Liquid footprints : water, urbanism, and sustainability in Roman Ostia

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"Indeed, we have become so accustomed to the presence of water in our daily life that it has been a long time since we have questioned its existence… Invisibility is indeed the height of conquest."[120]

Chapter 2: Theory and Methodology

2.0: Introduction

This chapter introduces the theoretical framework of this study, engaging with leading developments in archaeological theory to demonstrate new ways of thinking of, and with water. Such an approach offers new horizons for contextualizing our past and present relationship with water beyond increasingly more detailed technical or architectural studies. While it is tempting to place this study in opposition to the traditional technically focused approach, creating a dichotomy between the social and the technological would only reinforce this isolated view. Focusing only on the perception of water in the Roman world, or the social aspects of hydraulic systems would swing the pendulum too far in the other direction. The aim of this study is to identify fragments of the physical hydraulic infrastructure of Ostia, how this system changed over time, and most importantly, why this change even occurred at all.

After introducing several ancient and modern perspectives on water, relevant aspects of modern urban infrastructure studies are then presented. Expanding in scale, a brief introduction to the field of sustainable resource management is then presented, in order to investigate how urban water usage is studied today. Combining these different streams of inquiry, we present the methodology for this thesis, the Roman Water Footprint. This framework was created by the present study in order to develop a holistic and diachronic view of water usage in a Roman urban context. In this way, we can apply the diversity of approaches used in studying modern aspects of water to the investigation of Roman water usage.

2.1: Water and Culture

Studies regarding the diverse perceptions of water for past and present societies are numerous.[121] A brief overview is given here to contextualize this study´s methodology, as well as to demonstrate future directions for exploring water in the Roman world. Previous hydraulic research in archaeology has tended to view water as a neutral or easily defined substance, and not as a culturally reflective object. However, by engaging with current debates in materiality and phenomenology, this study also includes some of the ontological aspects of water. In this way, it explores how the conception of what exactly water is (or is not) has changed dramatically over time, reflecting the culturally circumscribed and often paradoxical nature of water.[122] The perception of water has experienced many theoretical iterations. Pre-Socratic philosophers like Empedocles and Anaxagoras advanced different materials to support an elemental monism of the universe. Rejecting mythological causes for change in the natural world, Thales of Miletus proposed water as the singular underlying element of the universe, although other candidates vied for supremacy.[123] The interpretation that elements are animate in some sense

[120] Goubert, J.-P. 1986, 24.

[121] Mithen 2012 compares water and power in different ancient societies, developing the view advocated by Wittfogel in his seminal 1957 work, *Oriental Despotism*.

[122] Aldrete 2007; Chang 2012; Hodder 2012; Kamash 2008.

[123] These Pre-Socratic views are recorded by Aristotle (*Metaph.* 983b6, 8-11, 17-21) and Vitruvius (*De arch*. VIII, 1). The latter details the preferences of each of the Seven Sages (e.g. Heraclitus suggested fire), and Empedocles suggested there were four prime elements (air, fire, earth, water).

(hylozoism), continued into later Platonic and Stoic thought.[124] Early Christian writers equally used the multiplicity of waters as metaphors for divine power.[125] Literary references from all periods of antiquity regarding different waters span the genres of law, medicine, philosophy, history, and religion.[126] However, central to the ancient perception of water was its locality and heterogeneity, with impressive catalogues and debates over which qualities and individual water sources were considered "best" for different uses.[127]

The perception of what exactly water "is" began to change with the theories and experiments of the Scientific Revolution in the 17th century. With the development of modern chemistry, water underwent an epistemological revolution by its new name: H_2O. Especially into the 19th century, water was increasingly seen as a homogeneous and universal force to be calculated and utilized in the Industrial Revolution. The personalities and local qualities of waters were no longer viewed as "scientific" enough, beyond how they measured up against "pure" H_2O. Bodies of water that were seen previously as beneficial, or moody, or cursed, were now calculated in terms of volumes, discharges, or economic potential. Water, and more broadly, Nature, were abstracted, and devoid of any human settlements or actions. This development has been called "modern water", and continued to change into the 20th century, when it became more connected with the activities and authority of the state.[128] This occurred together with the invention of the water cycle model in the early 20th century, and the contemporary creation of Hydrology as a discipline apart from Earth Sciences (Fig. 2.1).[129] The creation of "modern water" by 20th century scientists was framed as the end of a linear development of water development, judging antique and Renaissance views against how close or far away they lay from the "obvious" water cycle.

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[124] Although the idea that all things imbued with life is one of the main teachings of Stoic thought, the term "hylozoism" was only coined in the 17th century by Ralph Cudworth.

[125] August. *Conf.* XIII, 20; Linton 2010, 119-125 outlines the resurgence of this idea in the 17th-19th centuries, where natural theologians in Europe proposed that only God could have the power to create all the natural water systems in the world and to keep them in constant balance.

[126] Plin. *HN.* XXXI; Frontin. *Aq*. XCII; Hp. *Aer*. 7-9; PGM I, 76-79 for lecanomancy (divination by water in a bowl); Suet. *Aug*. 82; *Cod. Iust.* VIII, 3, 17; Juv. *Sat*. V, 51. This subject has yet to be treated as a whole, given the wide array of Latin and Greek literary genres it covers.

[127] Frontin. *Aq.* XCII for different uses of water from the aqueducts of Rome.

[128] Linton 2010, 47; Linton & Budds 2014 expands on the relational-dialectical approach to water and society.

[129] Linton 2010, 148-161 for a thorough discussion of the development and success of the water cycle model. The absence of people, social systems, or even technology idealizes water processes, and removes human action and responsibility from water. A drought can then be blamed on "nature", instead of improper infrastructure management or economically unequal access to water.

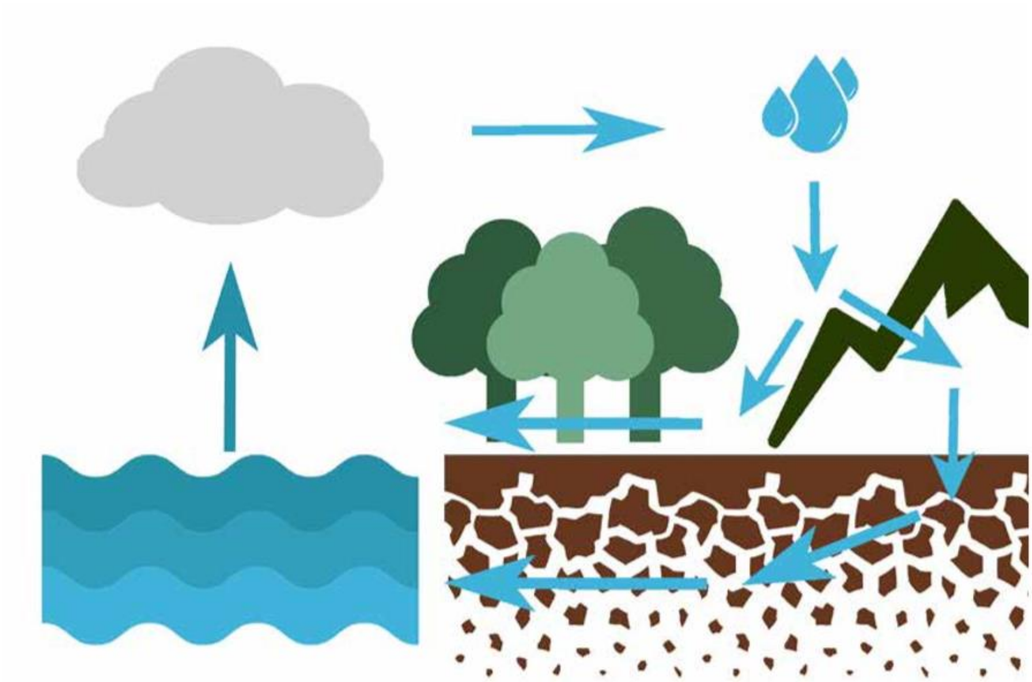

Figure 2.14: The water cycle, as originally outlined by Horton. The absence of people or cities, or different (non-European) geographies makes this model difficult to apply to diverse cultures and regions.

In its current iteration, water continues to be abstracted from its place of origin, towards a market-environmentalist model, with serious implications for social equality and environmental sustainability.[130] However, a new approach, the hydrosocial cycle, has become increasingly investigated and critiqued in the past ten years.[131] This approach moves beyond seeing hydrology (or hydraulic infrastructure) and social sciences as two discrete fields that should be simply combined.[132] Instead, it investigates the process through which water and society (re)make each other over space and time. In this way, "water" represents the constantly negotiated intersection of social structures, technology, and the physical properties of water.[133] After re-examining how the definition of water has changed so frequently and drastically even in the past few centuries, the potential limits of taking a 21st century Western approach to studying water in the Roman world become increasingly more clear.[134]

More recently, Latour's interpretation of the agency of inanimate objects has generated a growing number of debates under the banner of materiality studies.[135] In terms of natural resources, this swinging of the pendulum towards a materiality that eschews the symbolic and representative must be

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[130] Alberti 2014, 161; Bakker 2010 for the market-environmentalist model.

