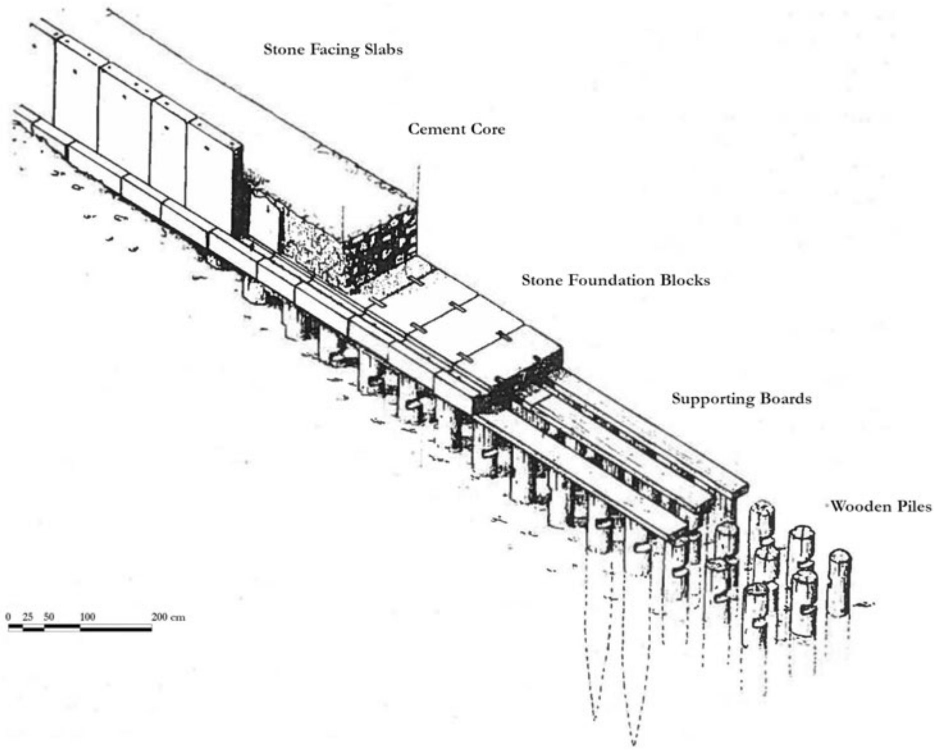

Fig. 2. Diagram showing the construction of the urban embankment discovered at Ivrea. Source: Finocchi, 1980: tav. XXVIIb (modified).

Rural embankments, while less commonly known than their urban counterparts, provided a different form of protection.[30] It is unlikely that these structures were primarily intended to function as flood defences (although this could have been a secondary role).[31] Instead, their main purpose seems to have been to prevent the erosion of the riverbank and subsequent lateral movement of the river's channel, something that could alter the structure of the landscape.[32] Channel avulsion routinely caused problems and was often commented on in antiquity. For example, several writers record incidents of the

[30] Rural harbours with embankments also existed, for example the section of wharfing discovered at Lago Tramonto on a palaeochannel of the Po, but they were generally smaller in scale than their urban counterparts (Bucci, 2015).

[31] Aside from providing river defences, embankments also had the potential to be used as towpaths, providing the continuous flat surface needed for those hauling a vessel (Medas, 2018: 157–8).

[32] For example, movement of the Po in its deltaic section is seen at Adria in the sixth century BC, where the main channel of the river dried up and shifted further south, with the river Tartaro subsequently occupying the abandoned channel (Corrò and Mozzi, 2017: 490).

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Fig. 3. The remains of the wooden embankment on the palaeochannel of the Brenta, Largo Europa, Padua. The Roman city wall is visible in the background. Source: Balista and Ruta Serafini, 1993: 99, fig. 6.

Po moving its path, and the property disputes this often caused as a result of the land created and lost on either side of the channel.[33] Ennodius described the Po as giving land to one 'that it steals from another', and Lucan records that after a flood, 'some owners their land deserts, while others gain new acres by the river's gift'.[34]

In the area to the west of Este, in the Veneto, evidence for this form of embankment survives. Two honorific inscriptions have been discovered at Ospedaletto Euganeo and Saletto di Montagnana which refer to work undertaken on the banks of the river Adige.[35] The expense and scale of the work in the vicinity of Este necessitated the involvement of public officials.

