Wetlands for water justice

A political ecology of water quality and more-than-human habitability in three constructed wetland projects

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Abstract

This thesis investigates three more-than-human waterscapes in rural India and Scotland where constructed wetlands have been built for wastewater treatment. My analysis of these constructed wetland projects draws from political ecology, more-than-human geography and critical water scholarship. I demonstrate how close attention to more-than-human relations can both strengthen and stretch the existing normative concerns of critical water scholarship.

I first explore how varied notions of justice can be found in the socio-technical imaginaries of constructed wetlands. The next section traces how water quality is judged and how water quality changes are interpreted in the focal waterscapes. Both technical and everyday ways of judging adequate water quality rely on the combination of more-than-human relations and broader knowledge formations. Interpretations of water quality changes draw upon different models of hydraulic, ecological and social processes. I argue that, in judging adequate water quality and interpreting water quality changes, an oversimplified understanding of more-than-human actions stabilises expert knowledge and sustains relations of domination in waterscapes. The final section contributes to an emerging literature examining the overlapping of infrastructures and multispecies habitats. Through bridging geographical and ecological theorisations of biodiversity, I uncover the relations, scalar connections and representations that allow varied life to flourish in constructed wetlands. I also demonstrate how spatial exclusions serve to redistribute the vulnerabilities of waterscape co-existence.

My research methodology makes an empirical contribution to discussions about the role of natural science methods in critical environmental scholarship. Through analyses of the knowledge politics and material transformations of these constructed wetland projects, this thesis advances the concepts and practices that might support more-than-human flourishing in waterscapes.

Ethics statement

The research described in this thesis was reviewed and approved by the University of Stirling General University Ethics Panel under application references 671, 827 & 1021.

Table of Contents

List of Tables

List of Figures

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1 Introduction: Waterscapes, wetlands and water justice

Introduction

As it flows, stagnates, permeates or evaporates, as it is pumped, diverted or ingested, water sustains a more-than-human world. In this thesis, I aim to understand how more-than-human relations shape variations in water quality and the habitability of water infrastructure. In common with critical water scholarship, I am interested in the forms and operations of power that build unjust waterscapes. My investigations also spring from an ethical commitment to multispecies flourishing (Haraway, 2008; Ginn, Beisel and Barua, 2014; Collard, Dempsey and Sundberg, 2015; Tschakert *et al.*, 2021) and to challenging human exceptionalism (Srinivasan and Kasturirangan, 2016, p. 126). On these grounds I develop a multispecies notion of water justice.

Research in three locations underpins my analysis: two rural villages in India and one rural settlement in Scotland. What connects these places is a form of wastewater treatment infrastructure known as a constructed wetland. As with any infrastructure, these wetlands are not only material formations, they are the fruits of socio-technical imaginaries and various projects of development. These wetlands are adjustments to broader more-than-human waterscapes; changes that were only possible through relations between scientific research teams, local people, microbial, animal and vegetal life, political structures, waters and other biophysical forces. Constructed wetlands are my starting point for tracing these complex assemblages.

Wastewaters and (constructed) wetlands

Wastewaters and wetlands have been connected for as long as there has been wastewater (Brix, 1994b). Pre-existing wetlands may be used as a wastewater disposal location, or new wetlands created through flows of discarded water. In a newly independent India, the East Kolkata wetlands were remade through the Kulti outfall scheme, which conveyed Kolkata's sewage to the wetlands, with the hope that this wastewater would sustain fisheries (Ghosh and Sen, 1987; Ghosh, 2005; Mukherjee, 2022). In Edinburgh, where this thesis was written, the Nor loch was sustained for several centuries by wastewater inflows from the city (McLean, 2014). In North America, a practice of discharging wastewater into pre-existing wetlands extends back at least to the early 20th century

(Kadlec and Wallace, 2008). This continued to be a focus of sanitation research until the 1970s (Vymazal, 2022). These examples illustrate the production of wetlands as part of human wastewaterscapes. The flow of wastewater is subject to the shaping influences of topography, friction and geology, as well as economics, politics and public health.

Several factors distinguish constructed wetlands within the broader history of wetlands and wastewater. In contrast to approaches that simply dispose of wastewater into wetlands, a constructed wetland is designed to *treat* wastewater flows. Technological means for wastewater treatment developed as growing cities and increasing water use made previous techniques[1] for dealing with sewage and industrial wastewater unviable. The inclusion of constructed wetlands within the repertoire of wastewater treatment technologies began with research in the 1950s. Up until this point, wastewater treatment technologies had relied upon primarily physical settling and chemical or microbiological degradation for the treatment of wastewater. Wastewater engineers were – according to some histories of constructed wetlands – dismissive of the potential for plants to contribute to water treatment (Vymazal, 2011, p. 63). German botanist Dr Käthe Seidel is credited as developing the first treatment wetlands that included wetland plants (The New York Times, 1975; Brix, 1994b; Vymazal, 2011). Seidel noticed that bullrush (*Typha*) grew well in polluted water from the Rhine. After feeding this water through newly established bullrush wetlands, Seidel measured reduced nutrient and pathogen concentrations (The New York Times, 1975). In the following decades similar wetlands were developed in several locations across Northern Europe and the United States. Kadlec and Wallace (2008) describe how research and practice developed along different paths. Constructed wetlands in North America were mostly 'free water surface' wetlands. In these wetlands, water flowed through ponds, with emergent plants. Meanwhile, wetlands in Europe were developed as subsurface flow wetlands. In these designs, wastewater flows either horizontally or vertically through a substrate of soil or gravel, coming into contact with the roots of plants, and microbial biofilm growing on the substrate. Through these interactions between wastewater and wetland ecologies the material properties of water are transformed.

The growing numbers of constructed wetlands since the 1980s (Kadlec and Wallace, 2008; Vymazal, 2011) are concomitant with a shift in attitude towards wetlands in Modern governance regimes (Brix, 1994b; Vileisis, 1999). While 'drain the swamp' may still serve as a powerful (or ironic) metaphor, the dominant key of wetland governance today is that "these precious ecosystems are in decline and require management, conservation and protection" (Gearey, Church and Ravenscroft, 2020, p. 12).

[1] Such as using wastewater as irrigation on "irrigation meadows"; another part of Edinburgh's wastewater history (Fairley, 1895)

Jenia Mukherjee draws on histories of American wetlands to note how wetland as a term works alongside a particular revaluation of 'swamps', 'mires', 'bogs' and other watery terrains, such that wetlands are "perceived only as a resource to be preserved" (Mukherjee, 2020b, p. 92). That wetlands are a focal point for conservation efforts reflects not only their 'ecosystem services' but also recognition of wetland ecologies. The central role of plants in the design history of constructed wetlands speaks to 'wetland' as an ecological concept[2]. Constructed wetlands are thus sites where matters of water quality and water infrastructure as an inhabited space are inextricable.

Within critical water scholarship, which I will refer to broadly as 'hydrosocial' research, both wastewater and wetlands have been marginal areas of study. One aim of this research is to bring these material constellations into dialogue with hydrosocial scholarship, and its concerns with power, knowledge and water justice.

Hydrosocial concerns: the state of waterscapes

While this thesis develops a political ecology of constructed wetlands, it does so with reference to the broader dynamics of hydrosocial relations. Global analyses point to intersecting forms of harm within waterscapes. Predominant among these is the maldistribution of water. An inability to access fresh water places a severe burden on people and other-than-human beings. In the contemporary politics of maldistribution, "water scarcity" remains a dominant discourse, and one that is well examined by critical water literature (Mehta, 2005; Bharucha, 2019; Mehta, Huff and Allouche, 2019). Political ecology analyses have examined how the maldistribution of waters is rooted in histories of colonial exploitation, capitalist globalisation and other inequitable political processes (Bakker, 2003, 2012; Swyngedouw, 2004; Linton, 2010; Budds and Hinojosa, 2012; Budds and Sultana, 2013; Gandy, 2014; Anand, 2017).

While there is much more that could be said about the distribution of water, this thesis is oriented around other waterscape concerns. Firstly, I situate this work in relation to global though unevenly distributed degradations in water quality[3]. Water pollution can be the result of an overwhelming range of different substances: nutrients, pathogens, toxic metals and other elements, plastics and organic compounds. Each of these pollutants has different effects on bodies of water and other living bodies. Many of these pollutants are characterised by their ability to accumulate in different bodies,

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[2] An ecological focus is also evident in recent social research on wetlands. Caterina Scaramelli's *How to Make a Wetland* (Scaramelli, 2021) and Emily O'Gorman's *Wetlands in a Dry Land* (O'Gorman, 2021) are two examples.
[3] As an illustrative example, rainwater in Antarctica exceeds drinking water health advisory levels for some persistent organic pollutants (Cousins *et al.*, 2022).

as with lead poisoning, where Flint, Michigan serves as an illustrative case of how such toxicity is enabled by broader toxic political structures (Pulido, 2016). A recent World Bank report describes the global picture of water quality as an "invisible water crisis" (Damania *et al.*, 2019). The presence of many pollutants is difficult to detect, while the long-term impacts of novel compounds on human and other-than-human bodies is scarcely understood. Hence, invisibility operates on multiple registers. Nitrogen is a central focus of the World Bank's report. The ecological violence of excessive nutrient loads from agricultural landscapes is well recognised: eutrophication, algal blooms and coastal dead zones. The authors of the planetary boundaries framework suggest that the quantity of nitrogen released into the environment is sufficient to push the global biosphere into a new state (Rockstrom *et al.*, 2009). However, statistical correlations suggest that human health is also negatively impacted by nitrate levels in drinking water (Damania *et al.*, 2019), through mechanisms that are not fully understood. The same dynamics that generate unequal water supply create a differentiated exposure to varied forms of water pollution.

Water pollution also results from the differentiated supply of wastewater infrastructure. An estimated 3.6 billion people lack access to 'safely managed' sanitation services (World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2021). The results of sanitation failures are reflected in child mortality statistics as well as the slow(er) violence of stunting and other issues (Coffey and Spears, 2017). Achieving greater sewage treatment is part of the sustainable development goal framework (UN Habitat and WHO, 2021). The critical literature on sanitation traces the multifaceted harms of inadequate sanitation, as well as the complex social and political effects of sanitation interventions (e.g. McFarlane, 2008, 2012). Meanwhile, research from different disciplinary traditions highlights the ecological harms caused by discharges of wastewater into water bodies (Wear *et al.*, 2021). Inadequate or malfunctioning sanitation infrastructures make human sewage a significant component of water pollution.

In addition to water pollution, there are further infrastructural violences that render waterscapes uninhabitable for other-than-human beings. Despite the re-evaluation of wetlands mentioned earlier, an estimated 87% of inland wetlands worldwide have been drained over the past three centuries (Tickner *et al.*, 2020, p. 334). Rivers have been dredged, extracted, straightened and dammed, breaking the connectivity between up and downstream and across floodplains that many organisms rely on. The movement of freshwater organisms facilitated by transport infrastructures has upended aquatic ecologies (Tickner *et al.*, 2020, p. 335). These alterations indicate an approach to waterscapes characterised by human exceptionalism. Summed broadly, one way of understanding this situation is a freshwater biodiversity "crisis": a higher portion of freshwater vertebrates are threatened with extinction than species in other biomes/habitats (Tickner *et al.*, 2020, p. 330). However, 'crisis' offers the wrong temporality for these deeply rooted violences. Many of the relations that sustain more-than-human flourishing have been systematically eroded (Nixon, 2011).

The past paragraphs have painted an overall negative picture. This may partly be because global analyses aggregate issues in ways that sometimes conceal more than they reveal. Waterscapes are still places of flourishing and more-than-human creativity. This is important to note because there are ethical and political issues with 'damage-focused' research (Tuck, 2009; Theriault and Kang, 2021). At the same time, this brief synopsis points to waterscape conditions that I believe critical water scholarship has a role in addressing. A sober reaction to these conditions requires the repoliticisation of waterscapes (Swyngedouw, 2010). Though this is not a task for research alone, highlighting and critiquing the histories, actions and conceptual architectures that shape contemporary waterscapes is an important building block for bringing other notions of justice to the fore.

Thesis aims and contributions

The constructed wetlands that are the focus of this thesis are part of broader social-ecological-spatial fabrics, which I describe as waterscapes. This is a common and flexible conceptual framing in critical water research (Budds and Hinojosa, 2012; Woelfle-Erskine, 2015; Karpouzoglou and Vij, 2017; Flaminio, Rouillé-Kielo and Le Visage, 2022; Leonardelli, Kemerink-Seyoum and Zwarteveen, 2022). My research offers a particular way of conceptualising the waterscape that foregrounds more-than-human relations. In this way, my understanding of waterscape resonates with Knut Nustad and Heather Swanson's description of landscape as "a material enactment of historically contingent more-than-human interactions" (Nustad and Swanson, 2022, p. 939). Approaching waterscapes as more-than-human collectives deepens insights into existing waterscape concerns – such as the power relations that underpin waterscape knowledge – while also urging an adjustment of the ethical positionality of critical water scholarship.

Overall, this thesis aims to orient water scholarship towards more-than-human flourishing in waterscapes – what might be called multispecies water justice. It does so through analyses oriented around two key themes: water quality and multispecies habitability.

In regard to water quality, a touchstone of my approach is that problems of water quality are not just about the material pollution of water. Max Liboiron (2021) argues that pollution represents the enactment of a colonial logic, linked to the idea of 'Land' as a freely available sink. Pollution also reflects the need for 'cheap' production (Moore, 2015). A political ecology of water quality must be attentive to the materialities of water and pollutants, as well as the power relations, concepts and political logics that shape how wastewaters are handled. This calls for tracing how water quality judgements translate between different places and are oriented towards certain bodies. I combine this with an analysis of the material relations that generate water quality knowledge. A second dimension of my water quality research is to examine how interpretations of water quality change are made. This analysis considers both the biophysical processes that are central to interpretation and the political effects that different interpretations may generate. Both analyses are motivated by a conviction that approaching water quality differently is required for multispecies flourishing in waterscapes.

This thesis also argues that multispecies habitability in waterscapes is an important articulation of water justice. Moving away from human exceptionalism makes evident that waterscapes are the shared home of many diverse beings. In this context, water justice is incomplete without a commitment to more-than-human flourishing (Haraway, 2008). My methodology explores constructed wetlands as inhabited spaces as well as infrastructural formations. My analysis of multispecies habitability is framed around two related concerns: biodiversity and vulnerability.

Researching a more-than-human waterscape requires a methodological approach that stretches beyond conventional modes of hydrosocial research to generate insights into social and ecological relations. This thesis connects to methodological discussions within more-than-human geographies (Hodgetts and Lorimer, 2015; Swanson, 2017; Gandy, 2022b) and within critical water studies (Krause and Strang, 2016; Rusca and Di Baldassarre, 2019), on the importance of interdisciplinary and multi-method research.

Weaving together disparate research methods is not a new challenge. Political ecology research has long been characterised by the tension of working across different ways of knowing environments (Nightingale, 2003; Walker, 2005; Doolittle, 2015). Researching land- or waterscapes requires investigations or descriptions of environmental processes. It also requires a critical reflexivity which recognises that all such descriptions are ultimately representations, marked by a certain social context and set of power relations. As political ecology scholars have argued, the tensions that come from using environmental science methods within a critical research context can be productive rather than debilitating (Doolittle, 2015). As detailed in chapter 3, my research draws upon interviews and other methods of qualitative analysis, deploys a set of hydraulic methods, and develops an approach to ecological investigations that combines quantitative and qualitative ways of tracing ecological relations. Such an approach often highlights the incompatibilities between different sources of data. This approach also necessarily works across scales. I pay close attention to the specific affordances these particular wetlands offer, from the production of scientific knowledge to the grip of a bird's foot around the stem of a wetland plant. But my methods also work outwards from these wetlands to consider the situated histories of significant concepts and practices. Through drawing together diverse methods I am able to generate deeper insights into the politics of these waterscapes.

Structure of the thesis and research questions

In chapter 2, I develop a conceptual framework for more-than-human water research. After first highlighting the multiplicity of water, I explain how the waterscape concept situates waters within complex and evolving socio-natural assemblages. Using the example of Modern water (Linton, 2014) I trace how alignments of knowledge and power often depoliticise water relations and generate water injustices. I then turn to three distinct disciplinary perspectives for approaching water as a more-than-human assemblage: (1) Indigenous cosmologies and analytics, (2) relational conceptions of water in social theory, and (3) the centring of life in water within aquatic ecology. Based on these perspectives, I consider how a more-than-human approach offers a revised perspective on wastewaters and water infrastructure. More-than-human relations are integral to the materiality, knowledge politics and ethics of waterscapes. In the second half of this chapter I examine existing frameworks for water justice, and bring these into dialogue with an open and performative notion of justice. I close by explaining the theorisations of power and politics that I draw on throughout the thesis.

Chapter 3 explores the methodology developed for this research, approaching this as a process of situating or positioning myself in relation to people, places, methods and disciplines. After first describing my personal positionality and offering short histories to introduce my three case study waterscapes, this chapter reflects on how water research can weave together hydraulic, ecological and social research methods.

In Chapter 4 I draw upon a review of constructed wetland literature to ask what are the rationales that support the use of constructed wetlands. More generally, I am interested in what these rationales suggest about the socio-technical imaginaries of (waste)water infrastructure. I highlight how the specific properties of constructed wetlands are imagined to align with normative visions of the arrangement of people, infrastructures and nature. By linking rationale to socio-technical imaginaries and desired futures, this analysis brings to light the various ethical ideals implicit in constructed wetland projects. Constructed wetland socio-technical imaginaries point to multiple dimensions of water justice, including those related to my concerns of water quality and water infrastructures as habitat.

The next two chapters of the thesis develop a political ecology of water quality. Transforming water quality is a central aim of constructed wetlands. I am interested in tracing what water quality *does* in these waterscapes, as an amalgamation of material forces, and simultaneously as a concept mobilised for varied purposes.

Chapter 5 asks how judgments of adequate water quality were made by both scientific teams and local people. The guiding question of the chapter is, what relations and knowledge formations are drawn upon to make water quality meaningful? I highlight how different ways of knowing water quality rely upon distinct more-than-human relations. I then consider the broader knowledge formations within which knowledge is made meaningful, including water quality standards and efficiency metrics. Tracing the histories of the scientific methods and metrics used by project teams uncovers how these practices are rooted in the concerns of very different waterscapes. My analysis suggests ways of knowing water quality that would support multispecies justice, through careful generalising and attention to ecological and historical contexts.

Chapter 6 explores how changes in water quality are interpreted. I examine the ways that water quality data from the constructed wetlands is presented and how both expected and unexpected patterns are explained. What are the foundations and fruits of this interpretation? I argue that all interpretations draw upon models – situated and partial understandings of the world – and that these models serve particular purposes. I first explore how the models deployed by the project team at one site produce an interpretation that simplifies more-than-human relations in order to facilitate the scaling up of constructed wetlands. This interpretation of water quality changes is congruent with interpretations in constructed wetland science more generally. In contrast, I develop a different interpretation of the processes that underlie changes in water quality in the three sites. I emphasise the thickness of more-than-human relations by positioning the actions of humans and other-than-human existents as creative responses to their conditions. This interpretation draws upon different models of water, plant, microbial and human doings. Drawing on these contrasting examples of interpretation, this chapter also asks, what are the political effects of interpreting hydrosocial dynamics? I suggest that the simplified interpretations of constructed wetland science normalise relations of domination between humans and over wetland ecologies. In contrast, interpretations that foreground diverse more-than-human capacities leave room for uncertainties. This in turn requires interpretations to be ongoing and responsive. Generating this responsiveness would enable better performing water infrastructure and undermine relations of dominance within waterscapes.

In the second half of the thesis I add another layer to my analysis of constructed wetlands by foregrounding their position as habitat for other-than-human communities. The aim of this section is to explore the politics of multispecies habitability in these waterscapes. I do so by developing and exploring concepts of biodiversity and vulnerability, working across geographical and ecological theorising.

Chapter 7 asks what processes and concepts are required to understand the variety of beings that inhabit each wetland. I first offer a critical perspective on biodiversity discourses and bring into conversation geographical and ecological theorising about the emergence of diversity. I then explore the processes that enable or constrain diversity, in relation to the plants, invertebrates and birds that I observed at each site. Accounting for the diversity of plants in the wetland requires considering, for example, the wetlands' position as scientific experiments and the material flows that enable plant motion. In the case of wetland birds and invertebrates, I highlight how their curiosity and unique understandings of space act alongside human-directed and abiotic changes to influence their presence over time. Tracing processes of biodiversification produces a richer understanding of the other-than-human beings that find a home in these spaces. It shows the relations, scalar connections and representations that must be engaged with to enable multispecies habitability at each site.

Chapter 8 turns to some of the troubling aspects of multispecies habitability. I ask how the vulnerabilities inherent to more-than-human waterscapes are recognised, responded to and redistributed. I pay particular attention to practices of exclusion – attempts to control the spatial distribution of other-than-human beings – as a focal point for more-than-human ethics and obligations. These exclusions are visible in efforts to co-exist with snakes and mosquitoes, which I argue can be judged more clearly by examining a longer history of co-existence. Redistributions of vulnerability are also embedded in the design of the wetlands, through the channelling of wastewater and through fencing that excludes some animals. Considering these cases, I argue that ecological knowledge is necessary to make ethical exclusions. Attention to the scale of exclusions and to who is responsible for deciding and enacting them is central to a (re)politicisation of vulnerabilities.

Finally, Chapter 9 recaps the arguments of the preceding chapters and draws out the key findings concerning vulnerability and knowledge politics in these waterscapes. I close by highlighting the theoretical and analytical contributions of this thesis that could contribute to future research towards multispecies water justice.

2 Water, life, politics: Theorising a more-than-human waterscape

Introduction

This thesis explores water flows, water quality transformations, constructed wetlands and their animal, plant and microbial inhabitants. I examine measurements of water quality, the experiences of local people living around these wetlands, models of infrastructure performance and the tensions of multispecies coexistence. I aim to account for a complex web of processes surrounding these constructed wetlands; and to critique the outcomes of these processes, where appropriate. What kind of theoretical framework is required to accomplish this task?

In this chapter I develop the concept of a more-than-human waterscape. I build on this to outline a vision of multispecies water justice. To begin I review relevant theorisations of watery relations across several disciplines, focusing on 'hydrosocial' scholarship. This literature highlights the co-production of water and society. It also offers a spatial perspective on water through the 'waterscape' concept. Following this, I examine three different strands of thought that argue for a greater inclusion of other-than-human beings in hydrosocial scholarship. These indicate the need for an approach to theorising waterscapes which centres more-than-human assemblages.

To further lay the foundations for the following chapters, I then highlight the insights offered and questions raised by existing critical scholarship on water quality, wastewater and water infrastructure. I conclude this waterscape section by examining the concept of more-than-human infrastructure. A rich evaluation of constructed wetlands in these waterscapes requires considering their functionality as well as the broader social, ecological and political significance of infrastructures.

In the second section of this chapter I ground the critical analysis of the thesis in a particular conceptualisation of water justice. I first review existing literature on water justice, which highlights several dimensions of this concept. I then layer this with notions of justice which challenge human exceptionalism. Finally, I explain my approach to the concepts of power and politics; central concerns for political ecology research and unavoidable concerns for efforts to bring about just waterscapes.