[131] Swyngedouw's (2004) idea of hybridized water is key here; for an earlier form of this global view, see Bachelard 1942 for the influence of water on 19th century literature and on the 20th century psyche: *infra* pp.295, *"A mythology of waters, in its entirety, would be only history."*

[132] This dualist view is also termed socio-hydrology, and comes more from an earth sciences approach. It seeks to integrate (or translate) cultural values, norms, and perceptions into quantitative values; see Pande & Sivapalan 2017 for an overview of socio-hydrology and its methods.

[133] Linton 2010, 69 outlines this model.

[134] Chang 2004 explores the same topic for the modern systems for measuring temperature; Chang 2014 convincingly argues against *only* seeing water as H_2O.

[135] Hodder 2012; Latour 1993, 6; Versluys 2014; this approach views objects as active agents entangled in a variety of relationships to other objects, people, and systems, rather than as passive vehicles for other symbols or statements.

wary of replacing one material monism with another.[136] It may be more practical (and realistic) to adopt a position of complementary discourse. This multiplicity or democracy of views has been advocated by, among others, Wittgenstein's idea of complementary discourse, which sought a dialogue between science, biology, and politics, in order to understand different yet interrelated aspects of human culture.[137] The collaborative aspects of complementary discourse have developed further into the theoretical approach of critical realism, which also advocates for using multiple simultaneous systems of practice to highlight different aspects of the archaeological record.[138] This does not imply a relativistic approach, but rather a scientific opportunism that continually (re)considers new and untested conceptions, regardless of how unusual they may first appear.[139] This approach seeks to undermine traditional theoretical dichotomies, like man-nature, subject-object, past-present. By expanding the definition of what water is, or could be, water continues to be used as a lens with which to explore increasingly diverse fields of research.[140] The academic playing field between human and non-human agents has started to become more balanced, provoking new questions on the agency of water, and the ethical ramifications of our relationship to it.[141] For the Roman world, this involves interpreting urban evidence of water systems on Roman terms: a river is not just an economic route for moving goods, but is also an object of cultic worship, an ally in military successes, and with defined realms of legal practice.[142]

While not focusing directly on water, there has been a longer tradition in archaeological research of giving (or recognizing) the agency of the landscape in human cultural actions. The assertions of phenomenology stress the impossibility of objectivity in the experience of any landscape.[143] Following this, there is an increasing awareness of the limits of valuing man-made modifications to the landscape over natural ones. The move away from descriptive or social constructionist views of a place has much to gain from the integration of changing sensory, meteorological, or temporal conditions. Culturally specific viewpoints of nature differ in time and space, yet despite these differences, the consistency of the physical characteristics of water allow for a measure of intercultural comparison.[144] All cultures create avenues of social interaction with water based on its different uses.[145] When human cultures interact with naturally existing water systems, there are often modifications or wholesale changes made

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[136] Heidegger 1977 [1954], 9, sardonically uses the transformation of the Rhine river into an energy source to show how modern science *"entraps nature as a calculable coherence of forces"* to prove to ourselves that *"our system of ordering nature is the best."*

[137] Bintliff 2000, 163.

[138] Wallace 2011 sketches the binary structures of Western philosophy (e.g. logical-illogical, true-false), and how to use critical realism to question these dichotomous positions when investigating archaeological material.

[139] Lehoux 2012 uses a similar method to interrogate Roman world views, which seem paradoxical to us, such as the incredible technical skills in engineering, but contemporary belief in one-legged civilizations.

[140] Scherer *et al*. 2015 connects changing isotopic values of oxygen ($\delta^{18}O$) in Mayan skeletal evidence with changing water acquisition patterns; Recent advances in researching water in planetary dynamics is equally robust and frequently makes its way into global news (e.g. Ojha *et al*. 2015).

[141] Ertsen 2016 places hydraulic infrastructure in dynamic dialogue with socio-cultural mores; Kamash 2008 with examples from dams in the Roman Near East; Neimanis 2017 develops a posthuman feminist interpretation of 21st century water usage: *infra* pp. 24 *"… changing how we think about bodies means changing how we think about water."*

[142] Campbell 2012 on legal definitions of when a river is public or private; Le Gall already in 1952 emphasized the mutually important economic and religious role of the Tiber river.

[143] Tilley 2008: The main methods of phenomenology in an archaeological context involve interpreting sensory experiences of landscapes, and how these (mostly visual and objective) experiences impact our understanding and perception of a landscape.

[144] Strang 2005, 2008, develops an anthropological approach to the water-culture intersection, highlighting similarities in water usage habits in a northern Australian aboriginal community (Kowanyama), and in a village in southern England (Stour Valley, Dorset).

[145] Neimanis 2017, 28 calls this the *"fluid turn"*; Rogers 2013 for *"waterscapes"*; Strang 2006 and Edgeworth 2011 for *"fluidscapes"*.

to the system. This in turn creates new system parameters for the human community and influences future levels of interaction between cultural and the natural elements.[146] This dynamic process is called human niche construction, and is situated within post-modern perspectives on the role of the daily actions of individuals.[147] Earlier scholarship on the role of water saw it from a top-down and often colonial perspective, regarding the implementation and running of a larger scale water system as the basic unit for control of an empire.[148] Human niche construction views water systems not as atemporal or monolithic objects, but rather as the constantly changing product of daily or seasonal choices by people interacting with the water system. While researching the monumental aspects of an aqueduct or irrigation network addresses its structural form, investigating systems of political management, maintenance, or changing daily habits gives a more dynamic and bottom-up view of water systems.

Water is thus a useful lens for investigating the dynamic dialogue between past human cultures and landscape, given its complete diffusion within all human physical and societal existence.[149] Although there are limits and serious criticisms of the phenomenological approach to landscape presented above, this study attempts to access some of these perceptions as they applied to resource usage by interrogating the role of water in Roman culture. A full account of the Roman interpretation of nature and landscape would be as varied as the geography over which the cultural blanket broadly termed "Roman" occurred. However, there are several clusters of ideas around which we can gain an insight into the Roman perception of the environment. In the Roman world, water played a central, although sometimes contradictory role in religion, imperial power, settlement planning, farming, and economics.[150] By investigating the Roman perception of water from a Roman perspective, we can start to fully appreciate the diversity, complexity, and flexibility of Roman urban water systems.

2.2: Sustainability and its Application to Roman Urbanism

The historical events that led to our current urban situation are complex and multi-faceted. The role of Roman urbanism and hydraulic technology within this story is equally complex, but a brief overview will demonstrate how we can begin to contextualize our stance on the hydraulic past. Early studies of Roman aqueducts and bath buildings were contemporary with the creation of the early sewer lines in European capitals.[151] Together with extant monumental water structures visible across Europe, this created a misrepresentation of Roman water systems as decadent, luxurious, and strictly monumental. This monumental approach also accounts for the traditional academic focus on aspects of supply.[152] Given the nascent state of urban infrastructure in the 17th century, this uptake is not surprising. However, in our 21st century globalized world, where water, waste, and infrastructure are all increasingly contentious issues, the basic assumptions of our urban infrastructure are being questioned. When we combine this contemporary perspective with the evidence of past diversity of water systems, it then appears that the "modern" city has in most cases tried to replicate *just* the monumental aspects of ancient cities. This could be part of the reason for current issues of water misuse, such as the lack of awareness for the actual value of water, as well as the chronic overconsumption that characterizes

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[146] Edgeworth 2011 for the anthropocene modification of almost all global rivers.

[147] Ertsen 2010 for examples of this process in irrigation systems; Laurence & Trifilò 2015, 100 extend this to individual urban actors at the local and global scale in the Roman world; Wilkinson *et al.* 2012 review 9000 years of water management systems in Iran.

[148] Purcell 1996, 200 for Roman mastery over nature as setting poor examples for modern colonial landscape modifications; Wittfogel 1957.

[149] Eliade 1958, 188: *"Water symbolizes the whole of potentiality; it is the fons et origo, the source of all possible existence."*

[150] Bruun 2015 gives an overview of the legal issues of water in Roman agriculture; Hughes 2014 for an overview of environmental issues in the Greek and Roman world.

[151] Euzen & Haghe 2012 for Paris; Gierlinger *et al*. 2013 for Vienna.

[152] Ancient drainage and waste systems have only begun to be researched, especially by Hobsen 2009, Jansen (2002, 2011), and Koloski-Ostrow (2015).