[33] See Campbell, 2012: ch. 3, for a wider discussion on rivers in Roman law and how changes could affect ownership of property. See also Hyginus Gromaticus, *De generibus controversiarum* 87–8, for specific rulings in relation to the Po.

[34] Ennodius, *Vita Epiphani* 21–2; Lucan, *Pharsalia* 6.272–8.

[35] *CIL* 5.2603: *Dec(uria) Clod/iana cu/r(atoribus) Q(uinto) Nae/vio L(ucio) Sei/o pig(neratore) C(aio) A/ntesti/o s(umma) h(ominum) / LXXXVIII / in sing(ulos) / h(omines) p(edes) XXVII / s(umma) op(eris) p(edes) / ||(milia) CCC/XCVIII*. *AE* 1916, 60: *Decuria / Q(uinti) Arrunti / Surai cur(atoribus) / Q(uinto) Arruntio / C(aio) Sabello / pig(neratore) T(ito) Arrio / sum(ma) h(ominum) XCIIX / in sing(ulos) hom(ines) / op(eris) p(edes) XLII / s(umma) / p(edum) ||||(milia) CCXIV*. Text taken from the Epigraphik-Datenbank Clauss Slaby, last accessed 29 July 2020.

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Both inscriptions, found along the line of the river's palaeochannel, refer to the *decuriones* who carried out the labour, the *curatores*, who seem to have been responsible for overseeing the project, and the *pigneratores* who provided the financing.[36] The Ospedaletto inscription refers to a team of 88 men that carried out work over a section of 2,398 Roman feet, while the one discovered at Saletto refers to a team of 98 men that carried out work over a section of 4,214 Roman feet. The inscriptions have been dated to the Augustan era, with the *decuriones* probably composed of veterans who had settled in the hinterland of Este (Buchi, 1993: 90; Bonetto and Busana, 1998: 91). The inscriptions are complemented by the exposure of an extensive series of Roman embankments stretching several kilometres along the southern bank of the Adige's palaeochannel, with sections unearthed at Borgo San Zeno, Montagna, Megliadino San Fidenzio and Este.[37] These were substantial structures, consisting of large blocks of rough, locally extracted Euganean trachyte placed against the banks of the river (Fig. 4). Excavated sections show that the embankments extended diagonally approximately 3 m from the bottom of the riverbed to the top of the riverbank over a vertical height of 2 m, with the core of the structure consolidated with fragmentary bricks and amphorae (Balista and Bianchin Citton, 1987: 18; Balista, Bianchin Citton and Tagliaferro, 2010: 143). The Augustan date of the embankments coincides with the division of land around Este for veteran settlement and it seems probable that they were intended to prevent the movement of the river towards the centuriation grid to the southwest of the city, which could alter its territorial framework (Boscolo, 2015: 337–40; Zara, 2018: 331–2). The creation of the embankments in Este's territory demonstrates a concern to avoid such events occurring in the newly divided landscape.[38]

[36] The Adige originally had a more northerly course that took it closer to the Euganean Hills (Brogiolo and Sarabia-Bautista, 2017; Zara, 2018: 329–30). *Curatores* also appear on an irrigation decree from the second century AD, found near modern Agón in the Ebro valley, Spain (*AE* 1993, 1043 = *HEp* 5 (1995), 911; Beltrán Lloris, 2006: 171–2).

[37] Balista and Bianchin Citton, 1987: 18; Balista, Bianchin Citton and Tagliaferro, 2010: 141–8; Bianchin Citton and Balista, 1991: 27–32; Bonetto and Busana, 1998: 92.

[38] This is supported by the discovery of an erosive surface behind the embankments, suggesting the Adige had begun to move during the early Roman period (Balista, Bianchin Citton and Tagliaferro, 2010: 143). Embankments constructed to prevent channel movement are also seen elsewhere in Italy. At Minturnae, there is evidence that the Garigliano was channelized and flanked with stone embankments from its mouth to the city further inland (Campbell, 2012: 301). Their purpose seems to have been to stabilize this area of the fluvial environment, important for accessing the river and ultimately Garigliano itself. In some cases, lateral channel movement seems to have been unavoidable, resulting in river courses moving away from the towns of Industria, Piacenza, Tortona and Vercelli. Rather than reposition the harbour or the town to restore access to the river, the decision seems to have been taken by the towns to construct artificial channels to link themselves to the river. The majority of these channels seem to have been constructed in the late first century BC–early first century AD. See Cera, 1995: 192–3; Spagnolo Garzoli *et al.*, 2007: 112; Zanda, 2011; Crosetto, 2013b: 101–8.