What is water? From H2O to more-than-human infrastructures and waterscapes

Water, knowledge and power

What is water? This is not a question suited to a definitive answer. Any definition will invariably overlook, simplify or ignore layers of materiality and social meaning. These layers make water into a different thing for different people, at different times, in different places. Water is characterised by multiplicity (Barnes and Alatout, 2012). This is obvious when considering the differences between water 'in general', wastewater, sea water, bottled water, holy water and so on. These waters are not only materially distinct but carry very different meanings. In general, meanings of water are linked, though not tightly bound, to the materiality of water; as potable, visibly clear, high in minerals, odour-free or a host of other factors. The combination of materiality and meaning positions water as, following Donna Haraway, a 'material-semiotic actor' (Haraway, 1988, 2008). Stefan Helmreich works along similar lines to describe water as a substance-concept (Helmreich, 2015). To answer the question 'what is water' requires drawing on certain concepts. And, as feminist (STS) scholars have emphasised, concepts and material worlds are not easy to separate. Astrida Neimanis (2017) argues "concepts do not invent the world ex nihilo, nor do they merely describe it. They… are co-emergent with the materialities they grapple with" (p. 183). In other words, "ways of studying and representing things have world-making effects" (de la Bellacasa, 2017, p. 30).

An example illustrates this entanglement. In his book *What is Water*, Jamie Linton traces the historical development of what he titles 'Modern water': "the dominant, or hegemonic, way of knowing and relating to water, originating in Western Europe and North America" (Linton, 2014, p. 112). Modern water is not a substance, but rather a way of knowing, coupled with conjoined operations of "abstraction, reduction, and representation that produce H_2O and the hydrologic cycle" (ibid., p. 111). In Linton's usage, H_2O points towards an approach that "abstracts all waters from the social, historical, and local conditions in which they are produced and reduces them to a common abstract and timeless identity" (ibid., p. 111). What are the social and material consequences of this conceptual abstraction of water? Linton argues that "there is an internal coherence between this way of knowing and representing water, the consolidation of hydrological expertise, the identification of water as a 'resource' to be 'managed', and the power of the state in managing and controlling this resource." (ibid., p. 113). Modern water co-emerges with the infrastructural formations of Modernity: Indigenous dispossession, concrete dams, State water agencies, straightened rivers, pivot irrigation and water bodies as sacrifice zones for pollution, among others.

Water becomes what it is through the meaning-making and world-making power of certain concepts (Neimanis, 2017; Povinelli, 2021, p. 130). This insight is central to this thesis in two ways. Firstly, in the following sections of this chapter I develop a concept of water a world apart from 'Modern water'. Conceptualising water as a relational and life-sustaining materiality offers a different way to research water, and a distinct notion of water justice. This concept of water animates my research methods and the explorations in the following chapters. At the same time, this understanding of water as a substance-concept suggests a need to trace how currently existing water concepts and knowledges are created and sustained within relations of power.

The nexus of knowledge and power is frequently worked through in human geography and political ecology with reference to Foucault (eg. 1972; 2008; see also Nustad and Swanson, 2022). Rutgerd Boelens, Jaime Hoogesteger, Erik Swyngedouw, Jeroen Vos and Philippus Wester draw upon Foucault to highlight how the production of water discourses "join[s] power and knowledge" (Boelens *et al.*, 2016, p. 7). They suggest that hydrosocial territories[1] are characterised by "a politics of truth which legitimates certain water knowledges, practices and governance forms and discredits others" (ibid., p. 7). In their work on water quality politics in Delhi, Timothy Karpouzoglou and Anna Zimmer (2016) follow a Foucauldian analysis, with a focus on the "knowledge-power nexus that builds a system of acceptable knowledge" (ibid., p.2). Karpouzoglou and Zimmer note that, in Delhi, the Central Pollution Control Board plays a powerful role in determining what information is 'credible'. What such accounts highlight is that – as science studies and other critical disciplines have long argued – the production of scientific knowledge is not an impartial process (Haraway, 1988; Lave, Biermann and Lane, 2018; Saini, 2020). The conditions under which biophysical or social explanations are produced are a shaping force for those explanations (Lave *et al.*, 2014, p. 4). However, this does not imply that there is a fixed and stable relationship between scientific knowledge and State power (Nustad and Swanson, 2022).

These insights are foundational for my analysis of how water quality is known and how changes in water quality are interpreted. While certain knowledges are sustained through relations of power, they remain partial. Donna Haraway (1988) points to the "radical historical specificity, and so contestability, of every layer of the onion of scientific and technological construction" (p. 579). A repoliticisation of water can be achieved through tracing where concepts come from, to whom they are obligated and what worlds they sustain (Povinelli, 2021, p. 130). Beginning from the small scale

[1] An alternative spatial conceptualisation to waterscapes. For an exploration of the distinction see (Flaminio, Rouillé-Kielo and Le Visage, 2022).

of two Indian village wastewaterscapes, I trace knottings of knowledge and power outwards, while examining the consequences of these ways of understanding water quality on the more-than-human inhabitants of these waterscapes.

Hydrosocial waters and waterscapes

Social sciences of water have coalesced around the concept of 'hydrosocial' research, applying a relational dialectical approach to waterscape research. Formalised by Jamie Linton as an alternative to the 'hydrological cycle', hydrosocial cycles are a theory not of 'what water is' but instead how water comes to be. The hydrosocial cycle names a "socio-natural process by which water and society make and remake each other over space and time" (Linton and Budds, 2014, p. 179). This suggests that ways of knowing and re-engineering waters are not only the outcomes of power; they are part of the process through which power remains powerful and axes of difference are reinforced. Power is (re)made through water relations.

A key conceptual tool for hydrosocial research is the waterscape; a political ecology perspective on watery socionatures, initially detailed by Eric Swyngedouw in his work on the politics of water in Guayaquil, Ecuador and Spain (2004, 2015). Swyngedouw describes the waterscape as "a manufactured landscape, one that is wrought, historically and geographically, from a mesmerizing mixture of local, regional, national, and international socio-economic and political-ecological processes and struggles" (2004, p. 30). Waterscape studies are attuned to how water's uses, relations and discourses are configured in specific contexts, and to the social effects of these arrangements. Swyngedouw draws upon Henri Lefebvre to argue for the "ontological primacy of process" (1996, p.73). Rather than taking water, infrastructures or social arrangements as stable entities, this approach explores how waterscapes are constantly reproduced or transformed. Waterscapes, as a concept, align with ways of thinking about space as historical, relational and encompassing multiplicity (Massey, 2005). Waterscape accounts work against the depoliticising concept of Modern water, to instead reveal the power struggles and ideologies that are involved in hydrosocial politics (Swyngedouw, 2004; eg. Götz and Middleton, 2020). To summarise a geographically diverse body of scholarship, the waterscape concept describes an evolving socio-natural assemblages of waters, discourses and imaginaries, people, institutions and infrastructures (see, for example, Acharya, 2015; Woelfle-Erskine, 2015; Karpouzoglou and Vij, 2017; Aigo *et al.*, 2020; Randle, 2021; Rusca and Cleaver, 2022). In this way, the waterscape connects to similar conceptualisations of landscape as "a material enactment of historically contingent more-than-human interactions" (Nustad and Swanson, 2022, p. 15). Waterscape scholarship engages with hydrological and hydraulic processes (French, 2019) as well as the cultural politics of water conflicts (Baviskar, 2007; Acharya, 2015). I take up the waterscape concept in order to work across site-specific assemblages of materialities, infrastructures, discourses and more-than-human relations.

Waterscapes as a more-than-human assemblage

Anupam Mishra, in his account of traditional methods of pond construction and maintenance across India, describes how more-than-human action was used for sustaining pond health:

> "The day water was filled in the pond; the same day aquatic life was released into it. These living beings included fish, crabs and even the crocodiles if the pond was big enough" (Mishra, 1993, p. 43).

Mishra also describes how different plants were added to contribute to water quality, while trees were planted on the pond's banks. To shape a rural Indian waterscape involved maintaining relations with other-than-human beings.

I have already highlighted the material-semiotic plurality of waters, and their socio-political significance. This section adds to the mix the ecologies of watery relations. I want to meander through three ways of figuring these ecological dimensions: (i) the diverse understandings of water put forward by Indigenous scholars and elders, (ii) more-than-human conceptualisations of water in social theory, and (iii) an overview of freshwater biodiversity in India.

Water in Indigenous cosmologies and analytics

Kate Neville and Glen Coulthardt (Yellowknives Dene)[2] write that "Indigenous conceptions of water, while emanating from diverse nations, position water as part of a living planet" (2019, p. 5). This living planet is sustained through a web of relations, whereby water supports and is supported by many more-than-human persons. Deborah McGregor (Anishinaabe) presents an Anishinaabe perspective on water:

> "To understand our relationship to water, we must look at the whole ecosystem. A holistic approach is required. We must look at the life that water supports (plants/medicines, animals, people, birds, etc.) and the life that supports water (e.g., the earth, the rain, the fish). Water has a role and a responsibility to fulfil, just as people do" (2009, p. 38).

[2] In the following paragraphs I will use parentheses to mark the affiliations of Indigenous authors. For an exploration of the politics of this citational practice see Liboiron (2021, p. 3 n. 10).

Describing the devastation of fish in Alberta, Zoe Todd (Métis/otipemisiw) writes that "turning our attention to treating fish as kin and more-than-human persons we have reciprocal duties to, is a necessary step in re-orienting our relationships to land, waters, space, stories and time" (2018, p. 74). Fish kin rely on healthy water (and people rely on fish for their own health), but human alterations of waterscapes have in many cases destroyed possibilities for water to support life. Recognising reciprocal duties to fish hence reorients relations between people and waters. Tina Ngata (Ngāti Porou) connects the liveliness of water to its intelligence and communicative abilities, arguing for a style of human-water relations based on intimacy and communication:

> "Water has intelligence, comprised of its nature and the multitude of life forms within it that respond to various stimuli. Water communicates its needs to us, and our comprehension depends entirely upon the intimacy of our relationship with it." (2018, p. 23).

Developing these relations can take many forms. As Nick Estes (Kul Wicasa) argues, "resistance to the trespass of settlers, pipelines and dams is part of being a good relative to the water, land and animals, not to mention the human world" (2019, p. 21). Across these accounts of human-water relations, the presence of more-than-human beings (including water itself) is foregrounded.

Another example provides a different analysis of how relations create bodies of water. Tjipel is a young woman/coastal tidal creek in Northern Australia. In *Geontologies*, Elizabeth Povinelli (2016) recounts teachings about Tjipel passed on to her by Ruby Yilngi. One concern of the chapter where Tjipel is introduced (*The Normativity of Creeks*) is to examine how the *thishereness*[3] of Tjipel can be conceptualised:

> "Where does she begin and end – where the sands accumulate to maintain her breasts or further down shore where they drift off to sea? Are the oysters and fish and mangrove roots and seeds and humans, who come and go as do the wind and tides, karrabing and karrakal, part of her no matter where they may stretch or travel?" (p. 99).

It's not simply that water is the medium for more-than-human inhabitation, that Tjipel and other bodies of water support life. Instead, Povinelli suggests that the key is the directionality, orientation and connection of (living and non-living) entities, whereby Tjipel creates (and is created by) an

[3] *Thishereness* is a concept that Povinelli introduces in her accounts of a Karrabing analytics of existence. In quoting this term I avoid offering my own characterisation of Tjipel, for example through reaching for the terminology of assemblage. Povinelli suggests that Tjipel "shows the concept of assemblage to be a paradox" (p. 103).

"estuarine normativity" (p. 94): "Tjipel's river mutation establishes something like a norm for how other entities within her reach behave, thrive and evolve" (p. 102). "All of the entities that compose her remain oriented towards each other in a way that produces her as a thishereness" (p. 100). These orientations extend to the humans who live near Tjipel: "Tjipel and her human kin were internal to each other's arrangement" (p. 94). Ultimately, though given a sense of unity through the linguistic reference of 'Tjipel', or an 'estuarine creek', "Tjipel… does not refer to a thing but is an assertion about a set of the obligated orientations without an enclosing skin" (p. 100). Across diverse Indigenous ontologies and analytics, an understanding of water that incorporates other living beings into a web of relations and obligations is a common thread.

Relational conceptions of water in social theory

A similar notion of more-than-human relationality is taken up by Astrida Neimanis, who thinks with water to develop feminist notions of embodiment. Neimanis suggests that "bodies of water undo the idea that bodies are necessarily or only human" (2017, p. 2):

> "circulation between biospheric and geophysical aqueous bodies evidences water not only as a 'thing in itself' (lake, snowcap, drainage ditch), nor only as that which primarily comprises other bodies (swamp cabbage, human, beluga whale—all mostly water), but also as a material medium of communication… Human bodies are thus very literally implicated in other animal, vegetable and planetary bodies that in a material sense course through us, replenish us, and draw upon our own bodies as their wells. This circulation inaugurates us into complex relations of gift, theft and debt with all other life."
> (Neimanis, 2013, p. 31).

Taken together these watery relations map a 'more-than-human hydrocommons' (Neimanis, 2017). A similar notion is explored by Veronica Strang, who suggests that a re-imagined notion of more-than-human community should be the foundation of bioethical water relations (Strang, 2018). Strang proposes a theoretical model "in which humans, non-humans, and material processes engage with each other relationally" (p. 23). In this model, waterscapes constitute a "shared lifeworld" (p. 21). One of the key outcomes of such a framework is this recognition:

> "while human activities almost invariably dominate events, the non-human species and things in every shared lifeworld have a role to play, through agentive capacities of various kinds that connect relationally not just to human activities, but to the multiple processes through which social and material systems are reproduced." (p. 23)

Strang's emphasis on more-than-human relationality as key to the reproduction of social and material systems aligns with Karen Bakker's (2012) observation that water is the basis for two forms of collectivity; connecting individuals to human collectives (what Nikhil Anand (2017) refers to as 'hydraulic citizenship'), but also "linking humans so integrally to the non-human world" (p.620). This recognition gives a greater richness to waterscapes. Amitangshu Acharya suggests that attending to how "water interacts with the non-human as well as the human" enables "political ecology to move beyond generic understandings of 'nature'" (p. 376). Attending to water in this way embeds human actions and politics in a complex more-than-human world.

Approaching the life in water through aquatic ecology

Modern water may function as an abstract fluid, removing living beings from the immediate concern of dam builders, 'Integrated Water Resource' managers and other water experts, but the life sustained by water is the foundation for other domains of policy and science. Freshwater biologists and biogeographers offer a quantitative account of aquatic fauna and flora that fleshes out Strang's reimagined community. In 2008, the total number of described freshwater species globally was estimated at 125,531 (Balian *et al.*, 2008). The introduction to the book *Current Status of Freshwater Faunal Diversity in India* notes that freshwater animal species across Indian waterscapes include:

- 1027 species of fish,
- 275 amphibians,
- 243 species of birds,
- 46 reptiles (including lizards, turtles and snakes),
- 6 mammals (namely the susu (Ganges river dolphin), and several species of otter and water shrew),
- 4842 species of insects,
- 253 species of mites,
- 422 species of Nematoda,
- 217 species of Mollusca (snails as well as shellfish) and,
- 419 species of microscopic rotifers (Chandra *et al.*, 2017)[4].

These are creatures for whom bodies of water are their dwelling place, but ultimately, as the phrase 'water is life' indicates, every living organism depends upon water.

The hydrosocial remaking of waterscapes has been particularly devastating for those beings who are dependent upon bodies of water as habitat. In the context of a global loss of biodiversity – "the

[4] This list is caveated by the authors with the disclaimer that many places and groups of species have not been adequately studied. Hence, these numbers are only a low estimate.

violent displacement and destruction of earthly life in its many forms" (Theriault *et al.*, 2020, p. 898) – freshwater is an epicentre of loss: "Of the 29,500 freshwater dependent species so far assessed for the IUCN Red List, 27% are threatened with extinction" (Tickner *et al.*, 2020, p. 331). While both biodiversity and extinction are biopolitical concepts deserving of closer examination (see, for example, Yusoff, 2012; Mitchell, 2016; Povinelli, 2016; Srinivasan, 2019a) I quote these books and reports here in an attempt to translate between different disciplinary traditions. They suggest that, from an ecological science perspective, a hydrosocial approach which includes diverse living beings is simply acknowledging an integral feature of waterscapes.

However, an argument for including a richer more-than-human world in critical water research requires more than pointing to ecological facts. The key question is how other-than-human beings *matter* in waterscapes. This question of *mattering* has two dimensions: effects and ethics. Firstly, the more-than-human relations of waterscapes have diverse effects. This is not to deny that (some) humans play a dominant role in these waterscapes. However, a deeper analysis of the role of non-humans is required. This means considering how living beings bring their own intentions and capacities into waterscapes, which may run counter to the desires of constructed wetland designers, drain cleaners or local residents. More broadly, this is an argument that more-than-human relations do more in waterscapes than the tidy functionality of 'ecosystem services' or 'ecological engineering' would suggest[5]. Studying more-than-human waterscapes is about mapping the capacities that are distributed across waterscape bodies and relations. How to conceptualise, recognise and trace these capacities is the central concern of my chapter on the interpretation of water quality changes. In examining both water quality and multispecies habitability, I argue that a significant material concern arises from how more-than-human relations entail a shared yet uneven corporeal vulnerability. The close examination of constructed wetland life in this thesis illuminates the complex effects of other-than-human life in waterscapes.

An ontological re-evaluation – such as that described by the concept of a more-than-human waterscape – is incomplete without a corresponding emphasis on ethical mattering (Srinivasan, 2022a). The three ways of figuring more-than-human waterscapes described above offer different perspectives on more-than-human ethics: whether in terms of the unethical violence of extinction, or the situated relationships of obligation described in Indigenous scholarship and taken up by Neimanis (2017) in their more-than-human hydrocommons. This thesis takes up these questions of

[5] For a critique of ecosystem services that extends this argument see (Lele *et al.*, 2013). On ecological engineering see (Mitsch, 2012).

ethics by asking how a more-than-human account of waterscapes might reorient the notion of water justice in multiple ways.

Water materialities and qualities

Though under-examined in comparison to water flows, water quality has always been a part of critical water studies. The concept of 'water quality' indexes a broad swathe of the materiality of water. Research on water quality both reinforces the key hydrosocial insight – the co-production of water and society – and, at the same time, provides a distinct viewpoint for examining water affects, knowledge and politics. For an example with significant resonance for Indian waterscapes, Farhana Sultana's analysis of technonatures and water quality is exemplary (Sultana, 2013). Following the deployment of millions of hand pumps for accessing groundwater in the Bengal delta, widespread arsenic poisoning produced a public health crisis. Sultana emphasises that "depending on what else is present at the molecular level, or dissolved in it, or carried with it, water comes to signify very different things" (Sultana, 2013: 348). The *kharap pani* (bad water) pumped from an arsenic-rich tubewell remakes affective relations of water access, and produces multiple physiological, social and political effects. A key purpose of this analysis is to explain how technonatural assemblages are enrolled in, or subvert, processes of 'development'. It is the variation in water quality from tubewells that turns them from a successful case of development into an example of development's contradictions and shortcomings. As another example, Maria Rusca and co-authors (2017) take up the political ecology of water quality through the analysis of the production of uneven water quality in Lilongwe, Malawi. They show how a spatial differentiation in water quality is co-produced with "processes of urbanization and the production and reproduction of first and second natures" (p. 144). Rusca et al. argue that attending to water quality as well as quantity offers a better understanding of socio-natural inequalities. These political ecologies of water quality emphasise that differentiations of water quality are both material and laden with meaning. They are the fruit of social, political, ecological and geological processes, and the grounds for remaking political and affective relations.

An important thread through Rusca et al. and Sultana's analyses is the question of how water quality can be known. In comparison to water quantity, the unevenness of water quality can be less immediately apparent[6]. As a result, water quality is a productive field for exploring the politics of knowledge production. The politics of water quality is tied up in the ability to know pollution. In a 2019 report, the World Bank argues that, on a global-scale, water quality constitutes 'the invisible

[6] This is not to say that water quantity can't be a site of knowledge contestation. Consider, for example, how household water consumption is tracked and the possibilities of hacking water meters or collecting water at flow rates below what a meter picks up.

water crisis': "water quantity challenges receive a great deal of attention from the development community, but water quality impacts may be equally, or more, important" (Damania *et al.*, 2019, p. xiii). The example of lead poisoning in Flint, Michigan illustrates how even severe cases of water pollution may be rendered invisible without political contestation (Pulido, 2016; Anand, Gupta and Appel, 2018). Many water quality impacts are characterised by what Michelle Murphy (2013) refers to as 'latency', the lag time between water quality degradation and its impacts. The invisibility of water quality is also a function of the huge range of possible water pollutants: nutrients, heavy metals, novel chemicals, plastics, bacteria and viruses and more. While some of these pollutants may receive sustained attention, others go under the radar. And each potential pollutant has its own spatiality and temporality (Damania *et al.*, 2019; Liboiron, 2021). Pollutants can't be understood separately from the sensing methods that bring them to light. For example, Santiago Gorostiza and David Sauri (2017) trace how water pollution appears as a palimpsest in the Llobregat River, Catalonia. The development of new sensing technologies makes previously invisible pollutants 'appear' as political concerns. A critical account of water quality needs to account for multiplicity and complexity; and to examine how these complexities are dealt with in different knowledge formations. In chapters 5 and 6, I mobilise water quality as a location for examining how water knowledge is produced and sustained within relations of power.

Thinking with wastewater

Wastewaters are a subset of waters where water quality and other materialities are particularly significant. Influenced by global discourses of water scarcity, wastewaters take on a hybrid character: both problem and resource (Harris-Lovett, Lienert and Sedlak, 2018; Haddaway *et al.*, 2019). The materiality of wastewater is first marked by the presence of waste. As the name suggests, – and as the Bureau of Indian Standards (BIS) (1973) defines it – wastewater is "water which contains contaminating waste products" (p. 32). Given the widespread alteration of water quality across lakes, rivers and oceans, this BIS definition could be read provocatively to suggest that *most* waters are wastewaters. The ability of water to dissolve and carry away waste is necessary to maintain the order of many socio-natural arrangements (Liboiron and Lepawsky, 2022). The huge diversity of materials discarded into waters is central to the complexities of water quality.

Other ways of defining wastewater hinge on an understanding of waste as something characterised by a lack of value. For example, within the UN Sustainable Development Goals wastewater is defined as "water that is of no further immediate value for the purpose for which it had been used or produced because of its quality, quantity or time of occurrence" (World Health Organization and UN-HABITAT, 2018, p. 11). Wastewater is the result of water *use*, a transformation of water into something that is no longer (immediately) valuable. And yet, as hinted by the important caveat of 'immediate' value, notions of value are steeped in political and cultural, as well as economic contexts (Graeber, 2013; Collard and Dempsey, 2017). An interest in 'resource recovery' from wastewater has arisen within a broader discourse of so-called 'circular economies' (Gregson *et al.*, 2015; Valenzuela and Böhm, 2017; Masi, Rizzo and Regelsberger, 2018). This combines interest in water reuse (e.g. Lekshmi *et al.*, 2020), with the reframing of other wastewater materialities – such as the chemical elements used in fertilisers – as potential resources (Harris-Lovett, Lienert and Sedlak, 2018; Haddaway *et al.*, 2019). Wastewaters generate complex geographies of both hazard and 'resource' (Turner, 2016).