Western water usage. The point here is not that we tried to emulate the Romans, but rather that when modern cities were built, the full complexity, flexibility, and diversity of Roman urban infrastructure was largely unknown. Recent research suggests that water supply, usage, and drainage systems in the future will have a strong tendency towards decentralized, hybrid systems that are more local.[153]

There is no doubt that the effects of resource shortages are a distribution curve well known to populations of all cultural and global timescales. The dramatic figures of growing water scarcity and resulting human illness and fatalities are often cited as examples for the high degree of waste existing in certain neighborhoods of our global city.[154] However, the majority of unsustainable resource usage comes not from a lack of sufficient technological means, but rather from culturally (and economically) bounded ideas of what "normal" resource use is (e.g. flushing a toilet with potable water).[155] A tide of reports from the UN and other international bodies continue to stress that sustainable water usage is a central challenge to growing global population and rapid urbanization.[156]

2.2.1: Systems Theory and Urban Metabolism

In order to schematize hydraulic systems, systems theory and network theories have long been in dialogue with complexity theory, which views human societies as open systems without equilibrium.[157] This evolved out of post-processual stances on subjective approaches to the past; it is more realistic to acknowledge the lacunae we have for the Roman world, and despite the presence of functioning systems, to assume a lack of order, cohesion, or uniformity. The feedback loop method of approaching archaeological material and past environments was inherently part of the post-processual rejection of overarching governing historical processes. It emphasized the malleable relationship between physical systems and cultural systems of organization or hierarchies.

When systems theory was applied to cities, they were seen to function like human bodies, being composed of numerous interlocking systems that require energy and produce waste.[158] This development of urban (socio-)metabolic studies works by analyzing the feedback mechanisms and affordances of resources and systems. Several recent studies have attempted to extend the study of resource usage from the modern period into the past by using iterative regressive models. These create increasingly older views of cities by georeferencing features of the modern landscape and projecting them into the past.[159] These highlight how and when crucial urban structures changed over time (e.g. streets, roads, ports). In the same vein as the cultural turn in sustainability studies, urban metabolism has included a socio-metabolic approach that can identify the manner in which human societies organize their growing exchanges of energy and materials with the environment. While the approach taken by urban metabolism studies has prodded earlier systems theories into a more complex and integrated direction, its modern focus studies the city in the present moment. In this case, man (or a body) may be the measure of all things, but borrowing a riddle from antiquity might help us to structure this principle in a way more conducive to archaeological material (Fig. 2.2). As part of the story of Oedipus, the sphinx asks Oedipus "What goes on four legs in the morning, two legs at midday, and three legs at night", with "man" as the answer. Oedipus' answer highlights how something singular can change

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[153] Poustie *et al.* 2015 empirically assess mixtures of centralized and decentralized systems of urban infrastructure in constructing *ex novo* water systems in Port Vila, Vanuatu.
[154] Galli & Mattoon 2013, 8 identified 1971 as the year when global consumption surpassed available sustainable biocapacity; Jones 2010, 5: 700 million people daily drink water contaminated with fecal matter.
[155] Benedickson 2007, 78-97 for the implications of the modern flushing toilet.
[156] 1992 UN Rio convention; *Climate Change 2014: Mitigation of Climate Change*; Water management is explicitly dealt with in UN 2015, Goal 6; UN 2016, secs. 72, 73, 119, 120, 122.
[157] Bentley 2003, 10 provides an introduction to applying complexity theory to archaeological material.
[158] Haberl *et al*. 2013, 32 examine the socioeconomic metabolism of Vienna, comparing its change from agrarian to industrial society (1830-200).
[159] Orengo & Fiz 2007 apply this regressive model to Tarragona in Spain.

some attributes over time while retaining others.[160] If we extend the analogy between a human and a city further, urban metabolism can give a good view of the current systems of the body-city, but has difficulty in tracking past structural changes. In other words, it cannot see changes or continuity between earlier versions of the body-city (i.e. infant, adult, elderly). However, the present study expands the approach of urban metabolism into a diachronic perspective, not privileging any one period of the city's life. If Ostia is conceptualized as a body with water flowing through its veins, then one of the aims of this study is to identify parts of the city's circulatory system, and to investigate how this system changed over time.[161]

2.2.2: Sustainability and Water Accounting Methods

Having introduced the approaches of archaeological theory and urban planning that are used in this study, we introduce its third and most important theoretical pillar, leading approaches to water and urbanism in the contemporary urbanizing world. The perspectives of sustainability and sustainable resource accounting offer a bridge for connecting hydraulic infrastructure with a social approach to water. The broad developments of sustainable resource management are here introduced in order to provide a background for this project's methodology, which was directly inspired by 21st century approaches to urban water management. The idea of resource sustainability and a global perspective of resource usage crept into mainstream and scientific ideology from the 1980's onwards.[162] In the mid-1990s, the idea of attempting to quantitatively identify global resource demand in terms of the available biocapacity resulted in the creation of the Ecological Footprint model.[163] This model attempts to calculate the "biologically productive land and sea area -the ecological assets- that a population requires to produce the renewable resources and ecological services it uses".[164] The Ecological Footprint method attracted critics questioning the reliability of the figures produced, since such calculations require huge amounts of data, numerous assumptions, and a variety of variables. Nevertheless, while resource accounting continues to refine its methodology and data sets to explore the human-nature dialogue, the main point here was to create a relative order of magnitude figure for personal, national, and global resource usage. These figures can then be compared against each other to identify previously hidden habits and trends in ecological resource usage.

[160] The riddle itself is never mentioned directly in Sophocles' drama, but is only alluded to.

[161] This analogy is borrowed from Aristotle's *de partibus animalium* III, 5, 668a: "The system of blood-vessels in the body may be compared to those water-courses which are constructed in gardens: they start from one source, or spring, and branch off into numerous channels, and then into still more, and so on progressively, so as to carry a supply to every part of the garden." Similar body-city comparisons of water and waste are made in Cic., *Nat. D.* II, 254, 141 and Ov., *Met.* IV, 121-4.

[162] Chambers *et al*. 2000 for an overview of Ecological Footprints and Sustainability.

[163] Rees & Wackernagel 1992, 1996.

[164] Galli & Mattoon 2013, 3.

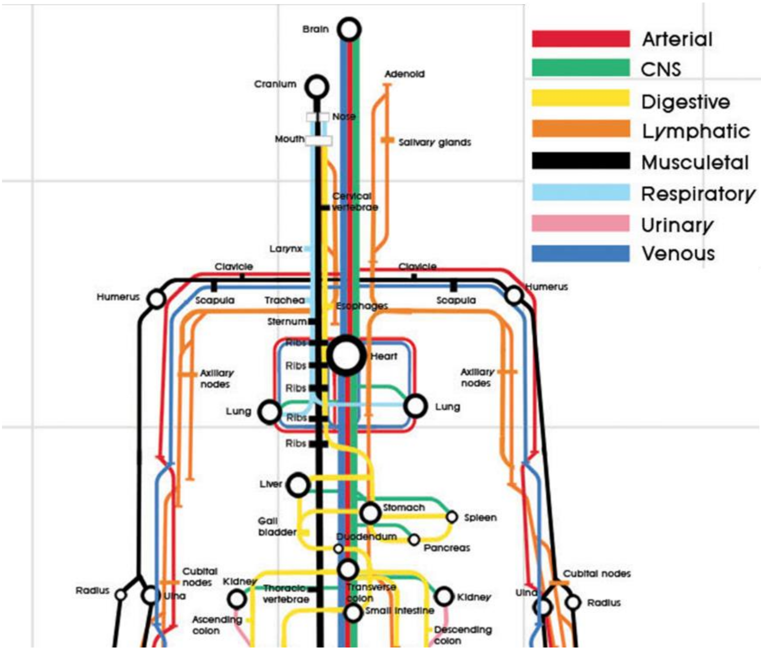

Figure 2.15: The biological systems of the human body conceptualized as a subway map (Sam Loman, *Underskin*, http://www.just-sam.com/just-sam/illustration.html).

2.2.2.1: The Water Footprint

Following similar research questions, the Water Footprint model was created in the early 2000s, and attempted to calculate the total volume of freshwater used to produce goods consumed by a group (e.g. family, city, country, etc.).[165] This diverged from the previous tact of studies dealing with modern urban water usage, which focused more on supply systems. The Water Footprint method took a systems approach and broke down all water into three categories: grey water, green water, and blue water (Fig. 2.3). By dividing the flow of water into these broad categories, this method attempted to identify how much water ("virtual water") was needed to make an object, like a pair of jeans, or a pizza. The goal was to measure the global debt, surplus, and trade of water in economic terms. The Water Footprint method achieved the goal of identifying different types of water and calling for more robust water accounting standards. But the accuracy of its accounting techniques has been rightly criticized, both for the homogenous assumptions made for the data, but also for its lack of local environmental or social factors.[166] As a result, this method has had little purchase in the wider hydrological science community.

[165] Hoekstra 2009; Hoekstra *et al.* 2011 for the Water Footprint method.

[166] Chapagain & Tickner 2012 outline the major criticisms of the Water Footprint method.