Fig. 4. A section of trachyte embankment from near Montagna, south-west of Este.
Source: Balista and Bianchin Citton, 1987: 14, fig. 6.

DYKES

Dykes complemented the bankside protection offered by embankments and were principally constructed for two purposes: first, to exclude water from an area and protect lives and property, and second, for the preservation of travel and communication routes by raising key roads above the hazard level of flooding.[39] In many cases, they performed both functions. Strabo described the Veneto as being 'intersected by channels and dykes', while Lucan refers to the land around the Po as being 'defended by dykes'.[40] These structures might not always be built directly adjacent to the waterways, instead being constructed in proximity to the areas they were meant to defend from inundation (Rickard,

[39] For example, at Strasbourg, a series of massive ramparts constructed between the Neronian and Antonine periods, located a short distance from the Rhine, were interpreted as dykes constructed to protect the fortress and *canabae* from flooding (Hatt, 1966: 313). Potential dykes constructed of earth have also been found at Bologna and Piacenza (Marini Calvini, 1985: 269 n. 28; Ortalli, 1993: 46–8; Bruno *et al.*, 2013: 1566). Tacitus (*Hist.* 3.21) records that the Via Postumia ran atop a dyke between Cremona and Ostiglia. Elements of the structure survived until the first half of the twentieth century, with the dyke apparently rising to a height of 2 m and being 20 m wide at its base (De Bon, 1941: 29, 47–8).

[40] Lucan, *Pharsalia* 6.272–8; Strabo 5.1.5. Further south, Varro (*Rust.* 1.14.2–3) recalls that along the Tiber to the north of Rome, 'one may see banks combined with trenches to prevent the river from injuring the fields'.

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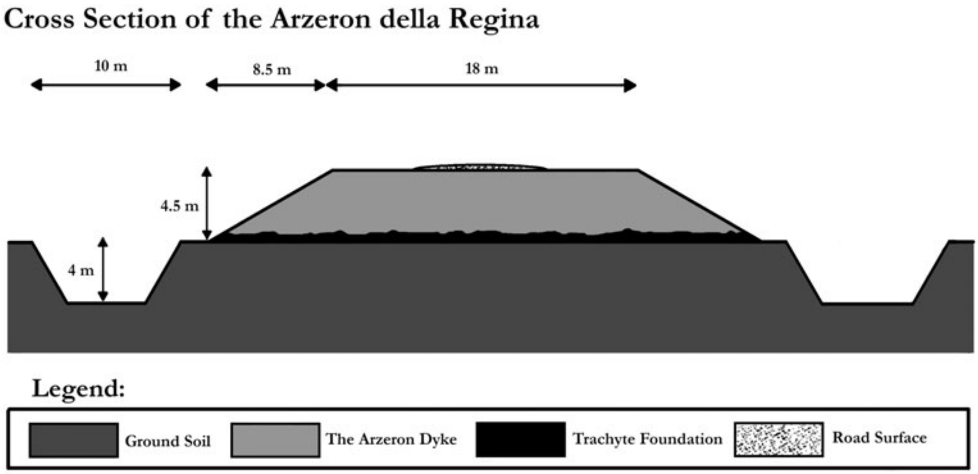

Fig. 5. Cross section of the Arzeron della Regina. Redrawn from Rosada and Bonetto, 1995: fig. 4.

2009: 14). Most Roman-era dykes seem to have taken the form of a trapezoidal structure, with gently sloping sides and a flat top. The structures were routinely flanked on one or both sides with a drainage ditch, with Varro (*Rust.* 1.14.2–3) commenting that it was common to see 'this type of enclosure … built along public roads and along streams'.