A more-than-human perspective offers a way to engage with wastewater beyond a simple waste/resource binary. Joshua Reno (2014) develops a 'semi-biotic' understanding of waste as a "sign or remnant of a form of life, whether human or otherwise" (p. 8), in contrast to a purely constructivist idea of waste as merely 'matter out of place' (Douglas, 1966). In this case of wastewater, such a formulation certainly aligns with how human excreta and urine are significant components of many wastewaters, both materially and symbolically. In a different vein, research in various disciplines examines how wastewater infrastructures afford opportunities for living (Park and Cristinacce, 2006; Holmberg, 2021). With their nutrients and organic matter, wastewaters can sustain or support rich (agro)ecological systems (Ghosh, 2018; Mukherjee, 2020a; Vansintjan, 2021). Alternatively, wastewaters may contain toxic chemicals, or promote toxic algal blooms and eutrophication, making water bodies deadly to many living beings (Levain *et al.*, 2020). Wastewater is ecologically more interesting than any purified potable water. The affordances and vulnerabilities that wastewaters offer for living beings make wastewaters materially significant in more-than-human waterscapes.

Wastewaters are an important but under-examined dimension of waterscapes. The critical literature on sanitation is one field where hydrosocial perspectives on wastewater are developed; even if 'wastewater' is not named as the key focus (see Gandy, 2008; McFarlane, 2008). For instance, Colin McFarlane (2008) takes 'drainage infrastructure' as a central empirical focus of his account of the historical geography of sanitation in Mumbai. In developing a framework for urban sanitation research, McFarlane (2019) notes that:

> "In many cities in the global South, and especially in informal settlements, excrement is not controlled, moved out of sight and treated, but is there in urban space, gathering in open

> drains, spilling into narrow streets and areas where children play, finding its way through insects or hands into food and water, oozing through rivers and streams in the city." (p. 1246)

This (perhaps uncomfortably explicit) sentence highlights the flows, relations and spatiality central to what has been termed 'wastewaterscape' research. Karpouzoglou and Zimmer (2016) argue that "there has been little attention by [urban political ecology] scholars to the importance of wastewater in urban waterscapes" (p. 1). They suggest that including wastewater into waterscape analyses contributes to a "full understanding" of 'socio-natural transformations' related to water (p.2). It is this fuller understanding that this thesis works towards. Wastewaterscapes are a key terrain for examining material vulnerabilities and the nexus of knowledge and power.

Water infrastructures

Waterscape research maps the social, economic, political and ideological forces that condition the distribution of water across space. Enacting this distribution is the work of varied water infrastructures: stormwater drains, dams, pipes, lakes and rivers, household water filters and wastewater treatment plants.

Studies of infrastructure – "matter that enable[s] the movement of other matter" (Larkin, 2013, p. 329) – have been taken up with great interest across the social sciences (Easterling, 2014; Anand, 2017; Hetherington, 2019; Wakefield, 2020). In much the same way that waterscape approaches have highlighted the sociality of water, these investigations approach infrastructures as "dense social, material, aesthetic, and political formations that are critical both to differentiated experiences of everyday life and to expectations of the future" (Anand, Gupta and Appel, 2018, p. 3). Many critical analyses of infrastructure have been developed through studies focused on water infrastructures. A recurring argument is that these infrastructures, while often promising universal betterment, instead generate or perpetuate differential access to water (Birkenholtz, 2013; Sultana, 2013; Anand, 2017; Anand, Gupta and Appel, 2018; Povinelli, 2021). Laleh Khalil (2021) summarises that "inequalities in the making of infrastructures emerge out of pre-existing forms of social prejudice" (para. 24). Research on water infrastructure in cities of the Global South has sought to highlight the distinctive ways in which water infrastructures are fragmented, heterogenous or in disarray (Bakker, 2003; Alley, Barr and Mehta, 2018; Niranjana R, 2021; Truelove and Cornea, 2021). At the same time, Nikhil Anand (2017) argues that water infrastructures "also divide and differentiate publics in the Global North" (p. 225). Reflecting on the recent water crisis in Flint, Nikhil Anand, Akhil Gupta and Hannah Appel (2018) argue "water infrastructure is a sociomaterial terrain for the reproduction of racism" (p. 2). Infrastructure emerges from these accounts as entangled with the constitution of modernity (Larkin, 2013; Gandy, 2014), colonialism (LaDuke and Cowen, 2020; Davies, 2021) and State power (Gandy, 2008; Meehan, 2014; Acevedo Guerrero, 2018; Uribe, 2019)). Dominant infrastructural formations create the differentiations that make certain forms of life possible and not others.

Recent scholarship on water infrastructures has also highlighted the (metaphorical) cracks in the concrete. Rather than marking a linear enactment of progress and power, water supply networks are held together through continual maintenance, tinkering and reworking (Anand, 2017; De Coss Corzo, 2019; Kemerink-Seyoum *et al.*, 2019; Silva-Novoa Sanchez, Kemerink-Seyoum and Zwarteveen, 2019). As Farhana Sultana (2013) observes, "water technologies are developed, rolled out, fought over, reformed, dismantled, and redesigned in various ways" (p. 343). Such accounts challenge a depoliticised technical framing of water infrastructures through an ontology of infrastructures as assemblages that incorporate materials, imaginaries, legal forms, and institutional structures (see, for example, Ranganathan, 2015). Beyond this, as numerous accounts have emphasised, infrastructures are thoroughly entangled with more-than-human life.

More-than-human (water) infrastructures

Maan Barua (2021) suggests that a "wider ontology of infrastructure" should account for multiple ways that infrastructures shape more-than-human life (p. 1467). Barua advances three modes of infrastructural enmeshment with more-than-human life: shaping of mobility, infrastructures as habitation, and "the rendition of non-human life itself as infrastructure" (p.1469). The fact that water infrastructures rely on life processes is not a novel proposition within the technosphere of water treatment; microbial metabolism is crucial to many treatment methods (Kadlec and Wallace, 2008; Hammer, 2013). Outside the bounds of the wastewater treatment plant, Colin McFarlane (2019) notes that "sanitation in the city is an ecology that shapes and connects different forms of life" (p. 1245). Barua concludes on a hopeful note, arguing that a more-than-human infrastructural ontology might open novel political possibilities. But other scholars have noted how the concept of 'nature' or 'ecosystem' as infrastructure is increasingly present within conservation and environmental management as a conceptual shift (and investment paradigm) that aims to 'secure human life' (Lewis and Ernstson, 2019; Wakefield, 2020; Nelson and Bigger, 2022, p. 86). These arguments point to a complex biopolitics emerging from infrastructural formations. For example, Sarah Wakefield (2020) explores a project designed to protect New York neighbourhoods from storm surges through constructing oyster reefs. In her analysis, what emerges is a double biopolitics. The oysters as infrastructures are supposed to sustain certain forms of human life, while this requires oysters to live and reproduce in a particular way. The constructed wetlands that are the focus of this thesis represent a similar enrolment of other-than-human life.

The other-than-human life of a waterscape is frequently central to infrastructural functioning or malfunctioning. As Jacob Doherty (2019) observes, "in addition to being accumulations of capital, dead labor in the Marxist sense, infrastructures are also vitally constituted by living human and more-than-human labor" (p. S321). Casper Bruun Jensen and Tora Holmberg describe more-than-human labour in Cambodian and Swedish waterscapes respectively (Bruun Jensen, 2017; Holmberg, 2021). For Jensen the multiple nonhuman beings "involved in making infrastructures, living in them, and changing them" (2017, p. 157) offer an explanation for "why the modernist dream of smoothly functioning infrastructures is so often disappointed" (ibid.). Following this thread, the biopolitical implications of infrastructure come not only from their intended function but also from infrastructural "geographies of failure and neglect", such as the mosquito outbreaks enabled by abandoned buildings (Gandy, 2014: p.5)[7]. More generally, infrastructural logics can have a powerful role in shaping more-than-human waterscapes. Atsuro Morita (2017) describes how multispecies relations between farmers and floating rice are part of the flood and irrigation infrastructure of the Chao Phraya delta in Thailand. Ashley Carse (2012) explores how the administration of the Panama Canal watershed has reconfigured this space, and the campesinos who care for it, into infrastructural components. In these examples, the drive to create infrastructures reconfigures lifeways.

A final set of examples illustrates how more-than-human infrastructures generate complex ecological, social and political effects. As Caterina Scaramelli (2019) describes in her ethnography of the Gediz Delta, Turkey, infrastructures and ecologies are "entangled and inseparable" (p. 389). Alex Nading and Josh Fisher (2020) describe trees in Managua, Nicaragua as a form of "minor infrastructure". Passed between families, mango trees stabilise soil and provide shade. They also mark family relationships and through their vitality "open up possibilities for an urban development that refuses both idealistic notions of multispecies flourishing and narrowly technocratic visions of sustainability" (paragraph. 23). Jacob Doherty (2019) uses the concept of 'animal infrastructure' to examine the lives of Malibu Storks in Kampala, Uganda. Doherty writes that:

> "Rather than romanticizing the endurance of animal infrastructures, it remains critical to ask what worlds they sustain and make possible, what regulatory norms support and undermine them, how they distribute power and precarity, what role they play in the

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[7] Also relevant here are the ecological effects of inadequate or mismanaged sanitation infrastructures (Wear *et al.*, 2021), which may generate a political force for reshaping infrastructural arrangements(see, for example, The Rivers Trust, 2020).

> reproduction of infrastructural violence, and what solidarities they engender across differences of all sorts, including species" (p. S331).

These questions – and the preceding theorisations of more-than-human infrastructures – are highly relevant for the study of constructed wetlands. First-hand observation shows that the constructed wetlands at Ibrahimpur, Berambadi and Loch Leven are constituted and inhabited by a variety of more-than-human life. In this thesis an infrastructural analytic works in conjunction with the more-than-human waterscape concept introduced previously. Such a combination resonates with Matthew Gandy's observation that "water lies at the intersection of landscape and infrastructure" (2014, p. 1). Chapters on water quality changes and constructed wetland rationale delve into infrastructural processes and imaginaries. Constructed wetlands, as a treatment infrastructure, not only move matter but also transform it. However, this functioning is complicated by the thickness of more-than-human relations (Lulka, 2009). Chapters which focus on these constructed wetlands as habitat investigate how they exceed infrastructural logics. Through tracing more-than-human vulnerabilities and the diversity of wetland life I examine how infrastructural differentiation occurs in ways that are orthogonal to infrastructural purpose. Approaching infrastructural assemblages in this multifaceted way brings questions of more-than-human justice to the fore.

Justice, power and politics in waterscapes

Water justice is plural

The struggle to fashion better waterscapes is animated by notions of water justice. Several recent works outline frameworks for water justice that can guide research and action (Schmidt and Peppard, 2014; Zwarteveen and Boelens, 2014; Boelens, Vos and Perreault, 2018; Angel and Loftus, 2019; Laborde and Jackson, 2022). These efforts begin with the acknowledgment that a "single, unitary water justice principle" (Perreault, Boelens and Vos, 2018a, p. 346), valid in all waterscapes, is the wrong approach. Justice should not be a "universal, transcendent concept" (Boelens, Vos and Perreault, 2018, p. 4). Instead, a plural vision is required. As Tom Perreault, Rutgerd Boelens and Jeroen Vos (2018) summarise water justice takes:

> "a variety of forms, from struggles over access to drinking water and sanitation; to the dynamics of water-grabbing and virtual water trade; (re)configuring hydrosocial territories; dam building and dispossession; sanitation and water pollution; contested water knowledges; and competing visions of conservation and environmental governance" (p. 346, [parentheses with chapters removed]).

These examples highlight multiple domains of contestation. Margreet Zwarteveen and Rutgerd Boelens (2014) offer a framework for analysing water justice struggles through a series of 'four echelons' where conflict and contestation can occur (p. 150):

-the *material* i.e. the distribution of water as a resource
-the *rules, norms and laws* that determine these distributions
-the *authority* over these laws, and
-the *discourses* that are used to conceptualise water problems.

Beginning with the first 'echelon', questions of distribution have rightly been a central concern for water justice scholarship. In this vein, Harris et al. (2016) ground their analysis of water justice in the stark global inequities in water access and quality. To describe the effect of inequitable waterscape power relations, critical geographers commonly use the concept of *unevenness* (see, for instance, Meehan, 2014; Budds, 2016; Taylor and Bhasme, 2021). An *uneven waterscape* is a common summation (for example, Truelove, 2011; Sultana, 2013, p. 348; Rusca *et al.*, 2017). This unevenness signifies unjust distributions of water and sanitation infrastructure. How are such inequitable distributions generated? Harris et al. (2016) highlight gender inequities as well as colonial and racial legacies as factors in these unequal distributions. Unevenness may be the result of elite or capitalist interests, with links to Marxist analyses of uneven development (Smith, 1984). Recognising unjust distributions is an entry point to considering overlapping hierarchies of power.

And yet, a focus on distribution may be too narrow a frame to capture a full picture of water justice (Jackson, 2018). It is promising that several explorations of water justice take up models from social and environmental justice scholarship. These go beyond distribution to consider three dimensions of justice, adding participation and recognition to the mix (Schlosberg, 2004; Fraser, 2010; Harris *et al.*, 2016; Jackson, 2018)[8]. Here, the other echelons proposed by Zwarteveen and Boelens (2014) are brought into the picture; a just form of participation redistributes authority and reshapes rules, norms and laws.

What remains less emphasised within water justice frameworks are the historical grounds for unjust distributions (as well as unfair procedures and absent representation). Reflecting on this starkly differentiated hydraulic citizenship, Elizabeth Povinelli (2021) asks "how might our response to water

[8] However, the suggestion made by Harris et al. (2016) that these dimensions of justice could be addressed "most readily" (p. 12) through participatory processes deserves further scrutiny (cf. Hickey and Mohan, 2004; Povinelli, 2021)

justice appear if we began in and never left" the grounds of racial and colonial histories? (p. 27). The unequal material distribution of access to safe water can only be understood through histories of colonial exploitation. Urban as well as rural waterscapes still bear the influence of colonial planning priorities (Gandy, 2014). As Astrida Neimanis (2017) summarises, "coloniality courses through the flows of water justice" (p.172). What if unjust water distribution was seen as a part of ongoing 'ancestral catastrophes' of capitalism and colonialism? (Povinelli, 2021). Responding to water might require reparations and numerous forms of decolonisation, that reshape every echelon of watery relations.

Water justice is multispecies justice

Earlier in this chapter I conceptualised water as a sustaining constituent of more-than-human relations. Based on this, I argued that water infrastructures and waterscapes could be viewed as multispecies assemblages. This framework suggests a need to think more broadly about the subjects of water justice. The nascent concept of multispecies justice offers some suggestions as to what this might involve. Danielle Celermajer and colleagues (2021) highlight several key features of this paradigm. Firstly, extending justice beyond the human means "radically rethinking the subject of justice" (ibid., p.8). To consider this question properly requires more than just including individual plants, animals or other beings, but also to ask whether the (mythical) 'individual' might be displaced by other collectivities (see Haraway, 1991, 2008, p. 11, 2016). Secondly – and related to the models of justice discussed previously – multispecies justice requires reworking the "grounds and role of recognition" (Celermajer *et al.*, 2021, p. 9). How might other beings and collectives evoke recognition? And how might we attune ourselves to recognising them? Finally, multispecies justice requires a comfort with difference, in contrast to the liberal concept of justice marked by universalism and equality. Indeed, Celermajer et al. (2020) suggest that working towards multispecies justice requires "deconstructing and decolonizing liberal hegemony" (p.11). Perhaps one of the most significant barriers that impedes multispecies justice is an ideology of human exceptionalism: "the premise that humanity alone is not a spatial and temporal web of interspecies dependencies" (Haraway, 2008, p. 11). Human exceptionalism combines ontological and ethico-political claims that sublimate the interests and wellbeing of other-than-human beings (Srinivasan and Kasturirangan, 2016). Multispecies justice scholarship rejects human exceptionalism on both levels.

While work that uses the term 'multispecies justice' has developed within particular academic contexts, there is an abundance of other scholarship that centres more-than-human relationalities within ethical frameworks. Janae Davis, Alex Moulton, Levi Van Sant and Brian Williams (2019) argue that ideas of multispecies justice are nothing new to "the numerous Black, Brown, and Indigenous peoples who have, for many years, advanced non-binary conceptions of the human–nonhuman relationship" (p. 10). One example of these concepts is found in work that builds on Sylvia Wynter and Katherine McKittrick's explorations of plot ecologies (Wynter, 1971; McKittrick, 2013). Davis et al. (2019) write "it is within the plot that we find relational modes of being, multiple forms of kinship, and non-binary ways of engaging the world that foster ethics of care, equity, resilience, creativity, and sustainability" (p. 8). Mythri Jegathesan (2021) centres these Black feminist literatures while considering the interspecies relations of plots tended by landless, minority Tamil plantation residents in rural Sri Lanka. However, while this kind of generalisation is generative, these histories should not be folded into generic articulations of more-than-human justice: "it is absolutely crucial to recognize that the ethics of the plot are forged in and articulated through grounded racial–political struggles" (Davis et, al. 2019, p. 8). In another vein, anarchist political philosophers and movements also develop concepts of multispecies justice, challenging hierarchies of speciesism or anthroparchy in the name of 'total liberation ecologies' (Springer, 2021). These diverse traditions articulate visions of multispecies justice grounded in particular theoretical influences and, more significantly, in situated histories.

Water politics in many places already strives for justice for the other-than-human beings living in and around water. Indigenous conceptions of water as the basis for reciprocal obligations, as explored earlier, are a clear example of this (McGregor, 2009; Todd, 2018; Estes, 2019). In this vein, Astrid Ulloa (2020) suggests that the struggles of Wayúu people against the Cerrejón coal mine in La Guajira, Colombia are an example of a relational water justice that is cognisant of the rights of human and nonhuman beings. To take another example, Caterina Scaramelli's research in the Gediz Delta in Turkey suggests that political disputes can be viewed through the lens of contrasting moral ecologies: "people's notions of just relations between people, land, water, and nonhuman animals, plants, buildings, technologies, and infrastructures" (Scaramelli, 2019, p. 389). As part of their exploration of water justice, Zwarteveen and Boelens (2014) argue that a fourth dimension – on top of the three-fold scheme of distribution, participation and recognition – is required for water justice. "Given the life-securing and life-threatening nature of the resource and its embeddedness in delicate and dynamically shaped socio-natural environments… a fourth sphere of water justice struggle may be referred to as 'socio-ecological justice'" (p. 147). However, beyond linking this dimension of justice to the contested concept of socio-ecological integrity (Rohwer and Marris, 2021), there is little exploration of what this concept might involve. My sense is that more-than-human concepts of justice have not been adequately incorporated into hydrosocial research. But the examples above suggest that seeds of multispecies justice might already be present in these waterscapes.

Keeping justice open

The preceding sections have offered a variety of ways that (water) justice might be conceived. While this may frustrate a universal understanding of justice, it allows us to understand justice as an open and performative concept. Irina Velicu and Maria Kaika (2017) think with the Rosia Montana anti-mining movement in Romania in order to develop a "post-foundational" account of justice, drawing on the political philosophies of Rancière and Derrida. The key insight here is to avoid any predefined and generalised idea of what justice is. They instead recognise justice as 'a transformative act, as an open egalitarian socio-environmental ideal that needs to be re-negotiated, re-embodied and performed" (p. 306). Rather than a set of principles to be logically devised, justice is a 'permanent invention' (Balibar, Mezzadra and Samaddar, 2012; quoted in Yaka, 2019). Velicu and Kaika hence point to the "insufficiency of construing justice only in terms of recognition/participation, fair distribution or basic human rights" (2017, p. 307). Özge Yaka (2019) finds a similar renegotiation of justice at play in struggles to protect more-than-human waterscapes in Turkey. Yaka draws upon Derrida to describe a tension between 'emergent' dimensions of justice and "historically given regimes of justice" (p. 354), a tension that is "performed by the claims of those whose experiences of injustice are not represented by existing regimes" (p. 354). We might say that this version of justice is political rather than philosophical.

These theorisations can be fruitfully compared to Zwarteveen and Boelens' distinction between 'formal justice' and 'socially perceived justice' (2014: p. 147). While open conflict and powerful social movements struggling for water justice receive a significant amount of attention in water research, the authors note that "most injustices occur in less spectacular ways and involve more subtle and long-winding processes of struggle" (p. 152). Hence, any formal definition of water justice is a mechanism of closure which may overlook struggles for justice.

At the same time, a significant implication of this theorisation of justice is that some ideals and performances of justice may clash with an emancipatory or democratic vision of waterscapes. One example from within the hydrosocial literature is Eric Swyngedouw's argument that 'hydro-social justice' was a powerful metaphor during the Franquist dictatorship in Spain. This was an ideal of justice enacted through the construction of concrete dams and other Modernist schemes (Swyngedouw, 2015). Swyngedouw argues that hydro-social justice played a role in "[holding] together the heterogeneous alliance upon which the autocratic Franquist political project was secured and solidified" (p. 34). In a similar vein, Harris et al. (2016) observe that claims of equity have been part of the argument for water privatisation. This is based on the idea that greater efficiencies will allow for more widespread (and hence more just) infrastructure coverage[9]. These examples suggest the need to recognise multiple coexisting ideas of justice in any (land or) waterscape. For example, Kristina Lyon's (2018) ethnography of farmers and ecologies in rural Colombia highlights how "everyday practices of ecological repair enact multiple, even incommensurable, variations of justice" (p. 421), taking place alongside political mobilisations and compensation claims. Liboiron et al. (2018) argue for "multiple forms of local, low resolution, uneventful, uneven, frustrated, desireful, ethical, appropriated and incommensurate forms of justice" (p.343). Multiple enactments of justice reside in the fabric of everyday life.

This thesis navigates varied forms of justice performed around these constructed wetland projects. The initial concept for this research was to investigate the 'multiple benefits' generated by these constructed wetland projects. In this framing, the distributional dimension of justice was foregrounded. However, my analysis suggested that the ethical issues in these waterscapes extend well beyond questions of distribution. Further, as Deborah Bird Rose (2007) observes, "distributive water justice rests implicitly on the premise that water is a resource to be managed" (p. 15). This paradigm denies the "living presence" of water (p. 15). Rather than following a distribution (or distribution-participation-recognition) approach, this thesis is oriented by a desire to develop articulations of multispecies water justice. This concept is a connecting thread through the thesis, whether I am examining water quality, wastewater transformations or wetland habitability. Following this thread involves asking what forms of multispecies justice are already present in these waterscapes, but also what is overlooked due to human exceptionalism. I also consider how to approach water justice in the wake of capitalism and colonialism. This includes engaging with Indigenous scholarship on water, Indigenous critiques of water quality approaches and colonial histories of water management and knowledge. Situated explorations can help to identify widespread forms of injustice, and steer towards just waterscapes.

Theories of power and politics

Achieving water justice requires political action that recognises and reconfigures power relations. It is helpful to be specific here about how I understand power and politics. These are both terms which generate significant debate in social theorising (Lukes, 2004; Li, 2019; Allen, 2021). As Stephen Lukes (2004) observes, debates about the appropriate definitions of power and politics are themselves a form of political contestation. We might also ask whether foregrounding the more-than-human

[9] However, as the authors summarise, "numerous case study examples have shown that the equity outcomes have frequently not been borne out" (p. 13).

within waterscapes alters how power and politics are conceptualised. My effort to theorise these concepts flows from the empirical context of the three waterscapes I studied.

Political ecology scholarship offers several typologies of power, drawing from broader social and political theory (Ahlborg and Nightingale, 2018; Svarstad, Benjaminsen and Overå, 2018). These typologies acknowledge that there are "deep, widespread, and seemingly intractable disagreements over how the term should be understood" (Allen, 2021, sec. 1). Amy Allen (2021) offers a simple categorisation of power theories, dividing them between action-theoretical conceptions and broader systemic or constitutive conceptions (para. 4). The differences between these concepts can be illustrated by using them to explain how constructed wetlands came to be present at each location.