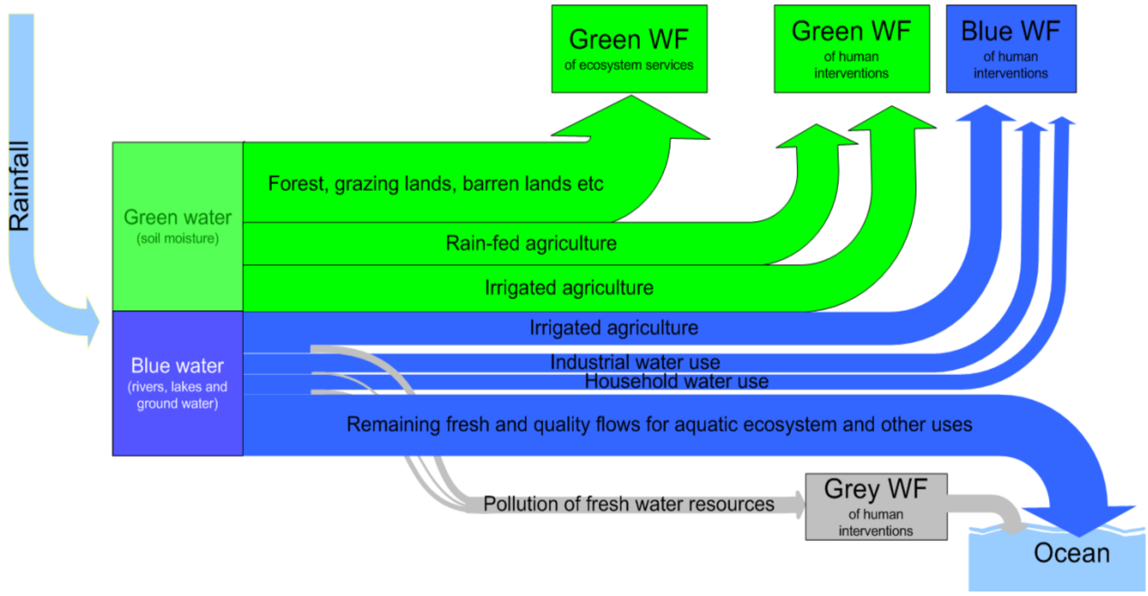

Figure 2.16: Parts of the Water Footprint model and the hydrological cycle, with Green, Grey, and Blue water separated (Chapagain & Tickner 2012, 565, Fig. 1).

2.2.2.2: The City Blueprint

The holistic integration of urban hydraulic systems with environmental and socio-economic factors was first proposed by Dutch researchers as a response to the failings of the Water Footprint model.[167] Their City Blueprint method used eight broad categories (with 24 sub-indicators) to assess the hydraulic sustainability of a city, comparing indices like water security, biodiversity, and governance. While the authors of the City Blueprint method admit that the resulting figures are only the tip of the iceberg, such an intra-city comparison has never before existed. This method has continued to develop since its inception, and its main success was in creating an easily applicable framework with which to compare cities across the world. It also identifies otherwise invisible interconnections between diverse water-related factors, such as the age of a sewer system, public participation, and energy recovery (Fig. 2.4).[168] These aspects are usually treated by specialists in widely different fields and are rarely presented together.

[167] Van Leeuwen *et al.* 2012. A similar model had already been advocated in the 1990s under the heading of of Integrated Water Resources Management (IWRM). This approach became the dominant global policy approach to dealing with the ecological, cultural, and economic values of water. Yet IWRM was criticized for defining water as an abstract "economic" good, and for lacking a method to translate global concepts to local applications; See Koop & Van Leeuwen 2015a, 4631 for a critique of IWRM.
[168] Van Leeuwen 2013; Koop & Van Leeuwen 2015a, 2015b; Van Leeuwen *et al.* 2016.

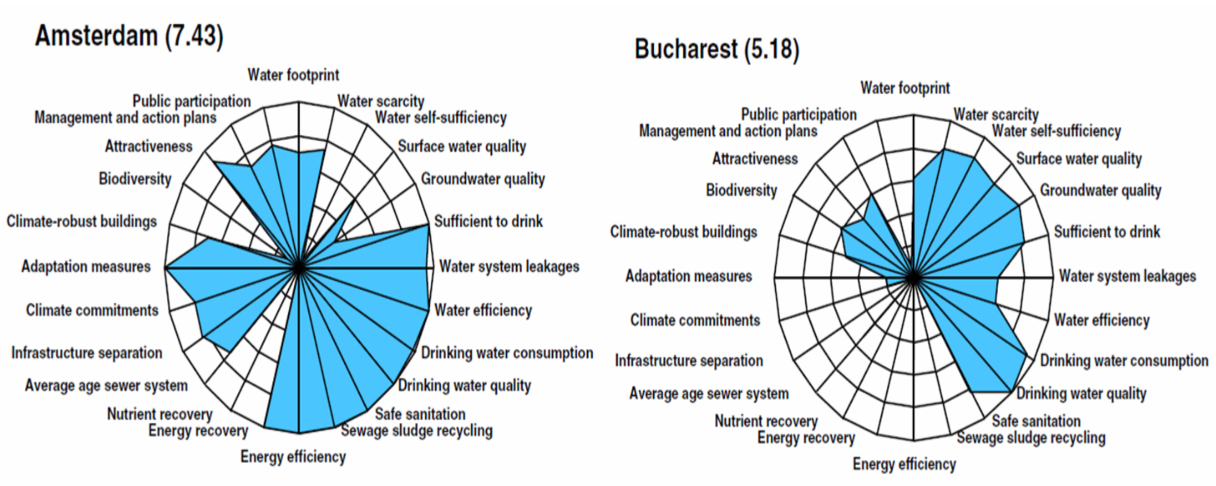

Figure 2.17: Examples of two City Blueprint analyses comparing Amsterdam and Bucharest. The categories with more filled-in areas represent a more sustainable score. By taking an average of the values, a city receives a score out of 10; in these examples, Amsterdam scores higher (7.43/10) compared with Bucharest (5.18/10) (Van Leeuwen 2013, 5196-97, Fig. 2).

Theoretical approaches in archaeology in the late 20th century have also reacted to this global environmental turn by developing an increasing dialogue and cooperation with civil engineering, geology, and urban planning. However, like all instances of initial communication between groups, issues of definition, perception, and intention must be navigated before meaningful dialogue can occur. While Mediterranean archaeology bears a host of ideological, political, and cultural baggage the subject of sustainability equally possesses a unique historiography and cultural framework, which is perhaps made more dynamic by its short life span. So then, to what degree (if at all) can the methods of sustainable resource usage be applied to past societies, and more specifically to Roman urbanism? Is sustainability too socio-temporally bounded as a 21st century world-view to have any meaning for the Roman world? This requires a definition of resource sustainability to see whether such a term can, in fact, be applied to the past. Most research on ancient resource usage usually revolves around three key issues: environmental awareness, recycling, perception of landscape.

2.2.3: Factors of Ancient Sustainability

It is well-attested from literary sources that Romans were keenly aware of their environment and the effects of farming, mining, and weather upon their local area.[169] The pressures of food and water supply for any large city will necessarily cause responsive political, military, or technological actions, whether that entails territorial expansion to ensure grain supply, or the construction of aqueducts from more and more distant sources. Although the Romans did not have our global view of the earth and its resources, they were well aware of the tenuous nature of resource supply, and wanted to ensure the growth of their cities and civilization. This local and seasonal information was often used in designing urban infrastructure, although the degree of diversity between these systems has received little previous attention. A well-known example comes from the aqueducts supplying Rome itself. The Porta Maggiore in Rome preserves evidence of two superimposed aqueduct channels, the Aqua Claudia and the Aqua Anio Novus. Each aqueduct line comes from a different spring, and while it would have been easier to just combine the two lines, the waters were considered diverse enough to keep them separated (Fig. 2.5).[170]

[169] Thommen 2014 and Hughes 2014 provide a useful general overview of the subject.
[170] Linton 2010, 82 for an overview of ancient attitudes to aqueduct waters.

Figure 2.18: The Porta Maggiore in Rome, seen from the Roma Termini train station with two superimposed aqueduct channels to ensure that the different types of water remained separated from each other.

In terms of recycling, there weren't many materials the Romans did not recycle or reuse, and some recent studies have gone so far as to label Roman cities as "self-cleaning".[171] Metal was costly to produce and would not be simply thrown into a landfill; wood was utilized for building projects or to light household fires or stoves. Organic waste could be consumed by slaves, livestock, or used to make agricultural compost. Even human waste could be utilized in a number of creative and lucrative ways.[172] Many Roman cities possessed landfills, and their excavation has revealed a rich source for understanding urban life.[173] Landfills were usually reserved for objects that could not be used or re-purposed for any other process, as with the oil-soaked amphorae sherds of Monte Testaccio in Rome.[174] This is not to say that Roman cities were "clean" by today's standards; the water and air pollution caused by cities dumping waste into rivers and smoke from innumerable oil fires certainly was a reality of urban life.[175] Water itself was reused, as is visible from the drainage systems of numerous Roman bath buildings, in which the water used in bathing was directed to flush out communal latrines. The increasing evidence of cisterns in the Roman world also points to a clear awareness of fluctuating periods of available supply.[176]

The most difficult aspect of understanding resource usage is identifying how a group thinks about its landscape. In trying to discover the complex and contradicting ways that water was viewed in the Roman

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[171] Rodríguez-Almeida 2000; Mart. *Ep.* I, 41, 3, X, 3-4; Juv. *Sat*. 5.46f.