While not at the same risk of erosion and destruction as embankments due to being located further away from the high-energy river channel, dykes dating to the Roman era have rarely survived. Being large structures, they were often demolished during landscape reorganization or were dismantled for their materials. However, several structures of Roman date from the Veneto have survived, mainly by being co-opted into later dykes. Perhaps the best preserved of these is known as the Arzeron della Regina, located to the northwest of Padua running parallel to the banks of the river Brenta. Excavation of its surviving sections revealed that the Arzeron sat upon a foundation of Euganean trachyte interspersed with brick fragments, with the core of the structure being formed of compacted layers of clay and silt (Fig. 5).[41] The width of the trapezoidal structure varied between 30 and 36 m at its base, narrowing to 18 m at the top, which was crowned with a gravel road at a height of 4–4.5 m (Bonetto, 1997: 34–44). Given the Arzeron's position running north–south parallel to the riverbank, it was probably intended as a flood defence, protecting the land to the west of the dyke from inundation.[42] Another dyke in the same area, the Terraglione di Vigodarzere, exhibits similar properties. The

[41] Rosada and Bonetto, 1995: 29 n. 96. They estimate that the total amount of Euganean trachyte used in the construction of the Arzeron della Regina equated to some 700,000 m^3.

[42] The Arzeron seems to have acquired a secondary use as a transhumance route between the Alps and the Venetian plain. The wide, raised pathway provided a reliable route across the Brenta floodplain (Rosada and Bonetto, 1995: 32–3).

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structure, located to the north of Padua, runs east–west for approximately 3.3 km from the eastern bank of the river Brenta to the Muson dei Sassi stream (Bonetto and Busana, 1998: 89). In a similar manner to the Arzeron della Regina, its foundations were formed of unshaped blocks of Euganean trachyte. The dyke also ran perfectly along the southern perimeter of the centuriation grid to the north of Padua, which did not extend beyond the structure. Although the un-centuriated land located beyond the dyke would have remained vulnerable to flooding, this would have been beneficial to the success of the structure. Allowing part of the floodplain to be inundated would have helped to reduce stress on the dyke and enabled a larger volume of water to accumulate before a risk of overspill developed (Rickard, 2009: 14). It is unknown, however, whether this was a deliberate choice on the part of the designers or an unintended additional benefit. Defensive works are expensive to construct and the lack of defences for the un-centuriated land may simply be a case of the designers choosing to concentrate their time, efforts and resources on defending property, rather than a conscious effort to maximize the effectiveness of the structure.

Where floodwaters could not be contained or ground sufficiently drained to create stable and reliable roads, the principal use for dykes seems to have been to elevate road surfaces, providing a stable foundation in marshy ground and keeping the roadway above the level of inundation.[43] This is seen on the Via Annia, where the road ran atop an embankment for long stretches between Altinum and Aquileia. The dyke was not a uniform structure and varied in form along its course. Where the Via Annia left the gates of Altinum the road was placed on a dyke composed of compacted sand, reinforced on the surface by a layer of pebbles and flanked on either side by ditches (Tirelli and Cafiero, 2004).[44] Further east at Ca' Tron, the dyke seems to have lost its surface covering and lowered in height to just over 1.5 m, although the two flanking ditches were retained (Basso *et al.*, 2004: 57–9; Mateazzi, 2009: 28; Papisca, 2010). The dyke's position, running parallel to the coast, also makes it possible that it doubled as a defence against coastal flooding during the tidal or storm surges that afflict the lagoon.[45]

[43] This is seen across Roman Italy. The Via Postumia has already been mentioned (n. 39), but evidence for raised road surfaces also comes from the remains of the Via Popilia where it runs near Adria, and the Via Claudia Augusta where it ran between Ostiglia and Verona (Calzolari, 1992: 162–5). Further south, the Via Appia was raised atop a dyke as it ran through the Pontine Plain (Quilici, 1990). For more information on dykes in central Italy, see Quilici and Quilici Gigli, 2020.

[44] Perhaps the largest known dyke is located to the north of Altinum, Via del Lagozzo. The structure had a height of 7 m, and was 32 m wide at its base, narrowing to 6–10 m on top. Similar to the previously discussed structures, its core was composed of compacted silt and clay placed upon a foundation of crushed stone and large pebbles (Cerchiaro, 2004: 244; Rosada, 2004: 56).

[45] A dyke or embankment structure may have been constructed as a sea defence in south Wales by the II *Augusta* legion (Mason, 1988: 181).

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CHANNEL INTERVENTIONS

Defensive works were significant human additions to the riparian environment, yet other engineering projects might not seek to add directly to the fluvial landscape, instead looking to alter or enhance existing conditions. These channel interventions represent more technical forays into fluvial management, with changes and alterations being made to active watercourses. As such, they often required repeated maintenance to sustain their benefits. The channel interventions discussed below are separated into the categories of rectification and diversion, and dredging.