An actor-oriented approach holds that power is something that actors exercise. Power marks the capacity to act (Ahlborg and Nightingale, 2018). Constructed wetlands at Ibrahimpur, Berambadi and Loch Leven represent the (relationally enacted but still individual) capacities of engineers, panchayat officials and other politicians, project funders and labourers. Their actions designed, approved and built the wetlands. Central to this view of power is the recognition that power is unevenly distributed. This requires understanding how each actor's power is constrained or enabled by the structures they are part of (Svarstad, Benjaminsen and Overå, 2018). Another characteristic of this exercise of power is that it enables these actors to enact their will even in the face of resistance. Such an actor-focused view links power to the concept of *agency* (ibid). Perhaps it could be argued that the wetland plants and microbial communities exercise their own (admittedly less-powerful) forms of power in enacting the wetland. Yet more-than-human scholarship suggests that rather than a broader distribution of (individualistic) agency, a more productive analytical approach is to shift power from particular actors to constellations of relations (Bennett, 2009; Abrahamsson *et al.*, 2015; Lemke, 2018)[10]. Feminist theory has been crucial for developing a relational understanding of power (Ahlborg and Nightingale, 2018, p. 385; Allen, 2021).

Further displacing individual actions, systemic concepts of power focus on historically established social structures which constrain and to some extent produce agency (Svarstad, Benjaminsen and Overå, 2018). Within political ecology, Marxist theories of power are highly influential (ibid.). Rather than simply mapping the capacities of individual actors, this approach to power asks us to consider

[10] Here it might also be helpful to consider Lukes (2005) insight that what is conceived of as power will be a subset of a broader web of relations through which people are always affecting and being affected (p.30). A useful definition of power points to the socially/politically significant relations in this broader web of interaction, within a particular context.

how, while making these wetlands, the actors mentioned above were working within the structural bounds of capitalist and state relations. In this view the wetlands are not merely the product of a particular exercise of agentive power. Instead, they can be understood as supportive of attempts to realise value within agricultural landscapes; a process driven by market relations and reliant on an adequate quantity and quality of water for irrigation. Systemic concepts of power focus on how "broad historical, political, economic, cultural, and social forces enable some individuals to exercise power over others" (Allen, 2021: para. 4).

Finally, some conceptualisations treat power as more diffuse and elusive. Such approaches to power often take inspiration from the work of philosopher Michel Foucault (Svarstad, Benjaminsen and Overå, 2018). For instance, power may be located in discursive formations[11]. Returning to our question of how constructed wetlands came to be built at each site, we might instead focus on the nexus of knowledge and power which generates and sustains discourses of constructed wetlands as a desired infrastructure. Attuning to this constellation – global in scope and developed over decades – dislocates power from any specific actor. Alternatively, constitutive analyses of power may foreground various mechanisms of government. Power here refers to the multiplicity of governing logics (discipline, 'truth', neoliberal rationalities, sovereign power) which combine to shape human subjects, land and waterscapes. In this account, constructed wetlands serve as infrastructural tools to enact Development (Deb, 2006; Srinivasan, 2022b) as well to ensure a "proper" relation between human subjects and the environment (Ahlborg and Nightingale, 2018). This theorisation of power highlights the "constitutive relationships between power, individuals, and the social worlds they inhabit" (Allen, para. 5).

Svarstad et al. (2018) and Ahlborg and Nightingale (2018) argue that holding different theories of power in tension can be analytically generative; "human agency and constitutive power are always in interplay and tension in complex and dynamic webs and networks consisting of humans and non-humans" (Ahlborg and Nightingale, p. 387). Taking the presence of a constructed wetland as an example demonstrates the utility of working between different notions of power. Structural and constitutive analyses of power support efforts to map power across different scales (Svarstad et al., p. 355). Actor-focused conceptions bring into focus specific more-than-human relations. Finally, it is important to realise that – however it is conceptualised – power is also limited, and produces contradictory effects (Ahlborg and Nightingale, 2018; Joronen and Rose, 2021). As the following chapters will show, the power to construct a wetland doesn't automatically entail control over how this infrastructure reshapes water quality and multispecies habitability.

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[11] Analyses of discursive power may also draw on Gramsci (e.g., Mann, 2009), Said (1978) or Lukes (2005).

Shifting from power to politics, the first thing to highlight is that my research methods did not bring to my attention any significant conflicts or contestations occurring around these wetlands and wastewaterscapes. At one point, I was told, farmers at Berambadi had demolished an earthen dam constructed on the authority of the Panchayat. This exception serves to highlight the lack of other contestations. Drawing on Jacques Rancière's political philosophy, Eric Swyngedouw and Henrik Ernstson (2018) argue that contestation, the attempt to remake relations, is the definition of politics. "The political is understood as forms of acting subtracted from or excessive to what is gestured to hold socio-ecological constellations together" (p.5). Politics is an interruption, an act of disruption. By this metric, the events that I attend to in these waterscapes fall beneath – or at least outside – the terrain of politics.

One way to interpret this state of affairs is through the notion of depoliticisation; the process of rendering issues as merely 'technical' (Li, 2007)). Political ecology has consistently emphasised the injustices created when the arrangement of land or waterscapes is depoliticised (Heynen, Kaika and Swyngedouw, 2006; Chhotray, 2011; Budds and Sultana, 2013; Swyngedouw and Ernstson, 2018; Aijaz and Akhter, 2020)). Jessica Budds and Farhana Sultana (2013) argue that "deficiencies and interventions in water-related development endeavours emerge from the fact that they are typically framed, analysed, and addressed in a technical manner, with insufficient regard for the politics that configure these processes" (p. 276). Expertise functions as an important driver and stabiliser of depoliticisation. Expertise, in Tania Murray Li's phrasing, "constitutes the boundary between those who are positioned as trustees, with the capacity to diagnose deficiencies in others, and those who are subject to expert direction" (2007, p. 7). The result of such boundaries can be, as Dhrubajyoti Ghosh terms it, 'cognitive apartheid' (Ghosh, 2014). Timothy Mitchell argues that attempting to claim the power of expertise goes hand in hand with creating "simple forces and oppositions" (Mitchell, 2002, p. 34). Such simplification is hence an enabling condition for depoliticisation. Given the multiplicities and complexities of water, a critical perspective on expertise affords opportunities for repoliticisation.

We might ask if the idea of politics as a disruptive event might overlook certain forms of political action. As Elizabeth Povinelli (2021) suggests, political theory is becoming attuned to "newer [accounts] that stress the quasi, micro-, and slow nature of political power" (p. 19). These "new modalities and dimensions of political eventfulness" (p.19) suggest that events do not need to be spectacular (or even perceptible) to make a difference. Max Liboiron, Manuel Tironi and Nerea Calvillo's (2018) description of toxic politics – the politics of living in a world saturated by toxicity –

proceeds from the corresponding idea that there are different 'genres' of political action. Viewing politics only as a matter of capturing social power risks missing politics as a "precarious and pragmatic achievement" (ibid., p. 337) built upon "slow, intimate activism based in ethics" (p. 331). Such forms of politics are often particularly significant in the wake of colonial and capitalist catastrophes (M. Murphy, 2017). Politics, in these accounts, is a more capacious and everyday concept.

A touchstone for this notion of politics is the connection between politics and ethics. Feminist scholars have argued that questions of ethics and justice should be approached not as abstract moralising but through the situated ethical doings and obligations that generate or sustain social worlds (Watts, 2013; Tsing, 2014; de la Bellacasa, 2017, pp. 132–150; Liboiron, Tironi and Calvillo, 2018; Lyons, 2018). Following Caterina Scaramelli (2019), we could say that waterscapes are 'moral ecologies' where the political and ethical are intertwined. In this form, politics is at root an attempt to realise ethical ideals (Liboiron, Tironi and Calvillo, 2018). Such a vision also sees politics as worked out through more-than-human relations[12]. This understanding of politics as always ethically laden, and occurring across a range of genres and scales, suggests that, while there might not be explicit contestation, there is a wealth of political action going on in these waterscapes. The coupling of ethics and politics suggests that developing rich ideas of water justice goes hand-in-hand with the repoliticisation of waterscapes.

Coda: the power of concepts

This chapter has developed concepts of a more-than-human waterscape and water justice. In doing so I am motivated by a pragmatist understanding of the ability of concepts to make or remake worlds (Povinelli, 2021, p. 130). My theoretical framework is oriented towards a normative interpretation of waterscapes, rather than following an approach which – drawing upon a different semantic meaning of theory – foregrounds causal explanations (Abend, 2008, pp. 178–181). Such a position has resonance with David Harvey's classic description of 'revolutionary theory' (Harvey, 2016). Harvey argues that "our thought cannot rest merely on existing reality. It has to embrace alternatives creatively" (ibid. p. 32)[13]. This thesis is shaped by my personal commitment to a more-than-human water justice. In developing my theoretical framework, I am driven by a conviction that theorising water differently is required.

[12] This is not to say that 'politics as excess' doesn't also have the capacity to consider other-than-human beings and forces as politically significant (see Bennett, 2009; Booth and Williams, 2014).

[13] Harvey emphasises that propositions and theoretical structures are not inherently revolutionary (or counter-revolutionary or status-quo upholding). Their position within this categorisation depends on their use in a 'particular social situation' (ibid., p. 35)

3 Methodology: Positioning more-than-human water research

Positioning myself as a researcher

In this chapter I approach research methodology as a process of positioning myself in relation to people, places, methods, disciplines, and knowledge formations. The interpretations and arguments offered in this thesis are moulded by the relations that orient me. Reflexivity about personal positionality is integral to qualitative social research (Tracy, 2019). Similarly, one of three key tenets of critical physical geography is that "the same power relations that shape the landscapes we study also shape who studies them and how we study them" (Lave, Biermann and Lane, 2018, p. 5). A critical reflexivity of how I was situated within power relations – and how this shaped the research – is necessary. This is particularly important for research conducted in a foreign context. As Edward Said writes, there is no vantage point "free of the encumbering interests, emotions, and engagements of the ongoing relationships" between cultures (Said, 1989, p. 216)). Finally, beginning this chapter with my own positionality serves to introduce myself to readers of this thesis (Liboiron, 2021, p. vii).

A key aim of this thesis is to challenge human exceptionalism and include other-than-human beings in concepts of water justice. To narrate this appreciation for more-than-human worlds, I could begin with a childhood on a farm in Aotearoa New Zealand. The ecological methods that I use within this research are in some ways a continuation of childhood projects of climbing trees and raising tadpoles.

Attention to colonial histories – in Aotearoa New Zealand and more widely – helped me to place this interest in multispecies flourishing within a broader critique: colonialism and capitalism continue to undermine the possibilities for living well anywhere on this earth (Moore, 2015; Sultana, 2022). In pointing to these forces, I am not working from a position of innocence; I continue to benefit from their (mal)distribution of resources and orderings of sensibility. Whiteness and masculinity lend me authority within racialised, patriarchal societies, whether that is India or the UK. At the same time, they deaden my sensitivity to some social dynamics.

A concern for waterscape injustices – the inequitable distributions of water and sanitation in particular – was one of my motivations for studying civil and environmental engineering at the start of my academic journey. My familiarity with hydraulic and ecological engineering was beneficial for approaching the technical dimensions of constructed wetlands in this research. I also found that it fostered good relations with project staff at Ibrahimpur, who trusted me to understand their work. This status aided in getting support during the research and conducting fruitful participant observation. While visiting the constructed wetlands in Berambadi and Ibrahimpur I was part of the 'project team'. When interviewing or simply speaking to local people, this connection brought with it a varied mixture of obligations, frustrations and hopes which influenced how these relations developed.

As I travelled to Ibrahimpur and Berambadi for only short periods during this research, I was unable to develop the language and cultural competencies to make sense of many social dynamics. Not speaking local languages is a serious issue for engaged qualitative research. This meant that project staff had a role as gatekeepers shaping what research was possible at each site. These dynamics precluded developing research objectives together with local people, making my research predominantly extractive.

At the Scottish research site, the residents' association were my contact point. They had the final say on research methods. However, I continued to develop lines of enquiry based upon my own research interests and desires. Hence, while the power relations were quite different, there were still broad similarities in how I positioned myself as an external researcher.

These reflections provide some indication of my personal positionality in this research project. At the same time, I concur with Gillian Rose's arguments about the impossibility of a "transparently knowable self and world" (Rose, 1997, p. 314). As Rose puts it "reflexivity may be less a process of self-discovery than of self-construction" (p. 313). While a full understanding of how my positionality shaped the research process remains an impossible task, this partial account provides important contextualisation for the research methodology.

Introducing and positioning case-study locations

Ibrahimpur

Though the waterscapes of Uttarakhand have been associated with flooding and hydropower development in the mountainous terrain of the Himalayas (Agrawal, 2013; Kala, 2014), Ibrahimpur is part of the Haridwar district, on the Ganges plain. The hydrosocial history of Roorkee – the nearest city to Ibrahimpur – begins with British colonial efforts to increase agricultural production in the

‘United Provinces’ of British India (Imperial Gazetteer of India, 1909, p. 138; Lucassen, 2006). The significance of irrigation in this region partly stems from patterns of monsoon rainfall. According to National Institute of Hydrology data, 83% of rain falls during the four months from June to September (Goyal and Singh, 2018); outside of these times, rainfall is limited. The Ganges canal, opened in 1854, flows through Roorkee, on its way to irrigate land in Uttarakhand and Uttar Pradesh. Many of the surrounding villages were established by labourers who came to build the canal, a history recounted to me by Ibrahimpur residents. The Engineering College established alongside canal construction is now the Indian Institute of Technology Roorkee. In 1978, the National Institute of Hydrology (NIH) was also established in Roorkee, a research organisation under the Ministry for Water Development (currently Ministry of Jal Shakti) (*National Institute of Hydrology*, no date). Today, through a complex confluence including the increasing pressure on farmers (Narasimha Reddy and Mishra, 2010; Nielsen, no date), the complicated politics of water governance (Mukherji, 2006) and the availability and affordability of electric pumps (Birkenholtz, 2009), the Ganges plain is an area of groundwater depletion (Castellazzi *et al.*, 2018). In this context, as part of their outreach activities, NIH conducted a ‘water conservation’ study in the Ibrahimpur-Masahi panchayat area[1]. Following on from this, NIH designed and built a constructed wetland, referred to in NIH reports as a ‘Natural Treatment System’. Elected local panchayat leaders supported this work. The Ibrahimpur wetland comprises a concrete settling chamber, and a triangular wetland section, filled with stone and bricks sourced from local factories and planted with canna lily (*Canna indica*). The wetland intercepts flow collected from drains in the village, and discharges water into a village pond.

Census statistics for Ibrahimpur and the neighbouring villages provide glimpses of broader waterscape dynamics. Data on water and wastewater from the 2011 census suggest that the main source of drinking water for almost 90% of Ibrahimpur-Masahi panchayat households is a hand pump. Interviews with Ibrahimpur households suggest that tubewells are now more common than this data suggests. Both tubewells and handpumps pull up water from various depths, with deeper pumps viewed as having better water quality. Once the water is used, according to statistics, 72% of households discharge wastewater to ‘open drainage’, and 27% have no drainage. Open drainage, judging by my observations, refers to an arrangement where water is channelled through the courtyard of houses into ditches along the side of the roads. The constructed wetland built by NIH is one of many small alterations that have shaped the wastewaterscape at Ibrahimpur.

[1] The gram panchayat is the lowest level of decentralised governance in India. Following the 73rd constitutional amendment in 1992, gram panchayats have authority over budgets within their area. As Fischer and Ali (2019) explore, the relation between Gram Panchayats and civil servants within regional development offices varies significantly.

A handover ceremony in November 2018 was my first encounter with the Ibrahimpur project[2]. During my visit in November 2018, I joined NIH staff, district politicians and local people for a ceremony including a round of speeches, the recitation of the Clean India oath and a visit to the newly built wetland. My engagement with this project reflects ties between researchers in India and the United Kingdom, and between the worlds of research and 'development'. In 2015 the UK government announced an increase in funding for 'Official Development Assistance (ODA) research' (*ODA research and innovation and NERC*, 2016). Researchers, including environmental scientists, could access funding for projects that would work in 'developing countries' in the name of sustainable development. One of these projects, SUNRISE[3], included sub-components across eight countries in Asia and Africa, and spanned topics of water and land management as well as air quality. In India, this project included research collaborations related to 'sustainable water management'. This work established connections between researchers at NIH and the UK Centre for Ecology and Hydrology (UKCEH) (Sarkar and Dixon, 2021).

Berambadi

At Berambadi, Karnataka a similar collaboration took place, but with a different cast of actors. The Scottish Government has, since 2012, developed a water resources strategy framed by Scotland as a Hydronation (Muscatelli, McKee and McGivern, 2020). Aligning with a stated desire to be 'good global citizens' (and political manoeuvring towards Scottish independence) the Scottish government also administers an International Development Fund (*International development*, no date). The Berambadi constructed wetland project sits at the intersection of these two policies. Water researchers at the James Hutton Institute in Scotland, working in collaboration with Indian partners from ATREE[4] and the Indian Institute of Science in Bengaluru, developed a proposal that was funded by the Hydronation International Programme (*Scotland-India research collaboration delivers clean water for primary schools*, 2018). The Hydronation program also provides funding for PhD scholars. A PhD proposal to combine findings from both Ibrahimpur and Berambadi was the genesis of my research.

In Berambadi, a pair of small constructed wetlands was designed and installed at the village school, as part of a newly developed sanitation system. Berambadi village lies within a catchment that has previously served as a case study location for hydrological research (see, for example, Buvaneshwari

[2] In describing the Indian constructed wetlands as 'projects', I am drawing on the work of Tania Murray Li (2007). I explore this 'project model' in more detail in chapter 6.

[3] In the best natural science project naming traditions, this is an abbreviation: Sustainable Use of Natural Resources to Improve human health and Support Economic development

[4] The Ashoka Trust for Research in Ecology and Environment, an independent research organisation in Bengaluru

et al., 2017; L. Collins *et al.*, 2020). These research activities set the stage for the school sanitation project, where the aim was to build a new toilet block and treat the wastewater produced. Funding for this project came from the Scottish Government, while the support of the local panchayat authorities and school administrators in the district was a necessary condition for this work. The team of researchers and engineers designed an interlinked set of components including rainwater harvesting and storage, greywater treatment and recycling, solar-powered pumps, septic tanks and two constructed wetlands. These wetlands were constructed as concrete tanks, filled with gravel and then planted with canna lily.

According to the 2011 census, Berambadi has a population of 2,982 people. As mapped by the project team, residents belong to the Lingayat caste, various scheduled castes, or scheduled tribes[5]. These different groups form segregated communities within the village. As at Ibrahimpur, agriculture is a major livelihood activity. Farmers pump water from the underlying aquifer. For drinking water, most households are connected to a piped supply. Census statistics indicate that in 2011, 82% of households in the wider Berambadi panchayat had a tap water supply, while hand pumps and tubewells were the main water source for the remaining 18% of households. The piped supply at Berambadi comes from a mixture of borewell water and water from a reservoir on the Kabini river. Compared to Ibrahimpur, Berambadi has a more comprehensive network of open concrete drainage channels. Because of the topography many of these channels are blocked with silt and filled with stagnant water, algae and plants.

Loch Leven

In the Loch Leven catchment in Scotland, UK, a constructed wetland was built as part of the enabling infrastructure for a new residential development of a dozen houses. The wetland was required in order to obtain planning permission for the development. The Perth & Kinross Council Local Development Plan (Perth & Kinross Council, 2014) explains that Loch Leven "has been degraded over the last 150 years by the addition of phosphorus through human activities" (ibid., p. 197). The council has introduced policies to reduce phosphorus, including a requirement to mitigate 125% of the phosphorus load from new developments (SNH, SEPA, Perth and Kinross Council, 2016).

The wetland was designed by a Scottish company that specialises in treatment wetlands. Wastewater from each house first flows to a rotating baffle treatment unit, which has an outflow to the constructed wetland. The wetland has two rectangular polythene-lined 'cells' planted with a

[5] Scheduled castes are designated as marginalised and have reserved places in education and government employment.

variety of wetland plants. Water then flows into a trapezoidal area which is planted with different varieties of willow. This system was designed to evaporate most of the wastewater that flows into it.

I found this constructed wetland because a colleague at UKCEH was aware of the site through ongoing research in the Loch Leven catchment and was able to introduce me to one of the residents. Due to the limitations on travel imposed by Covid-19, this site was important for several research methods that could not be implemented at other sites, particularly concerning constructed wetland habitat.

The methodological logic of case study research

Case study research is a typical approach to research in human geography and political ecology (Gomez and Jones, 2010; Bryant, 2015; Perreault, Bridge and McCarthy, 2015). The methods used within case study research are typically a mixture of interviews, document analysis and observations or 'ethnography' (Yin, 2017; Hitchings and Latham, 2020). Multifaceted engagement is a strength of case study methods, one that makes it well suited to hydrosocial research (Wesselink, Kooy and Warner, 2017). Case study research uncovers dynamics that are obscured by engaging with water issues on a larger scale. For instance, research in Mumbai has linked water and sanitation issues to political and social dynamics (Gandy, 2008; McFarlane, 2012; Anand, 2017). Focusing on one or several case studies allows for the development of rich narratives.

Case study methodologies capture the specific and contingent attributes that make each case unique, while pointing to some patterns and processes that extend beyond the case. This is a tension that case studies must balance. There are compelling arguments for greater extension of case study findings (Castree, 2005) but also for resisting the abstraction that turns places into cases (Kanngieser and Todd, 2020). Such a balance is particularly important for research such as mine which works across multiple cases.

I selected my cases based on a shared set of characteristics. The most obvious connecting thread across these three wastewaterscapes is the presence of constructed wetlands for water treatment. Another connection point is that these are three rural waterscapes. This is not to deny the huge differences between rural India and Scotland. However, rurality influences how wastewater relates to a broader waterscape. Matrices of rural land use are also significant when thinking about constructed wetlands as habitat. Finally, all three constructed wetlands are characterised by limited institutional oversight, as well as limited expert operations and maintenance. Designers were engaged during the building phase but maintenance (or lack of) is now solely up to the school, panchayat or residents' committee. None of these groups have specific expertise in managing water infrastructure. While this may seem unusual, it is characteristic of many smaller water infrastructures, perhaps more so in rural areas. Another commonality of the two Indian case study locations is that both projects integrated infrastructure design with the production of scientific knowledge. It is for this reason that I focus on these two sites specifically in the water quality knowledge chapter. These commonalities allow me to develop arguments across multiple cases.

While common threads connect these cases, I draw on specific cases to develop particular analyses or highlight certain issues. Different cases offer some points particularly strongly. This depends on the specificities of each site and the methods that I was able to use at some sites, and not others. For example, in exploring the interpretation of water quality changes, I turn to a paper published as part of the Berambadi project. In detailing ecological relations within the wetlands, the Loch Leven site has a richer dataset due to more frequent visits to this site. Juanita Sundberg's (2011) work on US-Mexico border regions offers an example of a similar layering of case studies. Weaving these cases together also required following threads that span different spatial and temporal scales. For example, understanding the politics of water quality knowledge required zooming out to look at how Indian water quality regulations were developed. From there I moved to examining the development of water quality regulations in early 20th century England and the United States. This approach to working across scales is reminiscent of the 'chains of explanation' approach in political ecology (Lave, 2015). The purpose of multiple case studies in my research is not to produce comparison-generated theory. Such comparative case study research is rare in social sciences of water (Wescoat, 2014). Instead of contrasting cases, I weave them together to produce richer analyses of water quality and constructed wetland habitat.