[172] Flohr & Wilson 2011 and Munro 2012 outline examples of these practices.

[173] Tarrats 2000 for excavations of the landfills of Tarraco (mod. Tarragona).

[174] Tarquini *et al.* 2014 for a non-invasive approach (infrared spectroscopy) to identify the provenance of different oils preserved on amphora sherds at Monte Testaccio.

[175] For literary mentions of the smog of Rome: Rut. Namat. *De Reditu* 1.193-94; Hor. *Carm*. III, 29.

[176] Bruun 2000, 220 offers some early points of discussion regarding water supply and scarcity, quoting Hodge 1992, 280: "If this second alternative were true (i.e. that the distribution was cut off for the night, in order to meet the next day's demand), it would of course imply a whole philosophy of water supply radically different from the continuous off-take principle traditional to Roman aqueducts. It would imply the acceptance of storage against future needs and something akin to the recognition of peak and off peak hours, an *un-Roman philosophy*", emphasis added by present author.

world, even a cursory glance reveals how amorphous this topic is, extending into the fields of class studies, economics, usage habits, and religion. From archaeological and literary sources we can infer a general Roman worldview about water: all types of water (i.e. rain, sea, river, marsh, fresh, foreign, bought, etc.) could be polyvalent, magical, possessing individual personalities and responses. Any investigation of water infrastructure and usage in the Roman world must take these diverse perceptions into account.

The theoretical framework of this study takes into account the diverse perceptions of how water has been viewed throughout time. By taking a position of active critical realism described above, it is possible to approach the subject of water and urbanism in the Roman city from the contrarian positions of the Romans, allowing for a multiplicity of views. The same democracy of views is advocated for by sustainable resource management studies in the current urbanizing world. These too, have started to turn away from Western normative ideas about what water "should be", and more towards what water is, and the multiplicity of identities that water can have. The recently developed City Blueprint model offers a structure with which to understand the amorphous nature of water in current cities. Given that the same multiple qualities of water are beginning to be identified in the Roman world, we are led to the point from which we can start to translate the approaches of the present into the Roman world.[177] This results in a dynamic dialogue between modern and ancient water habits, usages, and methods of calculations.

2.3: Methodology - The Roman Water Footprint

Given the theoretical framework outlined above, how can a 21st century model, with all its embedded assumptions, be applied to the Roman world? This can be achieved by combining aspects of different modern systems, namely from the Water Footprint method, and the City Blueprint model. The water footprint of a group is the quantitative indication of how much water is used within a given space and time, and is measured over the complete supply chain. The parameters for assessing the water footprint of any city are flexible, and depend on which scales are chosen for investigation.[178] In the context of this study, the systems perspective of water usage has been taken from the Water Footprint model, by tracing the path of water along its complete progression of water flow (acquisition, distribution, usage, waste, recycling). But, this study departs from the water accounting aspect of modern water footprints, as such a level of detailed economic and systemic information is absent for Roman cities. Several modern studies have attempted to generate population figures or average daily intake/usage amounts based on individual aspects of Roman water usage, such as aqueduct volume, cistern size, or length of lead pipes.[179] The resulting figures vary wildly given that the central variable in these calculations is often the "minimum daily requirement" of water, or "need". This value is difficult to estimate even for our contemporary world, given the differences in minimum water considered essential for daily life in, for example, Mongolia, Portugal, or Egypt.

Combining the volumes of known basins to arrive at population figures would seem to miss the mark. While detailed measurements of individual water features have been taken for the water features identified in this study, they are used more to identify changes to the system as a whole in terms of distribution and number of water features. Rather, this study is concerned with the archaeological traces of all types of water usage and how the number and distribution of these changed over time. To achieve this, the central inspiration for this project's methodology comes from the City Blueprint method's attempt to combine water systems with cultural and environmental factors. Following the data acquisition methods outlined in Chapter 1, the chronological beginning of every water feature is recorded in the first part of each chapters (Chapters 3.1, 4.1, 5.1). Every part of the identified hydraulic

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[177] Hartley 1953, 1, "The past is a foreign country: they do things differently there."
[178] Hoekstra 2009; Hoekstra *et al.* 2011.
[179] Dessales 2008 for Pompeii.

system is situated within four separate time slices, demarcated by periods of substantial hydraulic change within Ostia's archaeological record.

1) Initial settlement (4th century B.C.) until the aqueduct is created (ca. AD 50).

2) Response to increased water demand (ca. AD 50- 200).

3) Last urban "push" of development (AD 200-300).

4) Late Antique modification of urban space and demographic reduction (AD 300-600).

2.3.1: Water Features

Every water feature identified in this study is given a Feature Number that pertains only to the block under discussion.[180] For clarity and ease of identification, a chart and accompanying map are provided for each building to aid the reader in locating individual water features. Water features are described following the pre-established numerical order of the rooms in each building. After the description of all water features within a given building, the features are organized into temporal phases to present the diachronic hydraulic history of each building in the city block under question. Each of the three case studies (*insulae* III, i; IV, ii; V, ii) are described in three chapters split into two parts. The first part of each chapter (3.1, 4.1, 5.1) presents the chronology and water features from each building. The second section of each chapter (3.2, 4.2, 5.2) combines the water histories of the individual buildings to create a unified picture of water in each of the four water footprint phases across the entire insula (Fig. 2.6). In this way, the reader can access different spatial scales of detail (e.g. individual lead pipe, to the level of the building, the insula level), or temporal scales (e.g. all of the water features in an *insula* in one period, or diachronically). In the diachronic discussion in Chapter 6, the water footprints of all three insulae are compared to each other to present a wider picture of the hydraulic landscape of Ostia in the four different time periods.

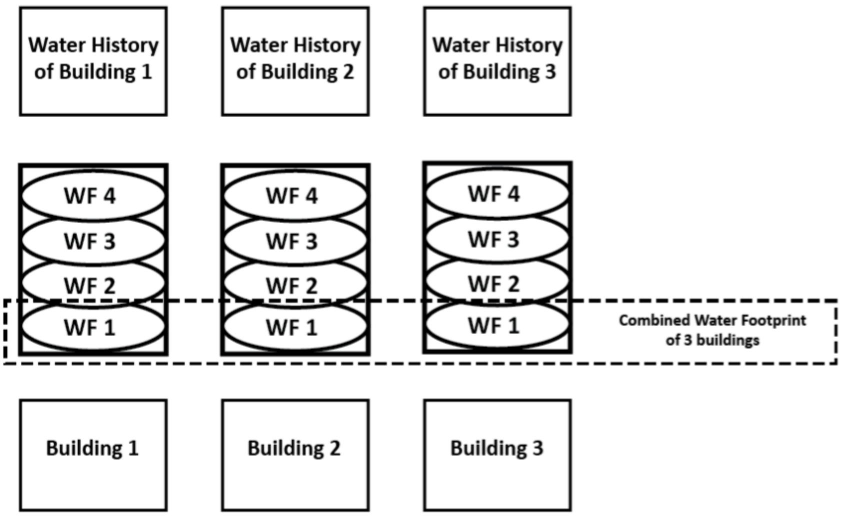

Figure 2.19: Schematic plan of the Roman Water Footprint's methodology.

[180] In this way, Feature 26 in *insula* III, i has no connection to Feature 26 in *insula* IV, ii.

2.3.2: Temporal Duration

The division into four large periods reflects definitive historical moments when the hydraulic system of Ostia significantly changed, and thus has left traces in the archaeological record.[181] This aspect of the methodology focuses on the hydraulic infrastructure, and presents the situation in each period, moving away from a linear (i.e. rise-decline-fall) interpretation of the evidence. Although each water feature has a moment of creation, many of them continue to function into later periods of time. Identifying this duration resolves the issue of how to interpret and contextualize an Augustan well that functions in a Late Antique structure (Fig. 2.7).[182] Where the duration of a particular water feature is unknown, the wider history of a building can be informative regarding whether or not such a feature could function at a later moment.

III, i, 4 Room #	Feature	Feature No.	Initial Water Footprint Phase	RWF period 1	RWF period 2	RWF period 3	RWF period 4
1	rect downshaft	16	2	x	**2**	3	4
3	semi-circ pool	17	4	x	x	x	**4**
3	nymphaeum	18	4	x	x	x	**4**
3	channel	19	4	x	x	x	**4**
3	channels	102	4	x	x	x	**4**
3	downshaft	20	2	x	**2**	3	x
3	sewer	100	2	x	**2**	3	4
11	well	21	1	**1**	2	3	4
III, i, 5 Room #	**Feature**	**Feature No.**	**Initial Water Footprint Phase**	**RWF period 1**	**RWF period 2**	**RWF period 3**	**RWF period 4**
7	well	77	1	**1**	2	x	x
22	basin	31	3?	x	x	**3**	x
24	basin	76	3?	x	x	**3**	x

Figure 2.20: Example of temporal duration identified for several water features in insula III, i.