CHANNEL RECTIFICATION AND DIVERSION

Channel rectification involves the realigning and straightening of the watercourse. A linear, as opposed to a meandering, channel enables water to move through it at greater velocity, allowing a larger volume to pass through the affected stretch before channel capacity is exceeded (Brookes, 1985: 60). This could contribute to reducing flood risk along the rectified stretches. Channel rectification continues to be used as a measure of flood control today, although its effectiveness is debatable, with high-magnitude precipitation events still likely to result in flooding (Nunnally and Keller, 1979: 6–13). Furthermore, allowing water to move through at greater velocity can simply result in the risk being transferred to areas further downstream, rather than nullifying it completely. To return to the embankments on the palaeochannel of the Adige near Este, while the structure formed a prominent intervention into the river's hydrology, they formed only part of a wider series of alterations to its watercourse. Excavations along the embankment system undertaken during the 2010s, attempting to map the full extent of the palaeochannel, revealed that significant efforts had been made to straighten and channelize its course through Este during the Roman period (Balista and Ruta Serafina, 2008; Balista, Bianchin Citton and Tagliaferro, 2010: 138). It was discovered that the stretch of the Adige that ran through the city (channelized on either side by embankments) had been straightened and narrowed considerably, reducing the width of the channel from approximately 250 m to 100 m (Balista *et al.*, 2005: 189; Balista, Bianchin Citton and Tagliaferro, 2010: 146). Aside from reducing flood risk, rectification might also be undertaken to aid the passage of vessels travelling upon rivers, a linear channel being easier to navigate than a meandering one. This is seen once again on the Garigliano, where the embankments mentioned above were constructed in conjunction with the straightening of the channel.

In extreme cases, moving the channel entirely might be suggested as a solution to either navigation or flood management, although this seems to have been something of a rarity.[46] During the reign of Tiberius, the diversion of the Clanis

[46] For example, Paus. 8.29.3 records that on the Orontes in Syria, the river's meandering course was difficult to navigate and so an unknown emperor (of Antonine date or earlier) 'with much

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into the Arno was discussed as a solution to reduce flooding of the Tiber (Tac., *Ann.* 1.79). The horrified reaction of the Florentines to this proposal, and its subsequent dismissal from the Senate suggest that the Romans had at least an abstract awareness of the dangers and unpredictable consequences of channel diversion.[47] A similar hesitancy to engage in such extensive intervention is seen between Pliny and Trajan over the connection of Lake Sophon near Nicomedia with the sea via a canal (Plin., *Ep.* 10.41–2). Even when channel diversion was undertaken, there were no guarantees it would work. At Reggio Emilia in the Po–Venetian plain, coring has revealed that attempts were made to redirect the torrential river Crostolo east of the town during the Roman period (Cremaschi, Storchi and Perego, 2017: 60–3).[48] However, the river's original western channel remained active and the newly created eastern channel was active for only a short time, with the attempt ending in failure.

DREDGING

Channel rectification and diversion resulted in massive alteration to the structure of the fluvial environment to achieve their goals. In contrast, dredging formed a less monumental intervention, adapting the existing channel rather than moving it. From the standpoint of flood defence, dredging removes riverbed sediment to increase channel capacity. While this might be effective during minor levels of high water flow, dredging is unlikely to increase channel capacity enough to cope with larger, high-volume incidents.[49]

Although dredging is well documented across the Roman world, most examples are related to improving the navigability of a channel rather than reducing flood risk.[50] In the Po–Venetian plain, there is possible evidence for

labour and expense … dug a channel suitable for ships to sail up, and turned the course of the river into this'. In the Po–Venetian plain, the *fossae Augusta*, *Claudia* and *Flavia*, para-littoral canals constructed in the first century AD running between Ravenna and Altinum, made extensive use of channel diversion (Plin., *HN* 3.119; Uggeri, 1987: 343; 1997: 60). The *fossae* connected multiple branches of the Po, at times by diverting them into each other, and bypassed the need to navigate long distances upstream to their point of divergence. It is likely the canals also utilized the extensive ancient lagoon system (Uggeri, 1978). There would be further attempts to divert the Po's channel in the post-Roman period, most notably by the Ferrarese (unsuccessfully) in 1152 after a catastrophic flood breach at Ficarolo diverted the river's channel away from the city, and then by the Venetian Republic in 1604 to prevent sedimentation in the lagoon. The modern Po continues to follow the course set by the Venetians (Nelson, 1970: 165).