Benefits, justice and an evolving research process

The central concepts and questions of this thesis developed over time, in an iterative process of research and reflection. This research project began in October 2018. I made an initial visit to both Indian wetland sites the following month. I was at each wetland site for only two days, with a few more days interacting with project partners outside of this time. At the beginning of the research a key framing was the concept of multiple benefits. This concept was central to the research proposal developed by my supervisors before I began the thesis. Such a framing aligns with a common discourse around nature-based solutions more generally (Liquete *et al.*, 2016; Kirsop-Taylor and Russel, 2022).

Digging into waterscape scholarship suggested to me a focus on process rather than static conditions (Swyngedouw, 1996). Following this line of thought, I decided that rather than aiming to measure multiple benefits a more interesting and rigorous research approach would investigate the social and ecological processes that produced benefits. Framed in ANT-inspired terms, I was interested in which actors and processes need to be coordinated to bring benefits to light. This framing guided much of my method planning.

Based on my initial field visits and literature I narrowed down a set of 'benefits': water quality, resource production (aquaculture and wetland vegetation), water conservation, cleanliness, and habitat. This list reflected a combination of the benefits identified by the project team, by people living around the wetlands or, in the case of habitat, my own normative judgement. My second field visit was in May - June 2019. I spent one week at Berambadi and two weeks visiting Ibrahimpur. Around the time of this trip I was working on mapping the processes and more-than-human actors that were connected to each benefit. This process mapping was not exhaustive. Instead, I selected key processes, then considered which methods could provide an understanding of each of these processes. For water quality my mapping included processes as diverse as water creating preferential flow paths and government agencies defining water quality standards. Importantly, I came to understand these processes as material-semiotic (Haraway, 1988; Lien and Law, 2011; Law, 2019). In other words, the benefits that I had identified were enacted both materially and symbolically. This intentionally broad understanding of 'process' pushed me to work across disciplines and methods.

Following my second visit to Indian case study sites, I began looking for a Scottish constructed wetland site to add depth and contrast to my research, given the limitations of remote fieldwork. After finding a site, I began research there in February 2020. I then made another trip to India in February-March 2020, spending two weeks around Ibrahimpur, and three weeks in Bengaluru, with 5 days spent at Berambadi. Further trips to India were intended but were not possible due to the COVID-19 pandemic. Hence, the total time spent at the Indian research sites is quite limited. This was partly due to travel restrictions, but also reflected the fact that local partners could not support longer visits. When UK fieldwork became possible again in August 2020 I resumed monthly water quality sampling at Loch Leven, continuing until September 2021. I also made one additional Loch Leven visit in December 2020 to assist with the coppicing of the willow. Beginning in the spring of 2021 I added several ecological sampling methods to this monthly sampling.

As I developed a richer understanding through field visits and social and ecological research, I realised that my process maps and research findings did not point towards the straightforward production of benefits, but instead to a more political and contested terrain of material change and meaning-making. Simultaneously, to do justice to their complexities, it was necessary to reduce the number of focal benefits: water quality and habitat emerged as key topics. Improving water quality was the central aim of the constructed wetlands. My focus on habitat reflected both a significant impact of the wetland for local people and a topic aligned with my interest in more-than-human geographies. The various methods described in the next section explore processes broadly related to these two areas. At a certain point, the tidy unity of 'benefits' gave way to other key themes, arguments and ideas, such as the politics of water quality knowledge and of more-than-human vulnerability. What bridges these ideas is the concern for more-than-human water justice, as described in the previous chapter.

Mixing methods for hydrosocial research

In working across the themes of water quality and wetland habitat, this thesis uses a range of methods. This section explores the methods used, dividing them following the thesis structure[6] to show how I drew on different methods in response to different research questions. The combinations of methods across different chapters are summarised in Table 3.1. Following on from the description of each method I offer more general comments on my approach to qualitative analysis. I then consider how this mixed method approach might be situated in relation to interdisciplinary research and more-than-human geographies.

[6] Except for Chapter 4, which has its own method section due to the distinct methodology used there.

Table 3.1: Methods summary by chapter

<table>
<tr><th>Chapter</th><th>4: Constructed wetland rationale</th><th>5: Water quality knowledges</th><th>6: Water quality interpretation</th><th>7: Diversity</th><th>8: Vulnerability</th></tr>
<tr><td>Site focus</td><td>Literature focused</td><td>Indian sites only</td><td colspan="3">All sites</td></tr>
<tr><td rowspan="6">Methods</td><td>• discourse analysis of literature</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="4">• group interviews with residents
• project team interviews
• participant observation
• secondary data from project reports and CW literature</td></tr>
<tr><td></td><td colspan="2">• water quality analysis</td><td></td><td>• water quality analysis</td></tr>
<tr><td></td><td></td><td>• waterscape mapping
• flow and conductivity measurements
• tracer experiments</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>• bird, insect and vegetation surveys
• wildlife camera surveys</td><td></td></tr>
<tr><td></td><td colspan="4">• qualitative ecological observation</td></tr>
</table>

Methods to explore water quality knowledge

Chapter 5 asks how water quality is known in these waterscapes and examines the history and ethical implications of these practices. My methods for this chapter span from environmental science methods to social and qualitative analyses.

Water quality testing

In this thesis, water quality testing is both a method and an object of analysis. At Ibrahimpur and Berambadi, members of the project teams did the sampling methods and shared their results with me. This was the only feasible approach at these sites. At Loch Leven I collected samples myself. At all sites, samples were collected approximately monthly for around one year. Samples were taken at different points within the wetlands (see figures below) and tested for a range of parameters. Table 3.2 provides the technical details of the water quality sampling methods at each site.

Table 3.2 - Details of water quality sampling

Category	Ibrahimpur	Berambadi	Loch Leven
Sampling locations	Four sampling locations, shown in Figure 3.1 below. Samples collected by filling a plastic bottle with a surface sample. Samples analysed in the NIH laboratory.	20 sampling locations, shown in Figure 3.2 below. Two parallel wetlands, each with two lines of perforated standpipes, which allow sub-surface samples to be collected within the wetland. For analysis the standpipes at the same distance along the assumed flow path are combined as a single 'row'. Samples were chilled and transported to ATREE laboratory for analysis.	Sampling from standing water in the end of the septic tank and in manhole 1 and 2, as shown in Figure 3.3. When the willow cell of the wetland was overflowing, surface samples were also collected at the overflow point. On two occasions, I also collected samples of the groundwater that was seeping into wetland cell 2. Loch Leven samples were collected in plastic bottles and transported back to UKCEH where they were filtered and frozen for later analysis.
Sampling dates (see Figure 3.4 *below)*	Sampling from November 2018 - June 2019. At this point the wetland was flooded by monsoon rains. Flooding was recurrent after this point, including outside of the monsoon. As a result, water quality sampling was only possible at the inlet to the grit chamber and in the pond.	Sampling over one year beginning December 2018. There was a break in April-May 2019, corresponding with a school holiday period in which no wastewater was generated.	Samples were collected monthly from August 2020-September 2021. On the 9th-13th August 2021, used an ISCO autosampler to collect samples every 30 minutes, which were combined into 2-hour composite samples. These summer dates were chosen to capture the highest activity of the wetland plants.
Testing parameters	Water samples were collected and analysed by project partners (NIH and ATREE) at the Indian sites. For both wetlands, testing included analysis of organic matter, nutrients and pathogens. The analyses used standard methods as set out by the American Public Health Association (2005). A summary of the significance of the various water quality parameters is provided in Table A.0.1. Table A.0.2 describes the testing methods in more detail.		Samples were analysed for nutrients and carbon only. Nutrient reduction was the (legislated) water quality purpose of this constructed wetland, and laboratory equipment for other tests was not readily available. Test methods were conducted on the SEAL-AQ2 and TOC-TN analysers.
Data quality	Less opportunity to ensure quality for data I did not collect myself.		Data quality assured through following standard methods under the supervision of laboratory staff and checking calibrations and blank samples.
	Data cleaning and removing outliers was part of the analysis process. For further validation, I checked the sensibility of my results and conclusions with those knowledgeable about water quality.		
Data analysis	Water quality data was analysed using RStudio. Paired t-tests were used to determine if differences between water quality at the inlet and outlet of each constructed wetland were significantly different than zero, with samples paired by date. Data was first tested for normality using Q-Q plots and the Shapiro-Wilk test. Non-normal data were transformed where appropriate using Box-Cox transformations. All charts in the thesis were prepared by the author.		

Figure 3.1 - Sampling locations at Ibrahimpur wetland. The codes in this figure are also used in charts in following chapters. gc_in: entrance to the grit chamber, gc_out: exit of the grit chamber, inlet to the wetland, cw_out: exit of the wetland into the pond.

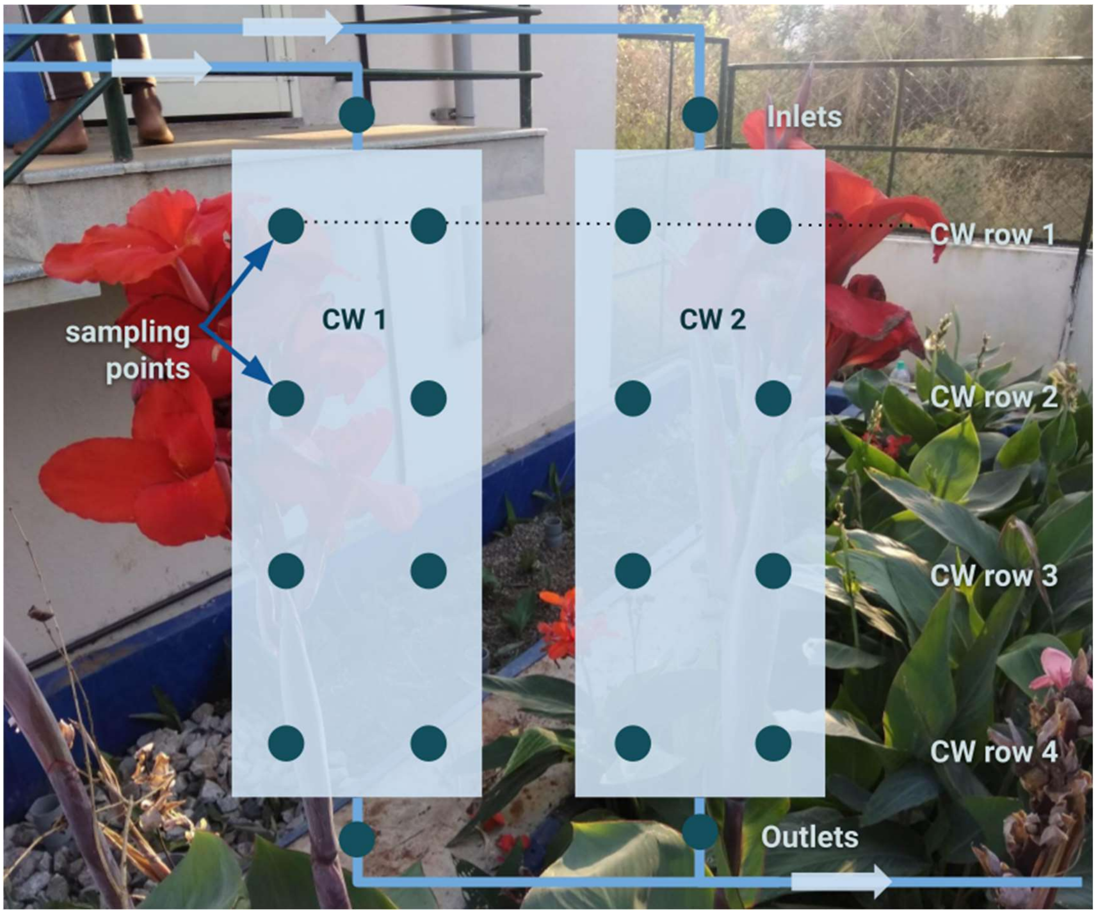

Figure 3.2 - Sampling locations at Berambadi wetland

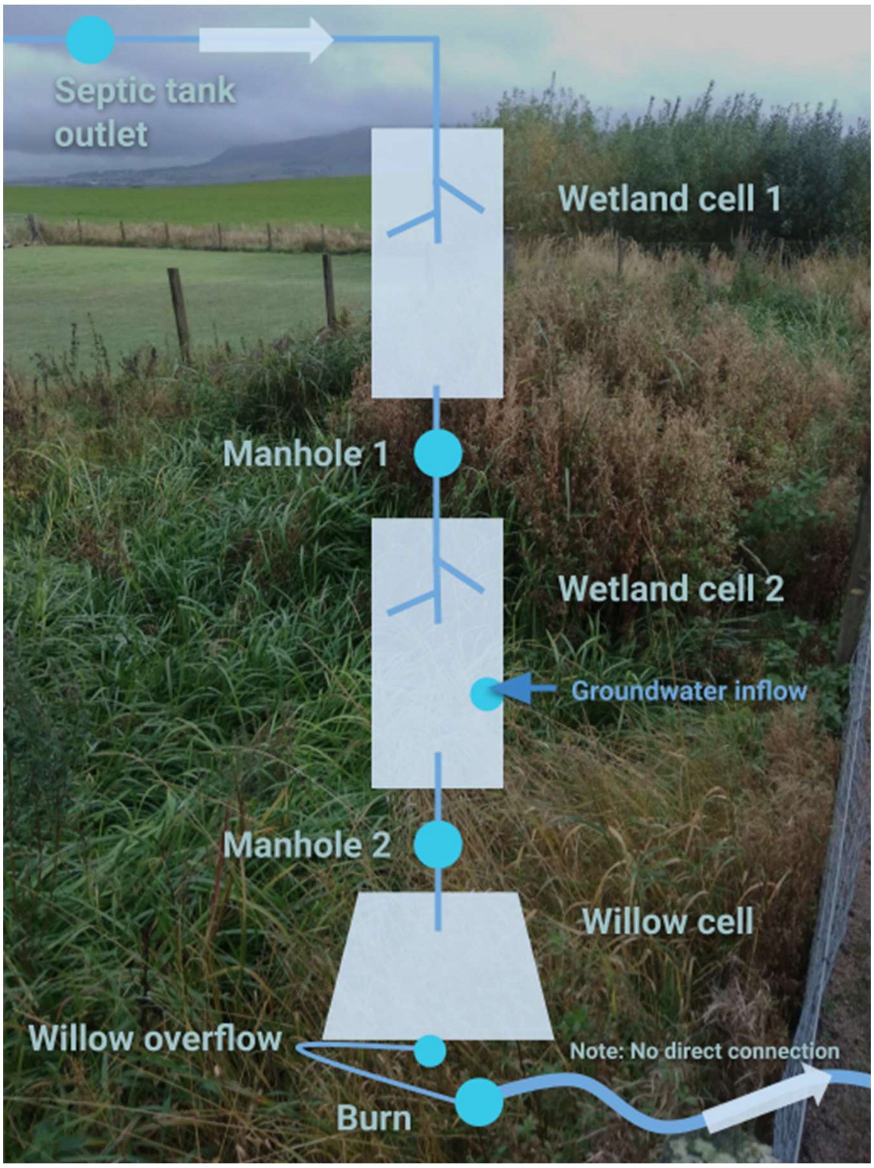

Figure 3.3 - Sampling locations at Loch Leven wetland

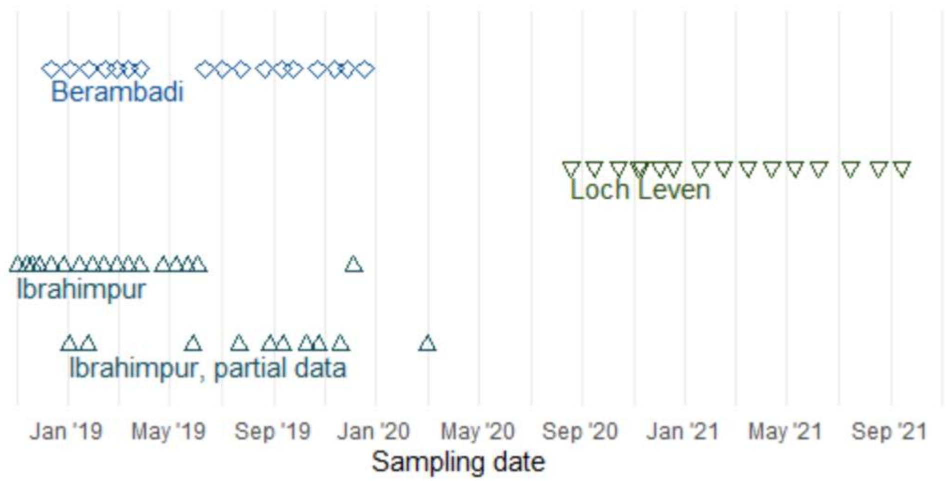

Figure 3.4 - Sampling dates at the three wetlands. 'Ibrahimpur, partial data' indicates dates where only 2 locations were sampled due to unintended flooding of the wetland.

Social research on water quality

Group interviews

Water quality knowledge is not only produced through technical sampling methods. To gain some insight into local understandings of water quality I conducted group interviews at Ibrahimpur and Berambadi. Group interviews were used as participants were more comfortable being interviewed in a group and were free to join or leave the conversation as they wished. For these reasons, I judged this format to be most appropriate and ethical for the context of the study sites. This approach is similar to focus group methods (Vissandjée, Abdool and Dupéré, 2002; Liamputtong, 2011), but I describe them as group interviews as there was a limited amount of interaction between participants. Interviews were convened in households, although they often included neighbours or interested people passing by.

Figure 3.5 - A group interview at Ibrahimpur. Photograph by the author, 2020.

The aim of these interviews was to explore the quality of the water that people used, either in their household or in the fields. For this reason, the connection or attitude of each household to the constructed wetland project was not significant. Sampling was based on a spatial sampling across the village, which, given the segregation of Berambadi and Ibrahimpur also ensured that respondents from different castes were interviewed. As they were in households, most interviews had a mixture of men and women, although some interviews with groups of farmers were only men. A local volunteer associated with the panchayat assisted with arranging interviews in Ibrahimpur.

While we collectively identified households to interview, this gatekeeper position may have led to some households or participants being excluded or choosing not to participate. In February and March 2020, I conducted nine interviews in Berambadi and eleven in Ibrahimpur. The number of interviews was determined by judging saturation, when further discussions were not adding more detail (Guest, Bunce and Johnson, 2006; Tracy, 2019). Because of the group interview format, the total number of participants is an estimate, but approximately 30 people were involved in discussions at Berambadi and 40 at Ibrahimpur. The people engaged in discussion tended to be older, with younger people being less likely to participate[7].

Discussions took place in Hindi (Ibrahimpur) and Kannada (Berambadi) and were facilitated by Indian research partners at each site[8]. A topic guide was used to structure the interviews. This is reproduced in Appendix II. Interviews were recorded, after consent was obtained from participants. The University of Stirling general university ethics panel approved the topic guides, recording and consent processes. Transcripts were translated into English by those who conducted the interviews. This translation process led to some simplification and loss in the nuance of the conversations, but this was a necessary compromise. Some simultaneous translation also took place during the interviews to allow me to ask follow-up questions. Notes made during the interviews were used to supplement the transcripts during analysis. Details of my qualitative analysis process are discussed in a separate section below.

Observation: participants and processes

Conversations with the project teams, and observations of their work, showed me the diverse ways that water quality was being evaluated in these projects. I consider this data generation to be a form of participant observation[9]. To record these insights, I wrote field notes at the end of each day. These were analysed alongside interviews.

Project team interviews

To give further depth to my analysis, after field visits I arranged six online interviews with members of the Berambadi project team at different institutions in Scotland and India. All members of the project team were invited to an interview, but not everyone responded. Due to their reduced ability

[7] This perhaps reflects cultural norms concerning who is encouraged to speak in different contexts (Vissandjée et al. 2002)
[8] This arrangement means that these interviews were seen by participants as a way of communicating with the project teams that built each constructed wetland. As a result, I felt I had a responsibility to pass on some of the issues raised in these conversations to senior project staff. I did this through a summary report.
[9] I am avoiding the term ethnography following with the distinction between ethnography and participant observation made by Tim Ingold (2017).

to join online interviews, as well as language barriers, I did not arrange interviews with Ibrahimpur project members. These interviews covered topics related to water quality (see topic guide in Appendix II). Interviews were transcribed and coded. To validate my findings, I presented my results back to project teams, in a summary document, and asked for feedback if they had concerns.

Secondary data

Secondary data was crucial for both understanding how scientific teams understood water quality within the Ibrahimpur and Berambadi projects and contextualising these approaches within a broad history of water quality methods and standards. For the former, I drew upon project documents including reports and scientific articles written by the project teams. These are detailed in Appendix IV. For the broader analysis of water quality, I used a range of sources including academic texts, and Indian government standards and legislation, these are cited as relevant.

Methods to explore the interpretation of water quality changes

Chapter 6 asks how changes in water quality are interpreted, and the political consequences of different interpretations. I first examine the models for interpretation used within the Berambadi project, before developing my own interpretation. This analysis drew on a variety of methods. I conducted further analyses with the water quality data whose generation was described in the previous section. I combine these findings with results from hydraulic methods, qualitative research and secondary data.

Hydraulic methods for water quality interpretation

Hydraulic methods were used to understand how water moved through each wastewaterscape and wetland. An understanding of water flow is crucial for interpreting changes in water quality. I carried out waterscape mapping, tracer tests, inflow measurements and measurements of hydraulic conductivity.

Mapping

Waterscape mapping at Berambadi and Ibrahimpur was carried out to understand wastewater flows at the village scale. I walked every road in both villages, making this similar to a transect walk method (for example, Paasche and Sidaway, 2010). On a set of printed satellite images, I annotated the location of wastewater drains or surface flows on either side of the road and the direction of flow (see Figure 3.6). I also made notes on wastewater blockages, stagnant water, and plants or sediment filling the drains. These maps were digitised in QGIS and used to delineate and measure the area of wastewater catchments.

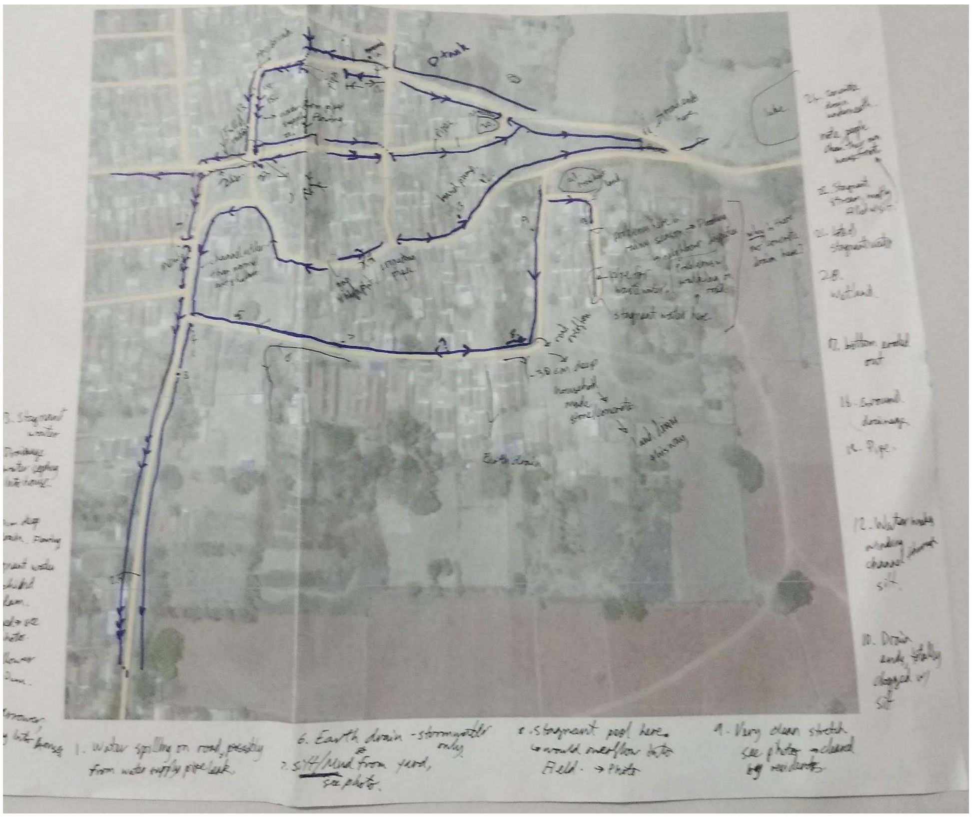

Figure 3.6 - Sample data collection sheet for waterscape mapping. Photograph by the author, 2019.