2.4: Indicators of the Roman Water Footprint

With the temporal aspect clarified, the functional methodology of this project, the *Roman Water Footprint* method will now be introduced. This method was devised by the present study and is based on three major indicators: Infrastructure, Culture, Nature (Tab. 2.1). The criteria for each indicator will be discussed, together with the varying number of sub-indicators it possesses. The majority of the sub-indicators count either the number of a certain kind of water feature, or the different types of a water feature. Given the lack of specific evidence for environmental and cultural data, several proxies are used. Although some of the indicators may appear broad, they were developed to be transparent, accessible, and most importantly, transferable to other urban case studies and other scales of investigation.

[181] For a more detailed description of each hydraulic period, the reader is invited to consult the preceding chapter.
[182] See Appendix 3 for the temporal duration of each feature.

Indicator	Sub-Indicator	Data
Infrastructure	Supply Systems	Rain Water
		Ground Water
		Aqueduct
		Total # of Supply Features
	Usage Systems	Number of Leisure Water Features
		Number of Industrial/Economic Water Features
		Number of Domestic Water Features
		Total # of Usage Features
	Drainage Systems	Sewer
		Downshaft
		Drains
		Total # of Drainage Features
	System Resilience	Number of Types of Supply
		Number of Types of Usage
		Number of Types of Drainage
		Total System Complexity
		Total # of Features
Culture	Private Oriented-insula	Total # of Features
	Public Oriented-insula	Total # of Features
	Private Oriented-Ostia	Total # of Features
	Public Oriented-Ostia	Total # of Features
Nature	External	Tiber River Floods
	Internal	Urban Garbage
		Urban Health (# of Baths)

Table 2.1: Roman Water Footprint framework.

2.4.1: Infrastructure

2.4.1.1: Supply Systems

The hydraulic infrastructure within the city of Ostia is extremely lacunose, but numerous scattered elements remain of the city's supply, usage, and drainage of water. Dedicated systems were built to collect and channel rain water, aqueduct water, and ground water. The easily available and high quality of the groundwater at Ostia promoted its use throughout the city's history, even supplying bath buildings.[183] From epigraphic and iconographic sources, we have evidence that water from the Tiber River, the city's nearby marshes, the sea, and perhaps even water purchased from elsewhere could be used depending on the intended activity.[184] The acquisition of these types of water supply leaves little indication in the archaeological record, and thus cannot be quantified. However, this study assumes

183 Bedello Tata & Fogagnolo 2005 for the ca. 5 m water wheel in the Terme dei Cisiarii; RS I, 21-68 for wells.

184 For the buying of water, see Jansen 2002, 154 discusses the epigraphic evidence surrounding Lucifer Aquatarius; for the unexpected uses of marshes see Horden & Purcell 2000, 63 for ancient uses of marshes as part of the *"the exploitation of minutely subdivided polycultures"*.

that water from these sources was constantly used throughout the life of Ostia, acting as a baseline for the city's water needs.

2.4.1.2: Usage Systems

Once water arrived to a structure, it could be used in many different ways. For the purposes of this study, three broad categories of water usage are applied: leisure, industrial/economic, and domestic. While each of these categories carries scholarly baggage with it, they are used here to highlight not only the division of water between these different activities, but also to emphasize examples where water is shared between buildings of a different primary function. This approach also defines water where it is used: a domus house that has a street-front taberna can have both domestic and industrial/economic water usage. Many (sub)categories could easily be added under this heading, but this broad division is intended to give a general overview to usage trends in structures/insulae over their entire life. The specific spatial context of each water feature is explained in the relevant chapters. By dividing the usage features into these functional categories, it reduces the weighting of more visible and luxurious features like *nymphaea*, and brings the more hidden or less glamorous parts of the hydraulic system into focus. The types of usage is also calculated to show the potential diversity in different structures and at different time periods.

2.4.1.3: Drainage Systems

After water had been used, it left its container either directly into a sewer, or first passed through a secondary system of drains. These drainage features range in size from the small outlets of a fountain basin, to vertical downshafts, and to larger sewer systems draining multiple structures. Known information about the wider urban sewer system is described in the relevant chapters. As the sewers under the streets were built by the city, they are not included in the Roman Water Footprint calculations, which takes the individual *insula* as the scale of investigation. Little is known about the historical development of Ostia's sewer network, but any available evidence is included to contextualize each city block with its local sewer network.

2.4.1.4: System Resilience

The final sub-indicator for Infrastructure pertains to the resilience of the system. Resilience is here calculated as a product of the overall complexity of the system. Complexity in this sense represents not just the total number of water features in a building or city block, but also what kinds of water features are present. So, the number of types of each part of the hydraulic system (supply, usage, drainage) are added up. Each of these categories has 3 types, and thus, the maximum possible score is 9/9; this indicates that all possible types of supply, usage, and drainage are present in the building or city block. The greater diversity a system has, the more sustainable it is, given that it can adapt to seasonal and annual variations, or maintenance issues. This also reflects how dependent a building is on a certain system; if the diversity is high, then there is minimal dependence on any single part of the system.[185] Also, by seeing how complex or diverse a building's water system is, it is also possible to see how these combinations of types changed over time. The total number of features is also calculated to give an idea of how representative the complexity is: if one building has a very low complexity, this may be a result of its connection to neighboring buildings, or simply an absence of material. Many modern studies stress the need for expanding urban centers to invest in more diversified and decentralized systems of water acquisition and drainage.[186] A diversified and decentralized infrastructure requires more private activity, but reduces the chance of widespread supply problems if one part of the system is disrupted. In the

[185] Ertsen 2016, 503 outlines the modern biases of defining what "complexity" means for past civilizations, and the potential opportunities in studying water systems through the perspective of human and non-human agencies.
[186] The study of "resilience" in combining natural and social science has been expanding since the 1970s. See Schwanen 2016 for an overview; see Bichai *et al.* 2015 and Liu *et al.* 2012 for research into alternative water supply sources in Australia and China respectively.

same way, identifying smaller scale systems and how they changed over time provides a higher chance of detecting the actions of individuals or groups of individuals.

2.4.2: Culture

An examination of the role of water in different periods of Roman and Ostian culture would require a separate study into changing cultural perceptions of water. Yet, creating a baseline assessment of Ostian perception of water is pivotal to this study in order to integrate the hydraulic infrastructure with its contemporary cultural landscape. This involves using the sub-indicators of “private” and “public” as proxies for the role, or at least the presence of different social applications of water.

2.4.2.1: Public and Private Investment in the *insula*

The broad labels of public and private are contentious, especially when dealing with the non-binary division of Roman domestic space, or evidence of joint industrial-domestic-religious activities.[187] To begin exploring why certain types of water features were used, every water feature identified by this study is labeled “public” or “private”. In this way, water features in a taberna are defined as “public”, those in a domus are defined as “private”, and those in an industrial/economic building are “public”. This approach means that if there is a domus, water features inside are private; but if the domus has a taberna that has water features in it, those are labeled public, since they are involved more with public life. While the exact definition of the functional aspects of every room and building can be further explored, these broad categories strive to highlight similarities and differences between contemporary structures with different primary activities.[188] Detailed discussion on the chronology and function of each building can be found in Chapters 3.1, 4.1, and 5.1. The current evidence from Ostia indicates that resource usage is not solely based upon the amount of available resources, but is largely determined by cultural habitus.[189]

2.4.2.2: Public and Private Investment in Ostia

The public-private division of the water features in the *insula* is then compared to those of the city, in order to contextualize the insula within the wider urban and historical context of the city. Data on the public/private labeling of water systems of Ostia as a whole come from the work of Ricciardi & Scrinari; while their data sets are fragmentary and highly problematic, they represent the only large data set available for Ostia as a whole for such broad comparisons.[190] The broader context of a given time period is necessarily the same in each of the case studies, so the character of Ostia in the Severan period acts as a temporal background for each insula. Yet, by identifying the public-private balance in each *insula* and comparing it to the public-private figures of Ricciardi & Scrinari for the wider city, this aspect of the Roman Water Footprint draws into relief the unique relationship between the *insula* and the wider city.

2.4.3: Nature

2.4.3.1: External Environmental Factors

Discussions about nature in the Roman world usually fall between the paleoenvironmental or phenomenological boundaries. In offering a well substantiated yet culturally appropriate view of water in the Roman world, a medium between these poles is proposed here. Roman perception of what classified a water source as “clean” or “dirty” differed largely from ours, and this multiplicity of water

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[187] Bablitz 2015, 63 identifies archaeological and literary examples of a private domus used for holding law trials with witnesses, judges, and other accoutrements; Nevett 2010, 90-104; Speksnijder 2015, 87.
[188] The categorization of each water feature (as private or public) can be found in Appendix 3.
[189] Haberl *et al.* 2013; Tàbara & Ilhan 2008.
[190] The author compiled a database of public-private water features based on the attributions presented in RS I and II; Jansen 2002, 129, 169 (note 57) rightly cautions against an uncritical reading of the data in RS.

usage is incorporated into the present study.[191] This is most evident in dealing with the Tiber River. Rivers classified by modern Western standards as "heavily polluted" continue to be used well in to the modern era for non-drinking purposes.[192] In the case of Ostia, the role of the Tiber as a water source has not been given its due owing to an economic focus on the river as a highway. Several recent studies on the development of the Tiber river, the inland salt marshes, and the wider geomorphology of the Tyrrhenian coast continue to offer incredible new dimensions into the environmental context of Ostia.[193] While not dealing specifically with Ostia, detailed studies of the Tiber river's turbulent interaction with the ancient city of Rome are used as proxy data by this study. This pertains mostly to the historical frequency of flooding events in Rome, which occurred irregularly, and are even more irregularly documented by ancient sources.[194] The effect of flooding on Ostia has only begun to be understood, but the high groundwater and vicinity to the sea suggests that flooding and its after effects would certainly have been a concern for the city.[195] In fact, once the riverine sections of the city were excavated to its Roman levels, flooding continued to occur in the 20th century. These flood events (e.g. 1915, 1938, 1941, 1948, 2012) were recorded in archival photographs at Ostia, which showed the extent and depth of water accumulating in the freshly excavated areas (Fig. 2.8).