47 A desire to avoid offending the majesty of the Tiber by reducing its flow seems to have been an important factor in the decision: Aldrete, 2007; Campbell, 2012; Keenan-Jones, 2013: 246–53.

48 The main channel of the Crostolo originally flowed to the west of Reggio Emilia and formed the western boundary of the settlement.

49 Lane *et al.*, 2007: 437–8, found that low-frequency flood events that occurred in river channels undergoing aggradation were often of a greater magnitude than those in non-aggraded channels. This was due to reduced channel capacity.

50 Dredging is well documented in ancient maritime harbour contexts, for example those at Portus, Ephesus and Miletus, although less so in fluvial environments. See Morhange and

dredging in response to hydrological risk on the Adige where it ran through Este. Excavation of the embankments that flanked the river's passage through the town disclosed that thick layers of alluvial sand were used to prepare their foundations. These matched those present in the palaeochannel of the river, suggesting that the sediments had been taken directly from the nearby riverbed (Balista, Bianchin Citton and Tagliaferro, 2010: 139, 148). This was interpreted as the dredging of the newly rectified channel in an effort to deepen and increase its volume as it ran by the city. Taken in conjunction with the rectification of the Adige's channel, dredging may have been carried out to reduce flood risk by increasing channel capacity and current velocity, improve the navigability of the river, or a combination of the two (Pepper and Rickard, 2009: 10). Alternatively, the river may simply have been seen as a convenient source of sediment for the embankment works, without any further water management goals.

RESPONDING TO RISK

In response to the risks posed by hydrological processes to those living in riparian environments, it is unsurprising that there were extensive Roman efforts to manage water. The above sections have highlighted some of the considerable infrastructure or interventions used across the Po–Venetian plain to counteract or prevent these processes. The scale of dykes and embankments reflects the time and labour that the Romans invested in hydrological defences, while attempts to rectify, divert and dredge river channels reflect more technical efforts to intervene in fluvial systems.

While these responses are individually impressive, their success in carrying out their intended purpose is harder to measure. Sporadic human intervention into fluvial networks could, and often did, have unintended consequences that exacerbated existing problems and created new ones.[51] For example, while the embankments at Este protected the southern bank of the Adige from erosion,

Marriner, 2010, for several maritime case studies. Ancient dredging can be difficult to identify in rivers, which are constantly evolving landscape features. Erosional processes often obliterate evidence, and palaeochannels can be difficult to locate and excavate. Some of the best archaeological evidence for fluvial contexts comes from northern Europe. Evidence for dredging is apparent at the site of Voorberg in the Netherlands, where it was carried out to maintain the town's accesses to the Rhine and Maas deltas, connected to the town by the *Fossa Corbulonis*. In a similar vein, at Xanten, dredging kept its harbour channel open until the late second century AD before it silted up and fell into disuse (Leih, 1994: 60–1). Geoarchaeological prospection at Ostia's fluvial harbour basin has uncovered evidence for dredging. These efforts were only partially successful, and the basin silted up towards the end of the first century BC and into the beginning of the first century AD (Goiran *et al.*, 2014: 397; 2017: 79).

[51] For example, Alline (2007: 72–4) highlights several Roman interventions undertaken in the urban centres of the lower Rhône valley that actually served to increase the risk, and exacerbate the consequences, of high water levels. Edgeworth (2011: 41) succinctly highlights the risks of intervention, observing that 'to intervene in river processes is to get entangled with the river, because it invariably responds to the intervention in multiple ways that are not entirely predictable, requiring further interventions', potentially creating a never-ending cycle.

this same protection prevented sediment extraction. This created a sediment imbalance resulting in the movement of the thalweg (the deepest part of the channel) away from the embankment, the creation of chute channels (leading to braiding) and the initiation of erosion on the northern, unprotected bank of the river (Balista, Bianchin Citton and Tagliaferro, 2010: 143–5). As a consequence, the formerly meandering path of the Adige became more linear in several areas. It is hard to say whether this was a deliberate result of the embankment project or an unintended outcome. Regardless, it would have had a potentially damaging effect on other landowners' property on the northern bank. In a similar vein, the dykes of the Arzeron della Regina and the Terraglione di Vigodarzere protected the areas behind them from inundation, but with the area of the floodplain reduced, the excess water would have been redirected elsewhere, potentially flooding land that otherwise might not have been at risk. The same can be said for embankments. While they may have protected the land behind them, research has shown that embankments can exacerbate flooding in downstream areas, increasing the height and speed of the flood wave (Sholtes and Doyle, 2011: 203–7; Lechowska, 2017: 656). The use of dykes to protect large areas of farmland could also have unforeseen agricultural consequences. Although the exclusion of floodwaters protected crops in the short term, dykes also excluded fertile alluvial sediment from being deposited, reducing the viability of the land in the long term. Furthermore, dykes could also inhibit drainage in the aftermath of a flood if they were breached, prolonging the event and causing additional damage.[52]