Tracer experiments

Adding a chemical 'tracer' to water flowing into the wetland and then measuring the concentration of this chemical compound in the outflowing water over time reveals flow patterns within the wetland, and indicates hydraulic problems, such as short-circuiting of the flow. I conducted tracer experiments at both Berambadi and Ibrahimpur. Methods for tracer study experiments and analysis given by Headley and Kadlec (2007) were the key reference for planning these experiments. At Ibrahimpur and Berambadi an NaCl (i.e. table salt) tracer was used, this allowed for the instantaneous measurement of tracer concentration using Electrical Conductivity (EC) as a proxy. NaCl was mixed with water to dissolve it fully and then poured into the wetland at the inlet at Ibrahimpur. At Berambadi it was poured in at the first sampling points to allow quick diffusion through the depth of the wetland. The concentration of salt used was calculated based on a balance of several factors. Firstly, I needed concentrations that stood out above the background EC values. On the other hand, high concentrations raised ethical concerns of harm to wetland plants and other life due to high salinity. Excessive concentrations of salt would also interfere with the experiment by making the salt water denser than the rest of the wastewater inflow.

Conductivity sampling was conducted with a Hach probe at regular intervals after adding the tracer. At Ibrahimpur, the tracer test started at 6am on day one (11 June 2019) and continued until 4pm on day three (13 June 2019). Conductivity was measured at both the inlet and outlet every half hour during the day, then hourly between 10pm and 6am. During the night, there was sometimes zero flow into and out of the wetland, so sampling was not possible. At Berambadi sampling was more intermittent. The experiment started at 9am, and EC measurements were taken at 10am and 2pm on day one (18 February 2020) then 10am, 12pm and 6pm on day two, then 9am and 1pm on day three. To account for vertical stratification of water, EC was measured at three depths in each row of sampling points in both Berambadi wetlands.

This method was developed in response to the constraints on time and materials in this research. Tracer methodologies include validation procedures (Headley and Kadlec, 2007). Based on these metrics, I judged my results to be unsuitable for determining residence time. High and fluctuating background EC concentrations at both sites added significant uncertainty to these results. A method using a different tracer or more intensive sampling over a longer time period may have provided a more rigorous understanding of how water flowed through each wetland. However, I was still able to use my data to call into question assumptions about the flow that could not be squared with tracer results. Their quality was adequate for this purpose.

Flow measurements

Inflow measurements show how wastewater flow to the wetland fluctuates. Measurements were taken at Ibrahimpur throughout the tracer experiment. Inflow was diverted through a length of pipe and collected in a container of known volume. The time taken to fill the container was recorded for three fillings. The key quality aspect for this method was ensuring that sampling intervals were frequent enough to capture highly variable flows. For this reason, more frequent sampling was used during the morning period of high flows. Flow was measured hourly at the inlet, and half hourly for the morning period of highest flow (6.00am to 9.00am). At Berambadi, flow measurements were conducted by the ATREE team, by emptying the outflow sump and recording volume accumulated the following day. These measurements were made on the 27-28 November (Weds-Thurs) and 16-19 December (Mon-Thurs) 2019.

At Loch Leven the arrangement of pipes and manholes meant that measuring flow rates was not feasible with the time and equipment constraints of my research. This was a significant limitation for my water quality sampling, as it meant that water quality results could only be expressed on a concentration rather than load basis, this adds a layer of uncertainty to the interpretation of results. It would have been better to establish this limitation during site selection, and to have chosen a different wetland where flow sampling was possible.

Wetland conductivity

Another method to explore flows of water is to test hydraulic conductivity: how easily water can travel through the wetland media. I tested vertical conductivity in the Ibrahimpur and Berambadi wetlands using the falling-head method described in Pedescoll et al. (2009). A plastic pipe was dug into the wetland stones to a depth of 20cm. Water was poured in to fill the pipe to a height of 1m above the wetland surface. The intention was to measure the rate of decrease of water level in this pipe as water infiltrated into the surrounding media. However, the results at both wetlands were outside the range of conductivity that could be measured in this way. At Berambadi the rate of infiltration was too rapid to be recorded. In contrast, vertical conductivity at 20cm depth was negligible at the Ibrahimpur wetland.

Qualitative methods for interpretation

The social research component of chapter 6 rests on two of the methods already described in the "social research on water quality" section. Firstly, the insights gained through participant observation were significant for understanding how members of the project team interpreted the performance of the wetlands. Time spent at each wetland site also allowed me to make my own observations – visually and through other sensory inputs – as illustrated by some of the photos in Chapter 6. My analysis of water quality interpretation also makes significant use of secondary data. In this chapter I again refer to project reports. I also draw upon the wider constructed wetland literature, including the standard text of constructed wetland science, *Treatment Wetlands* (Kadlec and Wallace, 2008). This provided information on how these infrastructures are supposed to work and on the conceptual models that guided their design and their evaluation. When considering the ecological processes within the constructed wetlands I also utilised broader literature on plant and microbial relations[10].

Methods to explore constructed wetland habitat

Chapters 7 and 8 explore constructed wetland habitat. These chapters use a combination of social and ecological research methods. In following this approach, I am putting into practice the argument that novel methods of research and analysis are required to explore infrastructural habitat (Barua, 2021, p. 1474).

Talking to people about constructed wetland habitat

A scoping interview conducted in June 2019 with twenty households at Ibrahimpur was my first source of data related to this topic. The survey focused on impressions of the constructed wetlands

[10] I discuss the use of this data further in the 'querying interdisciplinarity' section below.

and any issues they had related to wastewater. However, many households raised issues with different animals. Selection of households was carried out to cover those both living near the pond and constructed wetland and further away. Questions were translated into Hindi with the assistance of researchers from NIH before the interviews. During each interview a translation of answers was provided to me by one member of the research team while another asked the interview questions. Written notes were recorded for answers to the open-ended questions, as the conversation was not recorded. This approach and the question guide were approved by the University of Stirling ethics committee.

The group interviews at Ibrahimpur also included a section on encounters with animals around the wastewaterscape[11]. In analysing these interviews, the location of each interview in relation to the constructed wetland was considered. Discussions about animal encounters were conducted with people living near a different wetland area in Berambadi village, and with teachers at Berambadi school. Interviews with Berambadi project members also included a section relating to the constructed wetland as habitat.

Exploring constructed wetland ecologies

Bird, invertebrate and vegetation surveys

I investigated the presence of different beings in and around the wetlands through structured survey methods. Vegetation was surveyed at Ibrahimpur and Loch Leven – at Berambadi *Canna indica* was the only plant in the wetland during all field visits. At Ibrahimpur, a record of different wetland plants was made during the June 2019 visit. This was done sporadically as different plants were seen while moving through the wetland while carrying out other methods. I used a systematic quadrat survey method during the March 2020 visit. I selected fifteen 1 by 1 metre quadrats by dividing the wetland into a grid and selecting random grid numbers. For each quadrat I recorded the plants present, the presence of open water, and the average vegetation height. A similar approach was used to survey vegetation at Loch Leven. Transect lines were used along both sides of the two wetland cells. A 1 by 1 metre quadrat was surveyed every 5 metres along each of these lines, for a total of fourteen quadrats. I conducted four surveys throughout 2021, in April, July, September and November. To validate my survey approach, a UKCEH researcher with expertise in botanical surveys joined me for one of these surveys.

[11] The topic guide for this is included in Appendix II

I carried out bird surveys at Loch Leven by recording activity within the wetland area for a 30-minute period beginning one hour after sunrise. Mornings are when many bird species are most active (Scottish Natural Heritage, 2014). From April to November 2021, I did monthly surveys. My survey protocol was developed in consultation with supervisors who have expertise in ecological science, and with reference to standardised sampling methods published by the British Trust for Ornithology (2018).

The final component of ecological monitoring was an invertebrate survey. I conducted these in April, June, July and September 2021 at Loch Leven. Three random quadrat locations were selected in each of the sections of the wetland: cell one, two and the willow section (see Figure 3.3 for location map). For each quadrat, three minutes of observation were carried out, and any invertebrates seen within the quadrat during this time were recorded to one of several categories (see Table 3.3 below). This observation approach was developed in discussion with supervisors who had experience in ecological surveying. The choice of this specific method was also guided by my decision on ethical grounds to avoid trapping insects.

Table 3.3 - Invertebrate survey categories

Categories for invertebrate survey			
1.	Ants (Hymenoptera)	2.	Small* flying insects (midges, stoneflies, Diptera <5mm)
3.	Bees and wasps (Hymenoptera)	4.	Small* non-flying insects
5.	Flies (Diptera)	6.	Spiders (arachnid)
7.	Butterflies and moths (Lepidoptera)	8.	Snails and Slugs (gastropoda)
9.	Beetles (including ladybirds) (Coleoptera)	10.	Millipedes & centipedes
11.	Bugs (including aphids) (Hemiptera)	12.	Crustacea (e.g. woodlouse)
13.	Grasshoppers (Orthoptera)	14.	Worms (Annelids)
15.	Dragonflies (and other odonata)		** Small = less than 5mm*

For both bird and invertebrate surveys my aim was to investigate the diversity of beings at each wetland. The limitation of this approach was the amount of time that I was able to spend conducting these surveys. When ecological survey methods are used to compare sites, rigour is achieved by spending the same amount of survey effort at each site. Rarer organisms are equally likely to be overlooked. As my approach was not comparative, the robustness of my findings rests on having done enough surveys. This is not easy to judge, particularly as the weather and time of day both influence the ease of observing invertebrates (Ausden and Drake, 2006). I could always have spent more time exploring and observing the wetlands. However, due to time constraints my ecological surveys were carried out alongside water sampling. Invertebrate surveys were conducted at midday, except for the July survey, which started at 9am due to a different fieldwork schedule on this day. These limitations informed how I analysed the results, avoiding comparisons between seasons. But they were also generative, as they led me to consider more deeply the absences that are always part of attempts to survey biodiversity.

Automated wildlife camera recording

To extend the breadth of wetland observation, I used wildlife cameras to capture video over several days. For this method two Bushnell *Essential E3* wildlife cameras were set up to record 30-60 seconds of video and audio at regular intervals (either 15 or 30 minutes) during daylight hours. The cameras also recorded when triggered by motion. I positioned the two cameras at various locations around the wetlands. A summary of the time periods and videos captured is given in Table 3.4. To analyse the footage, I first made notes on both the visual and audio features of each recording. From these notes I derived some quantitative information on bird numbers, but mostly focused on qualitative observations. These notes primarily focused on bird behaviour around the wetland, as smaller creatures such as insects were not easily visible on the recorded videos.

Table 3.4 - Summary of camera trap footage

Site	Recording periods	Total videos recorded
Ibrahimpur	5-9 March 2020	296
Berambadi	19-20 February 2020	248
Loch Leven	6-10 November 2020 18-22 December 2020 9-13 April 2021 13-18 August 2021	608

Qualitative ecological observation

In carrying out the survey approaches described above, I concur with the observation that, for researching more-than-human assemblages, "categorizing, naming, mapping and counting might be tools of open and careful curiosity" (Nustad and Swanson, 2022, p. 929). However, such a process still produces results which side-line more-than-human relationality. To balance this, my approach also includes qualitative and ethnographic methods inspired by more-than-human research.

My approach to qualitative observations is influenced by the development of methods within multispecies anthropology and related fields (Tsing, 2013; Geiger and Hovorka, 2015; Locke and Munster, 2015; Bastian *et al.*, 2016). While these examples provided inspiration, the rhythm of my site visits and the living beings encountered at each location also guided my approach. The central ethics of this method was an attempt not to cause undue disturbance to any of the plants or animals encountered. During this observation I frequently used a phone camera to take photos and videos. Alongside these visual methods, I also sketched maps of vegetation, wrote notes and recorded audio memos. After each wetland visit, I reviewed these varied data sources and wrote a summary.

Methods for working with video and visual imagery are a key area for development in more-than-human geography (Lorimer, 2010). Photos and videos became an important way of presenting the results of my ecological investigations, serving as an alternative to identifying plants or insects taxonomically. I don't assume that scientific names are meaningful to readers, so images provide a richer and more tangible source of information. I present visual summaries alongside written results as part of the habitat chapters.

There are several characteristics of these observation methods that are worth reflecting on. These methods privilege particular observations due to the spatial and temporal scales that are available to human observers like myself (Swanson, 2017, p. 86). My work relied upon the visibility of infrastructure afforded by constructed wetlands and open drainage systems. I was able to work within the wetlands themselves, in proximity to wetland plants and animals. Yet even when observations are possible, the interpretation of these observations raises further questions. For example, my ability to interpret the actions of birds within the wetland is limited by the fact that I couldn't distinguish between birds of the same species. This strikes me as equivalent to doing interviews but not being able to tell my interviewees apart. And yet, bird behaviours were easy to interpret in comparison to many of the insects and other invertebrates in the wetland. Making varied ecological observations generated or amplified a curiosity about different creatures and their relations. This often led me to exploring published literature on birds, mosquitoes, snakes and other creatures, both in multispecies scholarship, and ecological science. This approach has antecedents in how Anna Tsing and other multispecies ethnographers engage with natural history (Gan, Tsing and Sullivan, 2018). However, careful generalisation was necessary in applying insights from these literatures to my waterscapes. Despite its challenges, this open-ended observation played an important role in my thinking about constructed wetlands as habitat.

Habitat for/with who?

Chapters 7 and 8 are built around stories of particular plants, animals or materials; diverse stories serve to illustrate a mosaic of wetland habitation. One methodological quandary in researching more-than-human habitat is that there is an overwhelming diversity of life to be considered. Within the small space of Loch Leven wetland we may encounter a migratory bird, travelling annually between the Scotland and the west coast of Africa; an insect, hatching from an egg inside the wetland and living a life of a single season inside the wetland; or a plant, building up a rhizome within the wetland bed, sending up shoots annually. At the same time, much of this life is not easy to observe. Aspects such as the microbial or fungal diversity of the wetland were not accessible with the research methods at my disposal. My approach here has been to overlay accounts that focus on different creatures. Why did I focus on the species that I did? Within the chapter on constructed wetland diversity, I discuss plants, invertebrates and birds. Plants are often treated as foundational to habitat. Methodologically, several aspects of plant behaviour could be easily observed, and their importance for wastewater treatment meant that they could be productively discussed in social research methods. Invertebrates were chosen because observations showed they were the most numerous and diverse aspect of constructed wetland life at each wetland site. Birds were visible – and audible – at each site in ways that other animals were not, especially through camera trap methods. Bird behaviours were also easier to interpret than those of invertebrates. Finally, within the vulnerability chapter, a focus on mosquitoes and snakes comes directly from the key findings of my social research; the investigation of fences and other exclusions was developed from my observations at each site; and the focus on ammonia was a response to thinking about toxicity after reading literature on ecological traps (Battin, 2004).

Qualitative analysis approach

Qualitative social and ecological research generated textual data (transcripts, notes and extracts from publications) as well as photos and videos. Interview transcripts, observation notes and secondary data were all analysed following qualitative coding methods (Braun and Clarke, 2006; Cope, 2010; Tracy, 2019; Saldana, 2021). This analysis was iterative, with a movement back-and-forth between empirical data and theory (Gomez and Jones, 2010; Tracy, 2019). As described by Meghan Cope, "the practices of data collection and analysis can be seen as blending together, affecting each other" (Cope, 2010, p. 442). For each chapter, my arguments were developed by working between theory and empirical data.

My analytical process was facilitated by the qualitative analysis software NVivo. I developed different coding schemes for different data sources, as well as for the different focal questions of each chapter. All data were given primary coding (Cope, 2010). The next step for most of my qualitative data was to develop secondary typologies or analytical structures to guide secondary coding (Cope, 2010; Tracy, 2019). These were developed through arranging hierarchical maps (Braun and Clarke, 2006). I used matrix and crosstab queries to explore the connections between codes. The overall process aligns with Cope's explanation that "the process of developing the coding structure for your project is one that is inevitably circular, sporadic and, frankly, messy" (Cope, 2010, p. 445). A process of revising my arguments and going back to the data for inspiration continued throughout the writing of each chapter.

Querying interdisciplinarity

The mixed method approach described above might reasonably lead to the question of whether this research is interdisciplinary. In many sectors interdisciplinarity research is seen as an 'obvious good' (Barry and Born, 2013; Lave, Biermann and Lane, 2018). As critical physical geography scholars argue, all landscapes and waterscapes are inextricably 'eco-social', with social power relations being internal to their arrangement, so "it no longer makes sense (if it ever did)… to separate research on the environment into the natural sciences and the social sciences" (Lave, Biermann and Lane, 2018, p. 5). But a critique of the current arrangement of disciplines does not immediately imply that interdisciplinarity is the solution. Undoing the disciplinary separations of water research is far from straightforward (Connelly and Anderson, 2007). It shouldn't be taken as self-evident that 'interdisciplinarity' is the right way to respond to what might be glossed as 'the Anthropocene condition' (Lave, Biermann and Lane, 2018). Simon Schaffer (2013) offers a crucial historical contextualisation of 'interdisciplinarity' as a discourse: "the current discourse of interdisciplinarity relies on a disciplinary history that claims that until recently knowledge systems were organised in formal, rigid, self-contained disciplinary fields and that somehow this organisation emerged alongside the European institutional and intellectual transformations of the Age of Revolutions" (Schaffer, 2013, p. 73). Schaffer argues such discourses represent an understanding of the history of scientific disciplines limited by a colonial myopia: "in scrutinising these claims, attention to the complex paths of imperial and colonial enterprises seems indispensable" (ibid. p.73). Clearly adopting the label of interdisciplinary research will imply different things to different audiences.

Perhaps it's helpful here to explore some typologies of interdisciplinary and transdisciplinary research. Much of the contemporary hype around interdisciplinary research positions this research as essential for 'problem-solving' (Klein, 2014; Krueger *et al.*, 2016). Interdisciplinary approaches are seen to be better able to offer solutions to thorny, complex or 'wicked' eco-social problems. Another interdisciplinary logic springs from the desire to create a unified field of knowledge, transcending the borders of disciplines (Klein, 2014). This idea of interdisciplinarity as the unification or integration of disciplines aligns with the "synthesis model of interdisciplinary" offered by Andrew Barry and Georgina Born (2013). As Barry and Born note, such an approach is often assumed when discussing interdisciplinarity in both policy and theoretical contexts (Barry and Born, 2013, p. 10). However, the power relations at play between academic disciplines make achieving this kind of integration difficult.

This leads us to Barry and Born's second mode – a 'subordination-service mode' – where "service discipline(s) are typically conceived as making up for, or filling in for, an absence or lack in the other, (master) discipline(s)" (ibid., p.11). While few interdisciplinary projects would frame themselves in this way, such a mode of interdisciplinarity is common. As Barry and Born note, this subordinate role is often played by social science disciplines, bringing 'social factors' into natural science research. The third and final mode is "driven by an agonistic or antagonistic relation to existing or prior forms of disciplinary knowledge and practice" (ibid., p.12). In this case, "interdisciplinarity springs from a self-conscious dialogue with, criticism of or opposition to the limits of established disciplines, or the status of academic research or instrumental knowledge production in general" (ibid., p.12).

The choice between integrative and agnostic modes – or between interdisciplinary and undisciplined research – reflects different understandings of the role scientific disciplines play in constructing social problems and responses. If particular scientific disciplines and their knowledge practices are implicated in the creation or stabilisation of injustice, then (ant)agonism rather than integration is required. For example, the paradigms of environmental science can – through their omissions and underlying frameworks – be actively harmful (Tuck, 2009; Liboiron, 2021; Theriault and Kang, 2021). Here the motivation for working across disciplines is not that these disciplines are limited. Instead, this is a concern about instrumental knowledge production directed towards the wrong ends. Marco Armiero, Stefania Barca and Irina Velicu (2019) might describe such an antagonistic approach as *undisciplined*. Their concept of undisciplined research is not only a critique of disciplines, but of the institutions and practices of academia which perpetuate oppressions and limit revolutionary possibilities. "Being undisciplined in academia could be part of a wider societal purpose of radicalizing and transforming our way of thinking politically about the socio-ecological conditions of human and non-human existence" (ibid., para. 8).

Mixed methods and more-than-human geographies

Perhaps geography offers some sort of disciplinary home for research using such broad-ranging methods while striving for critical reflexivity? Debates about the status of geography as a unified discipline make this an unstable answer (Heffernan, 2008). However, I am buoyed by a reminder from Sarah Whatmore that "the geographical habit of negotiating different kinds of knowledge and modes of producing it remains a more important touchstone than any prescribed method or approach" (Whatmore, 2013, p. 173).

Describing my methodological approach as a more-than-human geography reflects that the literature that I have found most relevant to my methodological concerns is not framed by interdisciplinarity. A wealth of scholarship in political ecology, geography and anthropology draws on natural science knowledge and methods to develop critical accounts of changing land and waterscapes[12]. Scholars across these disciplines have argued – and demonstrated – that investigating landscapes, waterscapes and other more-than-human assemblages requires careful rethinking or reworking of conventional methodologies (Nightingale, 2003; Walker, 2005; Whatmore, 2006; Lorimer, 2010; Hodgetts and Lorimer, 2015; Dowling, Lloyd and Suchet-Pearson, 2017; Swanson, 2017; Barua, 2021; Gandy, 2022b). To take one example, Hodgetts and Lorimer (2015) suggest three areas for developing animal geography methodologies, building upon technologies developed within natural sciences: "(i) techniques for tracking the spatialities of animal culture; (ii) scientific and artistic engagements in inter-species communication; and (iii) geographic tools afforded by genetic analyses" (p. 285). For Hodgetts and Lorimer, these methods contribute to a project of "taking animals seriously as subjects and ecological agents" (p. 291), enabling (among other things) "a richer description of what is going on in diverse places" (p. 291).

Multispecies anthropology has also developed methods that extend traditional ethnographic approaches by engaging natural science knowledges and methods. Anna Tsing (2013) describes a practice of 'critical description' situated at "the intersection of ethnography and natural history" (p. 28). Tsing describes such methods as developing the 'art of noticing' (2015). Research published in the journal *Ethnobiology* shows how this approach can work towards a symbiotic relation between research disciplines (Gan, Tsing and Sullivan, 2018). However, as Heather Swanson (2017) observes, these approaches privilege certain relations and forms that are visible to researchers – perhaps with a little patience, luck or digging. Swanson argues that there is a need to go further than using scientific papers for background information or talking to scientists (or other humans) as 'spokespeople' of other-than-human beings: "multispecies anthropology requires more intimate negotiations with science" (ibid., p. 93). This thesis is an attempt at these intimate negotiations.