2.4.3.2: Internal Environmental Factors

Turning from the external to the internal, studies of faunal depositions within Ostia are used in the Roman Water Footprint to approximate the degree of urban health in different periods. This data comes from recent osteo-zoological research, which collected available faunal material from previously excavated sites across Ostia.[196] The context of each of these deposits differ, with an uneven spatial and temporal distribution of the material, as well as the amount of preserved material. The majority of the faunal material comes either from distinct phases of building and leveling, or from the periphery of the city, such as the Porta Marina *castellum* or along the Via Laurentina (Fig. 2.9).

[191] Kamash 2008; Hughes 2014, 177; Frontin. *Aq.* XC-XCII assesses the poor quality of the water from the Anio Vetus aqueduct for drinking, but proposes its use for urban gardens and the lowest level of activities (*sordidiora ministeria*).

[192] Rivers like the Ganges continue to be used for a variety of cultural purposes, irrespective of the level of chemical pollutants; Euzen & Haghe 2012, 239 for changing attitudes to Parisian water choices in the 17th- 20th centuries. Despite numerous advances in water purification technology, that study showed that 42% of Parisians (in 2007) disliked their tap water in favour of bottled water.

[193] Mastrorillo *et al*. 2016; Sadori *et al.* 2016 for the pollen and ostracod evidence from cores.

[194] Aldrete 2007, 242-243 for the chronology of floods in ancient Rome; Several inscriptions found at Ostia refer to the position of *curator alvei Tiberis et riparum*, the position created by Tiberius to manage the course and banks of the Tiber river (e.g. AE 1975, 134, 135).

[195] See Aldrete 2007, 129-158 and Hammond *et al.* 2015 for a discussion on how the after-effects of floods are just as destructive as the flood event itself; Hori & Lavan 2015, 626-631 test different flooding hypotheses for Ostia based on recent laser scanning data.

[196] MacKinnon 2014, 187-195 for further description of biases inherent in the data. Much of the material comes from the more recent excavations of the DAI-AAR.

Figure 2.21: View of the decumanus maximus of Ostia flooded in 2012 (M. David).

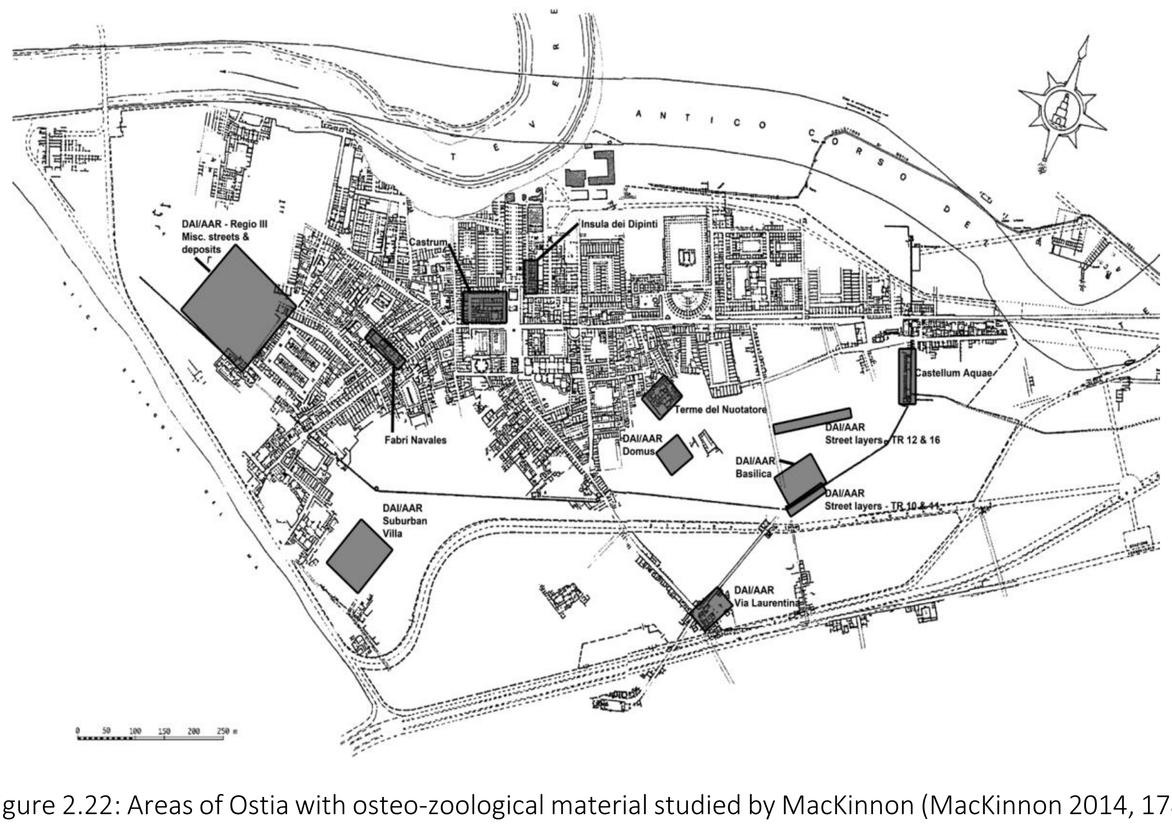

Figure 2.22: Areas of Ostia with osteo-zoological material studied by MacKinnon (MacKinnon 2014, 178, Fig. 1).

The quality of the data are similar to many other classes of information at Ostia, with the majority coming from the 2nd-4th centuries. However, the larger trends in the data do reflect the changing urban shape of Ostia, and can be integrated into the Roman Water Footprint framework. The osteological data of MacKinnon are here translated in order of their relative increase, to reflect trends on a scale that is compatible with the periods demarcated by the Roman Water Footprint. A value of 1 is given to the material from RWF #1 (4th century B.C.- AD 50) as it has the lowest amount of recorded information, and a value of 3 is given to the subsequent RWF #2 (AD 50-200) given the more than exponential growth in this period. A value of 4 is assigned to RWF #3 (AD 200-300) as it represents the maximum amount of osteological waste identified in the city. A value of 3 is assigned to RWF #4 (AD 300-600) to represent the slight decline but general continuity of material in this period. While the breadth of the categories employed here does not do justice to the detailed nuances of MacKinnon's analyses, or to the wider study of Roman waste habits, they add an important dimension to contextualizing the city's hydraulic system.[197] This is especially the case when waste deposits occur together with collapsed or abandoned buildings, increasing the chance for spreading infectious diseases.

More critical assessments of urban health and hygiene in the Roman world have been debated since the 1980s,[198] but recent research into the presence of ancient parasites has painted a very different picture of a Roman urban environment.[199] Bath buildings are often considered one of the most visible symbols of *romanitas*, and many studies on Roman baths directly connect the opulence of their internal decorations with a supposedly modern level of hygiene and cleanliness.[200] However, some recent research has seen past the marble veneer to the much more important social role of bath buildings, as places for displays of wealth, social status, and for many other non-washing related activities.[201] Although much more could be and has been said on this topic, water, especially in thermal establishments, is often the central vector for the spread of urban parasites.[202] While there are many other ways Romans could encounter endoparasites (e.g. tapeworms, whipworms), or ectoparasites (e.g. lice, fleas, bed bugs), Roman literature and paleoparasitology are full of examples of unhygienic activities occurring in the tepid pools of a bath building (Fig. 2.10).[203] It is unknown how often the water within bath basins was changed, but the lack of chemical additives implies a high degree of infectious diseases within bath water. In terms of the Roman Water Footprint, the number of bath buildings in the city will be used as a proxy for Urban Health, however with an *inverse* meaning (Fig. 2.11).[204] The higher the number of bath buildings, the *worse* the possible health of the urban population is interpreted to be, as there will be an increased risk of coming into contact with water-borne infectious diseases. This approach may seem contrary to the general perception of bathing in the Roman world, but the

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197 Rodríguez-Almeida 2000, 123-127 for Roman cities as "self-cleaning" by means of internal recycling practices.