The rectification and dredging of channels may also have had unintended side effects. With the creation of a linear channel, hydraulic energy that previously would have been expended against the banks of the river may instead be redirected towards the bed, resulting in channel incision (Brookes, 1997: 293–4; Sholtes and Doyle, 2011: 203–7; Lechowska, 2017: 656).[53] The long-term success of dredging projects is also debatable, given the organization and intensity of labour needed to sustain their benefits. The dredging of the Adige at Este seems to have been a one-off occurrence, with the extracted sediment being used in the construction of the embankments. Dredging undertaken elsewhere in response to sedimentation and flooding, such as on the Tiber, would have needed to be repeated to maintain increased channel capacity.[54]

[52] This seems to have happened at Orange, France, during a flood of the first century AD (Allinne, 2007: 76).

[53] There is evidence for this in France on the river Aude at Narbonne, where the funnelling effect of the embankments channelling the river resulted in the force of its current scouring the riverbed (Sanchez *et al.*, 2014: 132).

[54] Several ancient writers refer to interventions into the Tiber's channel. Suet., *Aug.* 30, reports that 'to control the floods he [Augustus] widened and cleared out the channel of the Tiber, which had for some time been filled with rubbish and narrowed by jutting buildings'. Although the widening of the channel would certainly have increased its capacity, it is uncertain whether the depth of the channel was increased beyond simply removing the obstructions. Aurelian (SHA, *Aurel.* 47.2–3) also seems to have dredged sections of the Tiber, professing to have 'dug out the

Furthermore, any artificial incision into the riverbed has the potential to alter channel morphology in unforeseen ways. While the exact response varies from system to system, dredging can run the risk of destabilising the bank and, in extreme cases, can lead to channel widening and incision (Marchetti, 2002; Chalov, 2021: 182–4). This is due to the energy, once used in the transportation of sediment, being redirected against the riverbank and bed.

The potential consequences of ad hoc water management strategies are readily apparent in the modern period, although they may have been less obvious to the Romans. Regardless, they did not act as a deterrent to riparian communities, which still elected to build defences and intervene along the watercourse. Uniformly, the water management efforts examined above were instigated at a community, rather than at a regional, level, and, with the exception of the Tiber valley, there is little evidence for regional organization in responding to hydrological risk.[55] The impact that piecemeal local schemes may have had on areas downstream is difficult to measure, but does not seem to have been a concern for those responding to hazards. Local defences were evidently considered worth the necessary time, materials, labour and expense, attested by the large number of examples found in the Po–Venetian plain and across the wider Roman world.

Of course, despite the protection offered by defences and interventions, there was always the chance of an extreme hydrological event occurring, the magnitude of which exceeded the capabilities of water management infrastructure. During the first and second centuries AD, it seems that only in extreme scenarios did hydrological hazards result in the abandonment of riparian settlement in the Po–Venetian plain. In various cases, affected sites demonstrated resilience (the ability to survive and overcome the effects of flooding), and continuity of occupation is visible in the archaeological record.[56] Even when defences and intervention failed, the benefits of being close to the watercourse outweighed the hydrological risks. However, fluvial regimes and river morphology did not remain static. The first section of this article cited several examples of hydrological events that resulted in serious and unavoidable

shallow places in its rising bed'. However, this seems to have been done as part of efforts to maintain the river's navigability to Rome, rather than reducing hydrological risk. Sedimentation seems to have affected the river from an early period, with geoarchaeological prospection at Ostia's fluvial harbour basin uncovering evidence for dredging from the second century BC onwards (Goiran *et al.*, 2014: 397; 2017: 79).

55 At Rome, the office of the *curatores riparum et alvei Tiberis* was created by Tiberius to maintain the bed and banks of the Tiber, monitoring the river so that it 'should neither overflow in winter nor fail in summer, but should maintain as even a flow as possible all the time' (Dio Cass. 57.14). See Campbell (2012: 317–20) for a discussion on the role of the *curatores* and water management in the Tiber valley.