In these examples of more-than-human research, methods are being unwound from the disciplinary methodologies to which they typically associate. The distinction between method and methodology is key here. Methodology extends beyond the details of particular methods to include philosophical foundations – embedded assumptions about "knowledge, reality, and the role of research in society" (McKenzie and Tuck, 2016, p. 79). Such reworking of methodologies raises some dilemmas,

[12] Returning to the discussion of interdisciplinarity above, this description aligns most closely to a 'subordinate' interdisciplinary mode.

particularly when attempting to torque methods towards answering different questions (Swanson, 2017; Gandy, 2022a). Adopting natural science methods also requires reflexivity concerning the assumptions or models that accompany these methods. As Amity Doolittle asserts, "representations of [biophysical] realities must be questioned in terms of the cultural context of their production, as well as the historical and political implications that flow from them" (see also, Escobar, 1998; Paxson and Helmreich, 2014; Doolittle, 2015, p. 518). My methodology attempts to carry out this questioning, while still drawing on these biophysical methods. In doing so, I follow Doolittle, who argues that integrating "realist investigation of the biophysical environment with a critical gaze linked to structural and post-structural thinking" can be a 'productive tension' (p. 517). In light of these dilemmas, we might say that attempts to work with natural science methods constitute "methodological experiments" (Swanson, 2017, p. 94, see also Gan and Tsing, with Sullivan). Experimenting is a way to accept methodological tensions and challenges as a part of the research process, and to pull methods into novel methodological combinations.

Working with diverse methods raises the question of how different data are combined. Triangulation – corroborating findings through multiple methods – is a common approach in mixed method research (Nightingale, 2003; Tracy, 2019). However, triangulation is not the only way to work with different data sources. Instead, I share Andrea Nightingale's (2003) interest in "the silences and incompatibilities that become evident when data sets produced by diverse methodologies are brought together" (p. 80). Nightingale suggests that natural science data can be utilised in a 'non-positivist' way, by rejecting the premise that these data sets are "telling the 'real' story" (p. 86). A similar critical distance is needed for integrating findings from secondary literature (Hustak and Myers, 2012; Paxson and Helmreich, 2014; Helmreich, 2015; Despret, 2021). Rather than attempting to seamlessly mesh data, or triangulate to validate findings, my approach to combining data uses the incompatibilities and tensions between methods as an analytical tool for examining the knowledge politics of waterscapes.

Research that stretches disciplinary conventions raises the question of how to evaluate research quality. Part of the disciplining work that academic disciplines do is to determine what counts as quality research. There is a disjuncture between notions of quality based upon 'objectivity' and 'replicability' versus those where 'rigour' is derived through triangulation, participant checks or thick description (DeLyser, 2010; Tracy, 2019). Illustrating multifaceted meanings contained within 'research quality', Sarah Tracy (2019) offers eight criteria against which the quality of qualitative research might be judged: worthiness, rigour, sincerity, credibility, resonance, ethicality, significant contribution and meaningful coherence. As suggested by the inclusion of resonance and ethics in this list, determinations of quality may be aligned to the normative aims and change-making capacities of research. Marcia McKenzie and Eve Tuck suggest considering the "legitimacy of [place-based] research based on its catalytic or provocative ability to impel action and be of use" (McKenzie and Tuck, 2016, p. 157)[13]. Here research quality can only be determined through tracing the broader influence of research.

While these concepts speak the quality of research as a whole, research quality is also relevant at the level of individual methods. Gunilla Öberg (2009) suggests the following question can guide evaluation of interdisciplinary research methods: "Has the information been collected in a reliable manner and is it of sufficient quality?" (p. 410). This question is consciously chosen to be open to various disciplinary understandings of 'reliability' and 'sufficiency'. In describing each method above, I detailed the measures taken to ensure reliable results, as well as the limitations of my approaches. Many of these limitations arise from the reduced time and attention that is available to develop a method when it is part of a mixed-method approach. This was compounded by my iterative research approach (as described in the 'evolving research process' section), and the limitations on field research due to pandemic restrictions. However, a mixed-method approach makes it possible to accommodate data that has a greater uncertainty or, as in the case of conductivity, is qualitative rather than quantitative. In many cases, this data still served to highlight important incompatibilities (Nightingale, 2003). Some of the uncertainty I encountered in generating data was also analytically generative, pushing me to consider the assumptions that enabled project teams to know and interpret these wetlands. While some results may not have been adequately robust for use within different methodologies, I found them sufficient for the research questions I was using them to address.

Conclusion: knowledge making and water justice

The third tenet of critical physical geography is a reflection on the ethico-political impacts of knowledge production: "our research has unavoidably political consequences; our choice is thus not between being political or apolitical but among different possible political commitments" (Lave, Biermann and Lane, 2018, p. 5). As this chapter has argued, political commitments are just one aspect of the positioning work of developing a research methodology. Negotiations of difference are a significant part of this positioning work. This applies whether dealing with the unequal power relations of researcher and research participant, bringing together different case study locations or experimenting with combinations of methods usually associated with different disciplines. This

[13] See also discussions of 'provocative generalisability' (Fine, 2006; Liboiron, 2021, pp. 152–5)

work of reflexivity and positioning means that methodologies are just as significant to the ethics and politics of research as the conclusions that emerge from the research (Liboiron, 2021; West and Schill, 2022). The research methodology described in this chapter aims to enact as well as illuminate multispecies water justice.

4 Simple, cheap and green: Analysing constructed wetland rationale

Constructed wetlands and socio-technical imaginaries

Why build a constructed wetland? In this chapter I suggest that the answers to this question are built upon what Sheila Jasanoff and Sang-Hyun Kim (2015) call 'socio-technical imaginaries': "collectively held, institutionally stabilized, and publicly performed visions of desirable futures" (p. 4). Describing imaginaries as desirable futures points to the ethical dimensions of infrastructure making. Imaginaries are ideas about how life ought to be; they encapsulate notions of justice. By using socio-technical imaginaries as my analytical framework I also follow Jasanoff and Kim in highlighting the close connection between technologies and social life. Socio-technical imaginaries are "animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (ibid., p. 4). The logic of a particular infrastructure develops from the interplay between its properties and the socioecological context it is embedded in. Hence, examining the socio-technical imaginaries of constructed wetlands illuminates important features of (waste)waterscapes more broadly.

In this chapter I focus on one way that these 'visions of desirable futures' are performed: the rationales given to support constructed wetlands in academic literature[1]. A standard dictionary definition of rationale is the set of reasons for a particular decision ("*rationale*," no date). In our case, this is the decision to build a constructed wetland, in place of another wastewater treatment infrastructure (or nothing). For example, 'constructed wetlands are a low-cost wastewater treatment technology' is a potential rationale statement, where low-cost is the key aspect. Academic papers that present technical results from constructed wetland experiments will generally include more general statements about the value of constructed wetlands. Rather than reading constructed wetland literature for their headline conclusions, I read these general statements to discern constructed wetland rationale.

[1] In focusing on academic literature this chapter steps away from my case study sites. This reflects the context of its production: the analytical work of this chapter was completed during Covid-19 lockdowns and travel restrictions when visiting my case study locations was impossible.

Constructed wetlands rationales reflect different priorities for infrastructure, as well as the power relations that determine whose priorities are heeded. These priorities and power relations are not fixed, and so socio-technical imaginaries also vary over time and space. The socio-technical imaginaries of constructed wetlands gain broader relevance if we consider these wetlands as an example of 'nature-based solutions' or 'green infrastructure' (For a critical perspective on these concepts, see, for example Meerow, 2020; Chandrasekaran *et al.*, 2021; Cousins, 2021; Randle, 2022). Analysing constructed wetland rationale becomes an opening for exploring socio-technical imaginaries and power relations around 'Nature-based' water infrastructures.

Analysing discourses in the constructed wetland literature

Rationales as discourse

This chapter is guided by the following analytical questions:

1. Which rationales are used to argue for constructed wetlands?
2. How does the prevalence of rationales vary over time and in different world regions?
3. What sociotechnical imaginaries are these rationales reinforcing or responding to?

The suggestion in question three – that rationale might reinforce a particular imaginary – emphasises that these rationales are not isolated sentences. Instead, I understand them as discourses: communicative statements that are part of a social world and contribute to generating 'common sense'[2]. Treating rationales as discourses indicates a particular approach to analysis. First, I am not interested in assessing the validity of the given rationale. Second, following a discourse approach requires an alertness to 'silences, paradoxes and unspoken assumptions' (Secor, 2010, p. 202). The concept of discourse positions rationales in constructed wetland literature as one building block of wetland socio-technical imaginaries.

Literature collation

Through keyword searches on Scopus[3], I built a corpus of literature to review. I limited my selection of papers to the six journals that published the most papers on constructed wetlands, as well as a

[2] Within geography there are a wide range of theoretical and methodological ways to engage with 'discourse' as a theory or empirical topic (Dittmer, 2010; Mattissek, 2018; Perreault, Boelens and Vos, 2018b). This makes a definition difficult to pin down. My approach here hews closer to Gramscian rather than post-structuralist notions (Mann, 2009; Dittmer, 2010).

[3] I included alternative terms used to describe constructed wetlands. The search term used was: TITLE-ABS("constructed wetland") OR TITLE-ABS("artificial wetland") OR TITLE-ABS("treatment wetland") OR TITLE-

seventh journal (*Environmental Management*) which I chose as a quality source because constructed wetland papers from this journal were well represented in my existing reference library. The search of these seven journals gave 2,973 results.

Table 4.1 - Number of review papers in each categorisation

Region	-2000	2001-2009	2010-2017	2018+	*Total*
South Asia	2	10	22	20	*54*
Rest of Asia	13	19	21	20	*73*
North America	15	21	20	20	*76*
Other 'Global North'*	15	24	20	24	*83*
Other/multiple regions	0	7	5	2	*14*
Total	*45*	*81*	*88*	*86*	*300*

*Europe plus New Zealand and Australia.

To select a subset of these papers, I split them based on the year of publication and their geographical connections. For years I chose divisions that split the total number of papers as evenly as possible. I also subdivided papers based on a regional affiliation, including papers from South Asia as a separate category given the location of my case studies. My starting point was to take the author affiliation address for each paper. When the paper was a review paper, this was the best determination I could make. However, if the paper referred to a constructed wetland in a specific location, I updated the 'region' categorisation of these papers. This is to account for cases where, for example, a publication focused on wetlands in Nepal despite having European or North American authors[4]. Table 4.1 shows the year and region categories with the number of papers from each subset. Starting with the most-cited papers I included papers within each combination of year and region up to a maximum of 20 papers. For some subsets, for example 'South Asia before 2009', less than 20 papers were available. To this selection I also added 32 additional references from two sources: (i) grey literature such as government and NGO reports, and (ii) publications which did not meet my search conditions, but that I had previously identified as highly relevant (for example, a paper titled *Prospects and challenges for sustainable sanitation in developed nations: a critical review* (Brands, 2014)). As shown in the table below, a total of 300 sources were analysed. These are the papers that I reviewed to create a dataset

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ABS("reed bed") OR TITLE-ABS("*surface flow wetland") OR TITLE-ABS("vertical flow wetland"). Title and abstract search was used, as including a keyword search brought up papers on related topics which did not centrally engage with constructed wetlands. Checks against my reference library revealed only a few papers that would be excluded by shifting to the title-abstract search.

[4] This regional categorisation is not perfect, but I believe it best (albeit messily) categorises how these papers are situated.

for further analysis. A preliminary survey of a subset of these papers showed that rationale statements were mostly found in the introduction section. I read the introduction section of each paper[5] and imported paragraphs that contained rationale statements into NVivo.

Analytical method

My analytical method was based upon methods of content analysis (Braun and Clarke, 2006; Berg and Lune, 2017; Tracy, 2019). The first step was primary coding. I tagged pieces of text based on the arguments I judged they were making. In this step I found it important to keep an open definition of rationale. For example, a statement such as 'conventional wastewater treatment plants are too expensive' is an argument for constructed wetlands as 'low-cost' and was coded as such. As some codes emerged partway through the process, I went back to re-analyse prior data. I also used text searches to ensure that I had not overlooked instances of each code.

The result of the initial coding was a set of 197 codes. I sorted these codes into a hierarchical scheme, discarding or merging codes with only a few references. I then carried out secondary coding and memo writing. For each code, I reviewed all the references tagged to this code, and wrote memos about how this rationale was presented across the sources. Through this analysis I refined the hierarchical scheme into five key themes, each with a handful of sub-themes.

Once I had completed this coding, I could also use coding frequency as a metric to compare between themes, as well as exploring variations over time or between regions. While this partially quantitative approach is a useful component of content analysis (Berg and Lune, 2017), I did not use statistical analyses and so I refer to the relative frequency of codes cautiously within my analysis.

During the analysis each source was referenced by an index number from the initial dataset, or by a number prefixed with the letter H for those sources that I added. This reference system is used in the following sections, stated in square brackets (e.g. [247]). The full source list, which links these numbers to the papers, is given in Appendix III (this approach keeps these references distinct from other references within the chapter and thesis).

[5] For additional references, which were often structured differently, I reviewed all appropriate sections.

Constructed wetland rationales and imaginaries

Wastewater futures and constructed wetland purpose

A good starting point for examining rationale is the statements that define the purpose of a constructed wetland: wastewater treatment. For example, "[constructed wetlands] are natural wastewater treatment systems" [1219]. While definitional statements give a sense of coherence around wastewater treatment, more diverse rationales are revealed by asking what results from this treatment. Where a more specific treatment aim was given, this often either the removal of nutrients (132 references), or a more generic 'pollution' [e.g. 1219, 13]. References to emerging contaminants, heavy metals, pharmaceuticals and pathogens as specific removal targets appeared more often in papers from recent years. Some rationale statements emphasise the wide range of wastewaters that constructed wetlands can handle. This includes domestic, agricultural and industrial flows, as well as less common sources such as mining or landfill leachate.

The result of treatment may be a water that meets water quality requirements (65 references) or alternatively 'improved' [e.g. 1747, 1953] – and possibly even 'high-quality' – effluent [e.g. 11, 131]. However, a widespread (118 references) theme is that constructed wetlands provide highly effective or efficient treatment, rather than a specific treatment outcome. In this context, effectiveness and efficiency appeared to be synonymous.

Wastewater treatment was a persistent rationale across regions and time periods. This persistence indicates a broad coherence in constructed wetland socio-technical imaginaries. The 'desirable future' for which these socio-technical imaginaries aim is one where all wastewaters are correctly and efficiently treated. This places constructed wetlands within a broader wastewater imaginary, but one that is far from being realised (UN Habitat and WHO, 2021). The desire to find the right technologies to reach this vision motivates constructed wetland research and arguments. However, divergent ideas of what constitutes effective treatment suggest that this imaginary of full wastewater treatment is not as simple as it appears. The following chapters on water quality will take up this question in greater detail.

Wetlands properties and social-technical orderings

The suitability of constructed wetlands for wastewater treatment depends upon several properties of these wetlands relative to other wastewater treatment technologies. The most common code related to constructed wetland properties was simplicity. Constructed wetland literature presents simplicity as a positive feature for the design, construction and operation of constructed wetlands (see examples in Figure 4.1). Many of the statements related to simplicity are very straightforward [e.g. 1213]. The desirability of simplicity is taken as read. Accompanying the purported simplicity of constructed wetlands is the argument that they are easy to maintain and operate. This rationale is found widely across the constructed wetland literature. A closely related property is reliability. This rationale is indicated in references to these technologies as 'robust' [212] and 'stable' [241]. Another aspect of wetland reliability is their 'self-adaptive' [e.g. 1055, 328] capacity to handle seasonal or stochastic variations in the quality and quantity of wastewater inflows [e.g. 779].

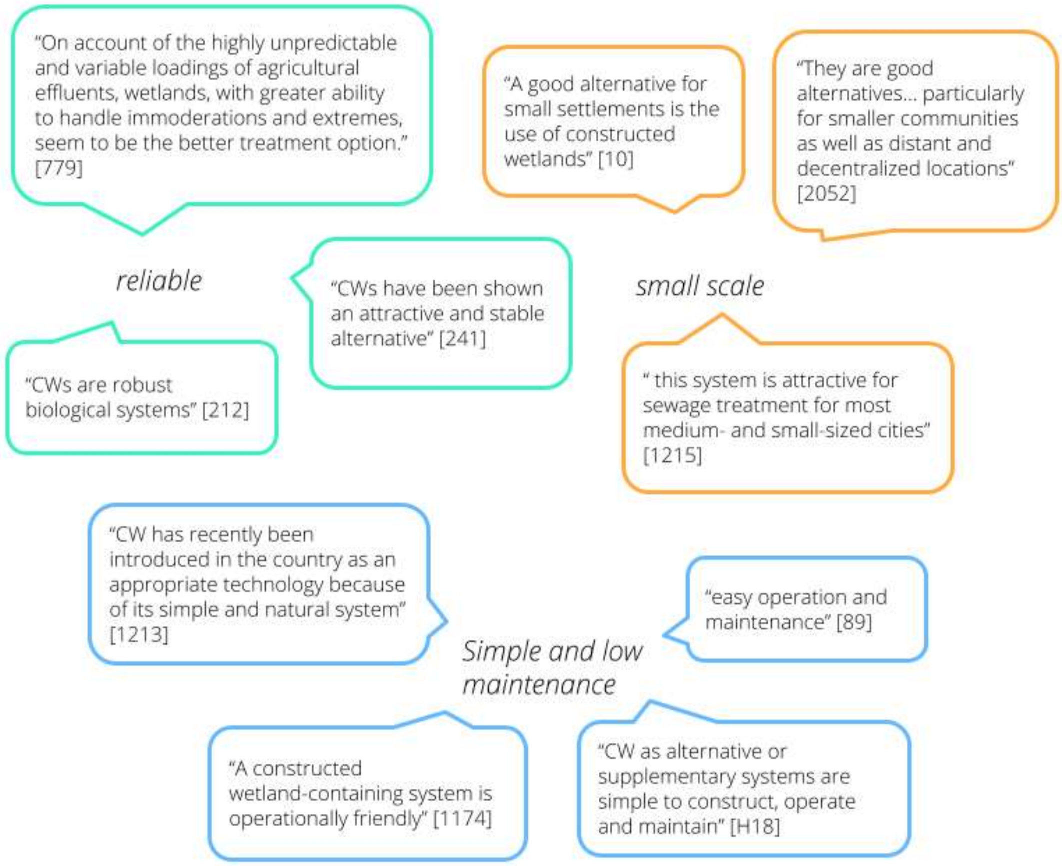

Figure 4.1 - Constructed wetland properties

Finally, a property of constructed wetlands that is also often presented as a rationale is their suitability for small-scale treatment. Several papers express this theme by referring to 'small communities' [e.g. 105, 127], but the scale here ranges from single households to medium-sized cities. The preceding properties of simplicity and reliability indicate a suitability of constructed wetlands for *decentralised* treatment, in light of the argument that 'future treatment of wastewater will increasingly require new forms of decentralised infrastructure' [1522].

However, decentralisation is a social as well as an infrastructural configuration. Avoiding bringing water to one centralisation location for treatment does not necessarily require decentralising the management of these infrastructures. While 'local ownership' may appear on the surface as democratic, it can also act as a justification for regimes of austerity. Literature on water infrastructure has argued that centralised management (see, for example, Massoud, Tarhini and Nasr, 2009) or at least 'co-production' with the State (Hutchings, 2018; Birkinshaw, Grieser and Tan, 2021) are better guarantors of ongoing effective performance. If constructed wetlands rationale blend the infrastructural and social dimensions of decentralisation, they cloud an important distinction. The implicit promotion of decentralised management aligns with other economic and social aspects of constructed wetland imaginaries, which I will discuss below. Socio-technical imaginaries can't be separated from desired 'social orderings'. A critical examination of the properties used to advocate for constructed wetlands draws our attention to ongoing disputes about the responsibilities for infrastructural care.

Constructed wetlands and ecological visions

More than half of the sources made some reference to an ecological benefit of constructed wetlands. In sum, constructed wetlands are a 'green' technology. These 'green' rationale showed a pattern of increasing prevalence in recent years (rising from 128 codes in the papers from 2001 to 2009, to 334 codes in the same number of papers since 2018). This theme maps to a set of distinct and occasionally contradictory claims about constructed wetlands and their ecological relations. The four inflections of 'green' rationale presented below suggest that socio-technical imaginaries are increasingly unsettled by an awareness of ecological catastrophe (Povinelli, 2016).

The surveyed literature often presents constructed wetlands as a green technology through arguments that they are better than alternatives [e.g. 350]. Several sources conclude that constructed wetlands have a lower environmental impact [e.g. 1818, 350, H31], or a small ecological footprint. This is often made more specific by referencing energy use. Sources that relate to wetlands as a 'low-energy' technology (69 references) are, at least partly, making an 'environmental' argument, though this can also be read as an economic or technical claim[6]. Some papers make a link to low fossil fuel use explicit [e.g. 4, 11, H18]. Papers from recent years also consider the greenhouse gas emissions of constructed wetlands. Constructed wetlands become 'low-carbon' treatment systems [621]. Discussions of energy use and carbon emissions position constructed wetlands as 'less bad' in relation to their impact on a global environment.

[6] As, for example, systems that don't require electricity can be installed more broadly.

Figure 4.2 - Constructed wetland ecological rationale

These rationales and their accompanying imaginaries deserve scrutiny on two grounds. First, presenting constructed wetlands as 'less harmful' reflects a particular 'desired future' where environmental harms are *minimised*. This sociotechnical imaginary aligns with a vision of human activities as predominantly harmful to 'Nature', a perspective that wrongly takes the exploitative nature of particular economic systems as universal (Moore, 2015). On top of this, focusing on ecological footprints, or greenhouse gas emissions, focuses questions of ecological impact only at the global scale. Accepting the rationale that constructed wetlands are less environmentally harmful on energy or 'footprint' grounds means accepting a particular vision of globalised ecological problems, causes and solutions.

On the opposite side are rationales that specify *beneficial* ecological impacts due to constructed wetlands, suggesting that these technologies are 'good for nature'. This set of rationales includes ideas such as environmental benefit through the restoration of water quality [1259] or a more generic role in protecting or conserving ecosystems [e.g. 30, 665] – including through the use of these wetlands as a buffer [e.g. 43]. One aspect of this is to position constructed wetlands as habitat (30 references), which can play a role in enhancing biodiversity [e.g. 2786, 584]. This idea of wetlands as habitat, and its link to the concept of biodiversity is something I will return to in chapter seven.

A related theme positions constructed wetlands as 'like nature'. This is expressed, for example, by describing constructed wetlands as 'natural technologies' [2810] – a categorisation somewhat at odds with the mined gravel and concrete that are part of their composition. There are also many references to 'natural processes' as key to the function of constructed wetlands [e.g. 1], along with a related argument that constructed wetlands replicate or imitate natural wetlands, constituting an 'artificial ecosystem' [239]. These discourses might point to normative ideas of nature as intrinsically valuable (Soper, 2001), or to the 'naturalistic fallacy': the idea that 'natural' is inherently better than non-natural. While this is therefore a weak rationale, there are strong sociotechnical imaginaries that are supported by positioning constructed wetlands as (close to) natural. These rationales point towards a desired future where technology works with and sustains Nature, while solving social problems. This vision has been articulated within academic and policy spheres in recent years through the concept of 'Nature-based solutions' (Cousins, 2021). In these visions, 'nature' is characterised by its self-regulating character and an ability to provide 'multiple benefits'. This discourse follows earlier concepts including green infrastructure and ecological infrastructure, but has gained particular prominence as it is linked to mitigation of – or adaptation to – global heating (Chandrasekaran *et al.*, 2021; Nelson and Bigger, 2022).