198 Scobie 1986 is the fundamental text in this debate; Jansen 2000a for a more updated position on the debate, especially in terms of literary references dealing with waste and pollution in ancient cities.

199 Mitchell 2015 collects evidence from across the Roman world of preserved parasite remains; Williams *et al*. 2017 for the identification of intestinal parasites (especially roundworm and dysentery causing parasites) in Sagalassos: a strong stomach is recommended when reading such reports.

200 Zajac 1999 for Roman baths as symbols of euergetism and personal legitimation, and less about cleanliness. She connects this modern perception of baths as places dedicated to hygiene with 19th century European mentality of viewing the cleanliness of the poor as a part of "the public good", and part of normative behaviour and public order; Tac., *Agr.* I, 20 for this view of baths.

201 Fagan 2011 gives an excellent overview of Roman literary sources dealing with the social aspects of Roman bathing culture (e.g. Mart. *Ep.* II, 42); see also Fagan 2000 and Jansen 2000b for aspects of the ancient hygiene debate; Smith & Kahila 1992 for the discovery of 100 infant skeletons deposited in the sewer of a late Roman bath building in Ashkelon, Israel.

202 Aspöck *et al.* 2011; Jansen 2000a.

203 Aus. *Ep.* 106 sometime sick were unclothed and washed their *ulcera scabie putrefacta* in hot pools; Cels. *de Med.* prescribed a trip to bath for open wounds, diarrhea, or other skin infections; Artem. *Oneirocritica,* I, 64 states that very sick people should bathe, but be clothed so as not to offend other bathers with the sight of their infirm bodies.

204 Medri & Di Cola 2013, 101 for the temporal duration of all known bath buildings in Ostia, with the newly discovered evidence of the Terme del Sileno (IV, ix, 7) included (David *et al.* 2014); the publication of Poccardi's 2006 work on the baths of Ostia may shift these figures slightly, but their overall temporal distribution is unlikely to be affected.

increasing evidence from paleoparasitology and studies of drainage systems of bath buildings strongly suggest that this perspective should be added to our understanding of Roman thermal establishments. Such a metric is included in the Roman Water Footprint to give at least a baseline indication of the water-related health of the population of Ostia.

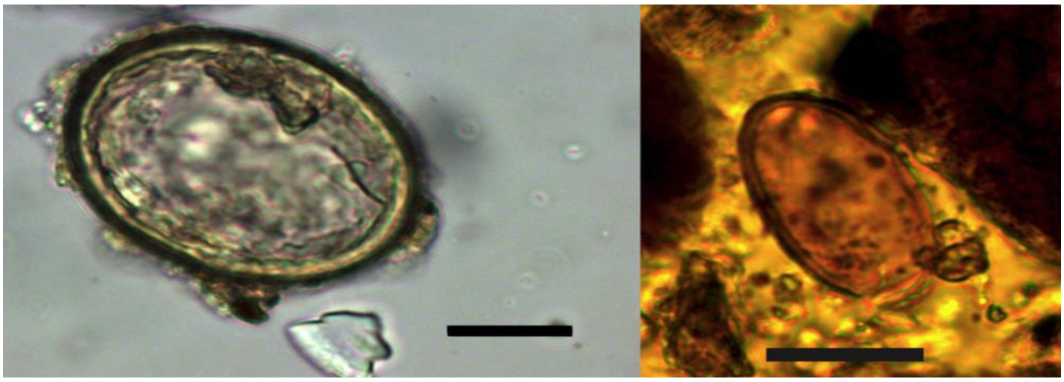

Figure 2.23: Intestinal parasites identified from the Roman latrine in the Imperial Baths of Sagalassos. At left a roundworm (*Ascaris*) egg, at right the egg of lancet liver fluke (*Dicrocoelium sp.*). The black bar indicates 20 µm (Williams *et al.* 2017, Figs. 4 and 5).

All data on the hydraulic infrastructure (supply, usage, drainage, system resilience), social data (public, private), and natural data (internal, external) are gathered together and entered into the Roman Water Footprint framework (Tab. 2.2). The temporal dimension for each of these indicators allows them to be separated into four contextualized "snapshots" of water usage in the area under study. The individual footprints can then be evaluated cumulatively to create a collated water footprint history for each insula.[205]

[205] See Chapters 4, 6, and 8 for the cumulative assessment of the Roman Water Footprints of each case study.

	50 BC-0	AD 41-70	AD 70-98	AD 98-117	AD 117-138	AD 138-192	AD 193-235	late 3rd century AD	4th century AD	5th century AD	6th century AD
Baths known only epigraphically	x										
Terme delle Provincie (under Via dei Vigili, II, iv, 2)		x	x	x							
Terme Domizianee (under Terme di Nettuno, II, iv, 2)			x	x							
Terme dell'Invidioso (V, v, 2)		x	x	x	x	x	x				
Terme del Nuotatore (V, x, 3)			x	x	x	x	x				
Terme di Buticosus (I, xiv, 8)				x	x	x					
Terme della Basilica Cristiana (III, i, 3)				x	x	x	x	x	x		
Terme delle Sei Colonne (IV, v, 11)				x	?						
Terme di Porta Marina (IV, x, 1)				x	x	x	x	x	x	x	x
Terme sotto il Foro della Statua Eroica (I, xii, 2)					x	x	x	x			
Terme del Mitra (I, xvii, 2)					x	x	x	x	x		
Terme di Nettuno (II, iv, 2)					x	x	x	x	x		
Terme dei Cisiarii (II, ii, 3)					x	x	x	x			
Terme Marittime (III, viii, 2)					x	x	x	x	x		
Terme dei Sette Sapienti (III, x, 2)					x	x	x	x			
Terme della Trinacria (III, xvi, 7)					x	x	x				
Terme del Perseo (outside Porta Laurentina)					x	x	x	x	x		
Terme del Sileno (IV, ix, 7)					x	x	x	x	x	?	
Terme del Faro (IV, ii, 1)						x	x	x	x	x	
Terme del Foro (I, xii, 6)						x	x	x	x		
Terme della Via di Iside (IV, v, 6)						x	?				
Terme del cd. Palazzo Imperiale						x	?				
Terme Bizantine (IV, iv, 8)						x?	x?	x	x		
Terme del Filosofo (V, ii, 7)								x	x		
Terme in Via della Foce (Piccole, I, xix, 5)								x	x		
Terme Domus dei Navalia									x		
Terme Domus dei Dioscuri									x		
Terme dello Scheletro (IV, ix, 6)									x	x	

Figure 2.24: Chronology and duration of bath buildings at Ostia (David *et al.* 2014 and Medri & Di Cola 2013, 101, Fig. 1.55).

III, i Roman Water Footprint # 2 (50-200 AD)			
Indicator	Sub-Indicator	Data	Quantity
Infrastructure	Supply Systems	Rain Water	0
		Ground Water	4
		Aqueduct	7
		Total # of Supply Features	11
	Usage Systems	Number of Leisure Water Features	5
		Number of Industrial/Economic Water Features	3
		Number of Domestic Water Features	1
		Total # of Usage Features	9
	Drainage Systems	Sewer	22
		Downshaft	11
		Drains	6
		Total # of Drainage Features	39
	System Resilience	Number of Types of Supply	2
		Number of Types of Usage	3
		Number of Types of Drainage	3
		Total System Complexity	8
		Total # of Features	59
Culture	Private Oriented-insula	Total # of Features	20
	Public Oriented-insula	Total # of Features	39
	Private Oriented-Ostia	Total # of Features	122
	Public Oriented-Ostia	Total # of Features	72
Nature	External	Tiber River Floods	6
	Internal	Urban Garbage	3
		Urban Health (# of Baths)	21

Table 2: Example of the Roman Water Footprint methodology, with data from insula III, i in its AD 50-200 time slice.

2.5: Conclusion

With the Roman Water Footprint methodology in mind, the following chapters introduce the three case studies, in which the archaeological evidence for hydraulic infrastructure from all periods of each city block's life are identified. The structure of each of these three case studies is consistent, to provide an accessible format for readers interested in differing scales of detail. The Roman Water Footprint acts as an initial step for integrating different scales and types of data pertaining to water in Roman cities. The application of modern water accounting and sustainability models is a novel approach to ancient urban studies, and presents a new face of Ostia's urban fabric. Beyond the technical hydraulic information, this method presents new insights into urban life of Ostia, bringing together several different types of information. The Roman Water Footprint offers a new perspective for the study of any building or group of buildings in Ostia, joining large scale infrastructure projects like aqueduct lines with local decisions, like where to build a bar counter. It is hoped that this method will continue to develop and refine its indicators, retaining its transferability and accessibility. Following the trace of water through these structures and through time gives us a window into the daily hydraulic negotiations and choices made by the inhabitants of the city. Our previous understanding of Ostia's urban fabric becomes enlivened when we imagine diversified networks of water flowing behind walls, under floors, underground, across streets, and around the city on its Republican walls. This bottom up approach highlights the decisions and systems created by individual people at specific moments, and creates a more contextualized picture of how Ostia existed in different periods of its life.