56 For example, at the sites of San Giorgio Canavese and Strevi in Piedmont, there is evidence for multiple phases of flooding from the first century AD onwards, the aftermath of which saw the rebuilding of the settlements at a new occupation level each time (Ratto and Crivello, 2014: 21–5; Quercia, Semeraro and Barello, 2015: 144).

consequences for those living in riparian environments, principally from the third century AD onwards. However, there is a disparity between the period of maximum hydrological risk and maximum investment in hydrological defences. Most of the interventions discussed above were constructed during the first century AD, with few examples of surviving evidence for large-scale interventions in the later Roman period.[57] Even where evidence does exist, there is nothing to rival the scale and ambition of structures and interventions such as Este's rural embankments, the Arzeron della Regina or the diversion of channels of the Po, while in the sixth century AD Cassiodorus' letters requesting the clean-up of, and removal of obstructions from, several Italian rivers (the Mincio, Oglio, Serchio, Arno and Tiber) suggests that river maintenance had been neglected.[58]

Riparian infrastructure requires strong financial investment and logistical support for it to be constructed, alongside ongoing maintenance for it to continue operating in its intended fashion. Growing social, political and economic instability during the later Roman period, coupled with geomorphological and hydrological changes to river regimes, may have made the upkeep of complex riparian infrastructure unfeasible. Changing climate may also have accelerated geomorphological changes to fluvial environments, making it difficult to mount an effective response. The increasing vulnerability and decreasing resilience of riparian communities in late antiquity suggests that there was no longer the coordination or inclination to combat fluvial hazards in the same way as in previous centuries. In the area between Reggio Emilia, Piacenza and the Po, field survey suggests a mass restructuring of the landscape in the post-Roman period, with rural settlement retreating to higher ground above inundation level (Brandolini and Cremaschi, 2018: 3; Brandolini and Carrer, 2021: 512, 521). The settlement pattern in the late antique and early medieval period shows high correlation with areas of low hydrological risk compared to the Roman era, suggesting this had become an important factor in site placement. While settlers did not abandon riparian areas completely, those who remained living along the watercourses of the Po–Venetian plain were forced to accept a greater degree of risk.

CONCLUSION

This article has highlighted some of the ways in which the Romans responded to the challenges posed by hydrological risk in the riparian environments of the Po–Venetian plain. Flooding, channel movement and sedimentation all invited

[57] There is investment in new port infrastructure (presumed to be attached to a canal given the city's distance from the river Oglio) at Brescia during the fifth century, and the port canal at Tortona was re-excavated in the mid-third century AD, prolonging its use until the end of the sixth century AD (Cera, 1995: 192–4; Crosetto, 2013a: 108–10).

[58] Cassiod., *Epistulae* 5.17, 5.18. Although this intervention shows a return of state interest in the upkeep of rivers, Cassiodorus' request was to aid the navigation of vessels, rather than combat fluvial risk to riparian communities.

interventions along the region's watercourses, with different hazards requiring different approaches. Embankments, dykes and diversion point to the importance of hydraulic engineering in protecting urban areas and territorial integrity in structured landscapes and transitional zones, while dredging and rectification show the importance of maintaining channel capacity for flow and navigation. Yet, while it is obvious that the Romans recognized the risks present in the fluvial environment and sought to alter and control hydrological processes, the success of their endeavours is difficult to quantify. Due to the nature of excavation and preservation, it is hard to map what the consequences of the piecemeal approaches to river management would have been on the ground, although this article has attempted to highlight what some of these might have been. Ultimately, whatever the downstream consequences of intervention were, riparian communities were not deterred in their attempts to shield themselves from risk.

The social and economic importance of riparian environments for those who lived in their vicinity makes it unsurprising that communities sought to manage them. The Romans were not passive agents in the landscape; the remains of aqueducts, bridges and irrigation schemes demonstrate their attempts to manage and exploit water. Roman hydrological defences and interventions in the Po–Venetian plain have been a missing part of this picture despite having formed a vital component of the region's landscape. The interventions discussed here, their attempts to alter the characteristics of fluvial systems or prevent undesirable consequences of hydrological risk, reflect the concerns and needs of those who lived in their vicinity. In an empire that included the Rhine, the Danube, the Po and the Euphrates, the risks faced by the many who lived along Rome's rivers were significant.

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