Finally, a significant proportion of the 'green' rationales (101 out of 466 references) were short claims that were too vague to be positioned in any of the previous categories. For example, describing constructed wetlands as 'environmentally friendly' [e.g. 11], 'eco-centric' [e.g. H27], or simply 'green' [e.g. 1535]. These claims did not have enough context to make them meaningful. They seem to imply a generically positive relation between wetlands and their surroundings, rather than an ecological relationality that will always be more complex and situated. Such claims mobilise the ecologies of constructed wetlands in a manner more akin to greenwashing (Barua, 2021, p. 1478).

Resources and economic imaginaries

The predominant economic rationale for constructed wetlands is that they are less expensive than alternatives. The phrase 'low-cost' appears over 100 times in the dataset. When combined with more detailed descriptions of "lower operational and maintenance cost" [11] and references to constructed wetlands' 'cost effectiveness', low cost is the most common code across any theme. This often becomes a part of how constructed wetlands are defined, for example "constructed wetlands are low-cost wastewater treatment systems" [107]. The argument that other treatment options would be prohibitively expensive is made several times [159,163][7]. Where these rationale statements are more detailed they consider both building costs (35 references) — including the use of cheaper local materials [e.g. 1213] — as well as operating costs (47 references). In a variety of ways, these sources argue that constructed wetlands are a cheap approach for resolving wastewater treatment issues.

That low-cost wastewater treatment is a good thing appears to be common sense. However, there are several interpretations of why low-cost is significant for deciding to build a constructed wetland (or not). Expanding on these interpretations highlights some of the underlying imaginaries that sustain 'low-cost' as a dominant discourse. First, low-cost could be figured as economic efficiency. The more economically efficient wastewater treatment is, the more systems can be built (and maintained) for the same amount of money. This suggests that when deciding to build wastewater infrastructure, the lowest cost option should be chosen. However, such an approach sets aside other benefits and impacts that might also be a relevant part of decision making.

Another model positions 'willingness to pay' as crucial to whether or not wastewater treatment gets built [e.g. 1173]. New wastewater treatment infrastructure should only be built if the value of its various benefits exceeds the cost to build and maintain it. While 'willingness to pay' is a central part of many economic imaginaries, it is a poorly fitting model for wastewater provision. Many impacts of infrastructure are not easily amenable to economic valuation (Lele et al. 2013). Willingness to pay is also grounded in a human-centred approach, as the preferences of other beings are counted only indirectly. Finally, the 'willingness to pay' argument implies that the most significant factor holding back wastewater infrastructure is that it is too expensive, rather than stymied by a lack of demand or weak regulation. An alternative approach is to view wastewater treatment, alongside other basic public goods, as a necessity for which this kind of economic rationality need not apply.

The prevalence of these economic rationale in constructed wetland literature constructs a desired future, or at least an imagined present, where particular economic logics dominate waterscapes. This could, as Barua (2021) suggests, anticipate a future of austerity where "ecotechnologies that help fashion visions of the 'entrepreneurial city' [or countryside] go hand in hand with a reduction in public spending and reliance on voluntary labour to maintain infrastructures" (Barua, 2021, p. 1481). This critique is congruent with work on the 'neoliberal' rationality of water and environmental

[7] This argument clearly depends on which alternatives are chosen for comparison. As BORDA show in their research, for rural and decentralised sanitation, other technologies are available at similar or lower cost (BORDA, 2016).

governance in contemporary India (Birkenholtz, 2009; Mateer, 2017; Rao, 2020). What low-cost rationales gloss over is the extent to which infrastructure choices are also political decisions that reflect the experience and preferences of different actors involved (see for instance, Gondhalekar and Drewes, 2021). Rationales which place economic efficiency at the centre of arguments for constructed wetlands hence may play a mystifying role. Low-cost rationales align with capitalist economic imaginaries but do not necessarily correspond to how wastewaterscapes are constructed in practice.

We could also ask exactly what exactly is made cheap for a technology to have low operating costs? Constructed wetlands do not require chemical or energy inputs beyond those provided by wastewater and the sun. However, there are also arguments in the source literature that wetlands can be maintained by local people or require only 'low-skilled maintenance'. These suggest that one contributor to low operating costs are assumptions about the work required to sustain wetlands, who will do this work and how they should be compensated. Feminist political ecology of water has repeatedly shown that women's work in sustaining water supply networks is devalued (Sultana, 2011, 2020; Truelove, 2011; Hanson and Buechler, 2015). Constructed wetland rationale could be argued to rely upon and sustain a similar devaluation of maintenance work.

A secondary economic rationale is that constructed wetlands may also produce resources, principally treated water and wetland plants. The range of suggestions for the reuse of treated water indicate the diverse waterscapes that constructed wetlands are part of. Agricultural irrigation and aquaculture are common, but there are also references to use for 'golf courses' [55], 'washing of vehicles' [H11] and gardening [1213]. The focus on water reuse in South Asia reflects the influence of broader discourses of water scarcity which are powerful shapers of waterscapes. Meanwhile, plants grown in the wetland are mostly figured as biomass, useful for burning or biogas production [e.g. 4, 2057], or as fodder for livestock [e.g. 371, 746][8]. Finally, some of the rationale statements related to this theme speak of resources only in a more abstract fashion; it is not only water, but resources in general that need to be 'recovered' [139] and placed into 'sustainable cycles' [H32].

[8] However, this rationale deserves some scrutiny. As [230] note "harvesting is labor intensive and costly, which is antithetical to the passive character of wetlands technology". Use of plant material is almost always presented as a potential that is yet to be realised in the projects being described. For example [H33] describes how wastewater is reused for irrigation, while biomass 'could be' gainfully utilised.

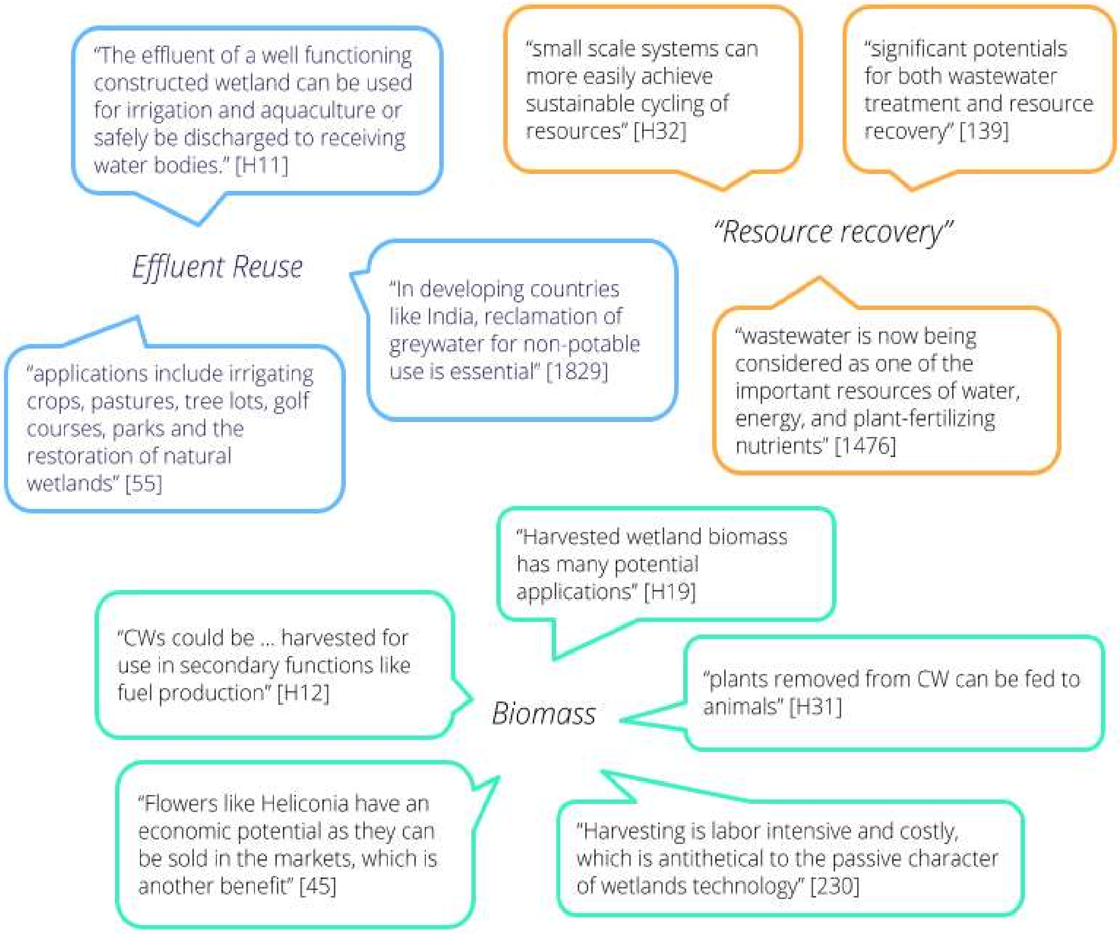

Figure 4.3 - Resource imaginaries and rationale statements

Whether water, plants or resources more abstractly, the idea of creating value from waste emerges within a broader context where the unsustainability and ecological devastation of existing modes of production are widely recognised. Resource production attempts to reorient wastewater, from outcast surplus to a source of value (Collard and Dempsey, 2017). While this cannot be convincingly demonstrated from these sources, I would suggest that these rationales have a logic beyond maximising economic benefits or responding to scarcity. Making waste into resource is also about constructing and stabilising an imaginary of sustainable or green economic growth (Valenzuela and Böhm, 2017; Zhang, 2020). Resource recovery or 'circularity' hence carries a normative weight above the simple economic value of the resources derived from wetland ecologies.

The social ends of constructed wetlands

The final set of constructed wetland rationale addresses how these wetlands impact the people who live around them. Many of these socially oriented rationales align with what could be termed 'social improvement', the idea that communities will have a better life due to these wetlands. Unsurprisingly, this improvement looks quite different in different places.

In papers related to Asia and South Asia, rationale statements often argue that constructed wetlands contribute to rural, sustainable and/or integrated development. The components of development that are included in constructed wetland rationale in Asia and South Asia include providing employment [832, H26, H27], and one reference to women's empowerment [H27], along with the more straightforward references to improved sanitation. Arguments that constructed wetlands can provide employment or even empowerment are closely tied to the expectation of community maintenance. Here the capacity and desire to do this work is assumed. In these arguments, social improvement and development are connected.

In contrast, 'social improvement' in papers linked to the Global North is about providing an attractive recreational amenity. Constructed wetlands are described as a recreational area, asset or facility [e.g. 30, H16], often without specifying which forms of recreation are afforded. Tied to this invocation of recreational value are statements that highlight the aesthetics of constructed wetlands. For example, the argument that "constructed wetlands emulate natural wetlands in both form and function. This is part of their beauty" [1173], Given the historic processes of wetland clearing in many areas (Vileisis, 1999; Parsons and Fisher, 2021), this shift towards viewing wetland nature as aesthetically pleasing deserves some scrutiny. One answer perhaps comes from references to ornamental plants [e.g. 213, 1829] and aesthetically focused landscaping [e.g. 2561] which are part of some constructed wetland designs.

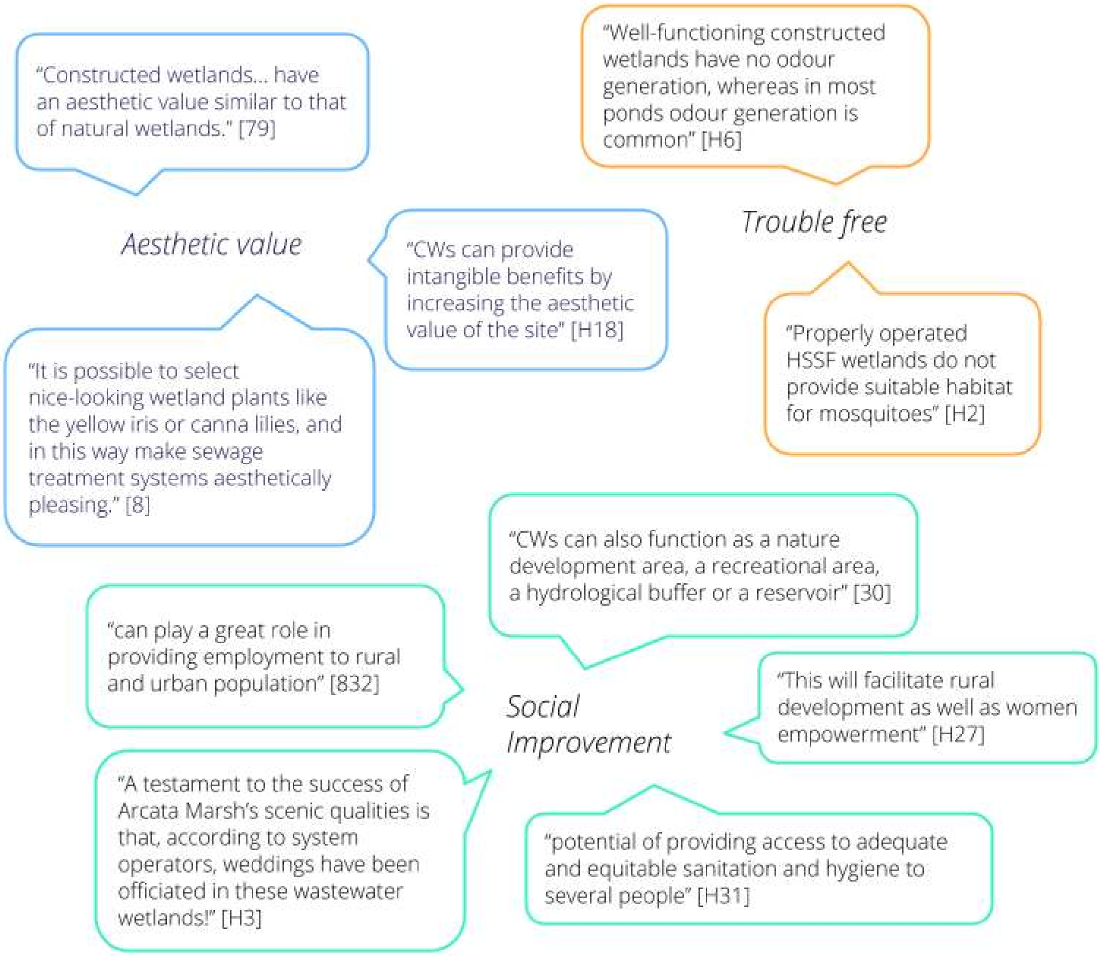

Figure 4.4 - The social values of constructed wetlands

Finally, besides these varied forms of social improvement, constructed wetlands are also argued to be socially preferable due to the lack of two significant issues associated with wastewater treatment, odours and disease vectors. A horizontal wetland design where water flows only beneath the surface is argued to minimise the potential for mosquito breeding [H12]. I return to this topic in chapter eight, as all three of the case study wetlands are of this type.

Conclusion: constructed wetland futures

This chapter has analysed the rationale given for constructed wetlands, dividing them into five themes:

- While the *purpose* of constructed wetlands is oriented towards reducing pollution or treating wastewater, there is variation in what effective treatment entails.

- Rationale relating to wetland *properties* – simple, reliable and suitable for small-scale treatment – position these wetlands within a socio-technical imaginary which merges both technological and social ideas of decentralisation.
- The *ecological* valence of constructed wetlands is understood in various ways. While rationale statements in this theme share an understanding of ecological concerns – extending from water pollution to global heating – they respond to it in different ways. Some statements align wetlands with a damage-minimisation approach. Others suggest the blending of nature and infrastructure that is characteristic of nature-based solutions.
- The dominant theme of constructed wetland *economics* is the 'low-cost' nature of constructed wetlands. The socio-technical imaginaries that connect to these arguments are dense with assumptions about how infrastructure should be designed and maintained. There are also a set of rationales which position constructed wetlands as contributing to imaginaries of a circular economy.
- Finally, rationale statements that speak to the *social* impacts of constructed wetlands are divided depending on the regional focus of the paper, with some arguments emphasising the aesthetics and recreational potential of wetlands while others suggest that wetlands can contribute to 'development'.

The aim of this chapter was to connect constructed wetland discourses to broader socio-technical imaginaries. The concepts of discourse and sociotechnical imaginaries allowed me to analyse what were often simple and unevidenced rationale statements. Even basic and generalised assertions play a part in constructing and stabilising imaginaries. At the same time, generalities and vagueness prompt further consideration about the producers and audience of this scientific literature. Are some of these texts simply rehearsing claims that their audience will find familiar? Or do some of the generalities and vague comments point to the difficulties of making general claims about infrastructures that are specific to places? My analysis attends to how socio-technical imaginaries vary in different locations. Arguments relating to the social impact of constructed wetlands are one example of how the context of discourses is crucially important, even if it is not stated explicitly. Socio-technical imaginaries of constructed wetland infrastructures position their properties socially, economically and ecologically. They reveal these domains to be intertwined. This points to a crucial task for analyses of 'nature-based solutions': to follow the impacts and representation of these infrastructures across interlocking ecological, social, political and economic domains. As the following chapters will show, this task requires a location-specific analysis and careful generalising.

Returning to the argument made in the theory chapter that waterscapes may contain multiple, incommensurate forms of justice, we could also consider the normative socio-technical imaginaries examined in this chapter as visions of water justice (and injustice). Framed in this way, untreated wastewater is an injustice that constructed wetlands aim to rectify. In doing so, these wetlands might also align with ideals of justice marked by the desire to ensure economic efficiency, or environmental harm-minimisation. And in their social impact, constructed wetlands might be bringing about social justice through development, or alternatively creating an unjust distribution of responsibilities. And if we acknowledge constructed wetlands as valuable habitat for other-than-human beings, then perhaps this is one opening to more-than-human modes of justice.

Working with socio-technical imaginaries involves locating simple statements – constructed wetlands are a low-cost solution – within currents of ideology. It also means working with tensions between incompatible rationales and incommensurate visions of water justice. My aim, in uncovering the tensions within constructed wetland rationales, isn't to discount these rationales, or critique constructed wetlands as a technology. These tensions reveal that sociotechnical imaginaries are in ferment, open to change and responsive to ever-shifting discourses as well as technological alterations. Constructed wetlands, as well as other 'green' infrastructures, could fit into different sociotechnical imaginaries, enabling other more-than-human social orderings and more desirable futures.

5 Ecologies and Histories: Situating water quality knowledges

Making sense of water quality

Figure 5.1 - A view of Ibrahimpur pond. Photograph by the author, 2019.

I took the photo above while conducting a hydraulic conductivity experiment at Ibrahimpur wetland. We arrived that morning to find the pond full of vibrant green algae. At the outlet of the wetland, small rafts of algae swirled in the eddies created by inflowing water. Further out it foamed in matcha latte green. At the bottom of the picture is a Hach multimeter with attached probes that measure electrical conductivity, and dissolved oxygen. When I look at this image, I see two different ways to read water quality, spanning globally distributed constellations of biosensing and technoscience.

Generating water quality knowledge was a focus of activity for both Indian constructed wetland projects. At Ibrahimpur and Berambadi, research assistants visited the wetland monthly, dipping electronic probes into the wetland water, collecting water samples in milky-white plastic bottles, storing them in a cool box to be taken back to laboratories for filtering and analysis. Through my involvement in these projects, I could trace how water quality knowledge was produced and made meaningful[1]. A key question in this process was 'are the wetlands working adequately?'. Despite the time I have spent in each waterscape, and analysing the water quality data at my desk, this is a question I cannot answer. What appears to be a simple question expands infinitely in light of the chemical and ecological specificities of waterscapes.

At the same time, people in the project teams didn't share my puzzlement. Neither was it shared by those living around the wetland who I spoke to. While their methodologies were different, everyone seemed to have found ways of generating meaningful water quality knowledge. Was my paralysis simply the result of academic over-thinking? By tracing diverse knowledge practices within these waterscapes, I argue that, on the contrary, thinking carefully about water quality is important for understanding water justice.

Compared to the patchy distribution of water, the unevenness of water quality can be less immediately apparent. But issues of water quality are just as significant for waterscape flourishing. Degradations in water quality impact far too many waterscapes (Damania *et al.*, 2019; Wear *et al.*, 2021). Considering this, Maria Rusca and colleagues argue that, with a few exceptions, urban political ecology research has "failed to attend to the material properties of water" and hence "been less attentive to questions of quality" (Rusca *et al.*, 2017, p. 139). Further political ecologies of water quality are needed. Such work needs to thread the careful path of political ecology scholarship; engaging with biophysical sciences while maintaining a critical distance (Doolittle, 2015). This chapter explores how this might be done for water quality research.

My argument unfolds through two sections. First, I consider the various ways that water quality knowledge is generated through more-than-human relations. I position these water quality measurements, whether technical or otherwise, as forms of biosensing. Approaching biosensing as a more-than-human conversation highlights the potential for miscommunication. If water quality knowledge is to contribute to water justice, it requires careful generalisation through ecological situatedness, rather than assumptions of universality.

[1] I also conducted my own program of water quality sampling at Loch Leven. This is not included in the analysis in this chapter.

In the second section, I turn to broader knowledge formations and techniques for making water quality knowledge *meaningful*. Standards and efficiency metrics were used in both waterscapes. By tracing the history of these techniques, I question the universalism that they assume and rely upon. Water quality standards developed within specific contexts should not be freely translated between waterscapes. I also explore the social connections and divisions that framed how water quality could be made politically meaningful at these sites.

Together these two sections argue for replacing universalism with situated knowledge (Haraway, 1988), that is cognisant of historical and ecological specificity. As Richard Chavolla (Kumeyaay) puts it, "for knowledge you *must* understand where you are" (from the documentary Guts, quoted in Liboiron, 2021, p. 152). I close the chapter by considering the implications of such a shift, highlighting the co-production of water quality knowledge, water ethics, infrastructures and social orders.

Knowing water through more-than-human relations

Plant indicators

Visiting the Ibrahimpur wetland in May 2019, with the pre-monsoon sun pushing temperatures above 40 degrees, Kumar explained to me that this was when the wetland performed best. Looking at the tall canna plants, with thick green leaves, and crowning stems of orange-yellow flowers, it was easy to agree. Yet, as Kumar also explained, things hadn't always been so good. A few months prior, accumulating sediment disrupted the flow of water through the wetland. At that moment, wilting canna leaves signalled that something was going wrong. Kumar and I were both drawing on a lifetime of human-plant interactions to interpret the health of the canna and to judge the constructed wetland's performance.

Healthy plants suggest good water quality treatment, but plants are not always healthy. In October 2019, canna in the Berambadi wetland was infected by a rust disease, with many leaves covered in orange and brown spots, before withering and dying[2]. When this issue was raised in a project meeting, one person estimated a 20-30% reduction in water quality treatment performance. This conclusion was somewhat surprising in its certainty; the ability to infer water treatment from plant health had been converted to quantitative prediction. Through paying attention to canna, project members made conclusions about treatment efficacy, and hence the water quality of the wetland

[2] Damp and crowded growing environments are ideal conditions for the rust fungus, and this is exactly what the wetland design created.

outflow. Working alongside scientific teams allowed me to see how the health of the canna plants became a proxy for wetland performance and water quality improvements.

To explore other water quality knowledge, I asked farmers at both Ibrahimpur and Berambadi about the quality of the water they pumped from aquifers for irrigation. The most common response was that the quality was good; the proof was that crops grew well. The sugar cane, wheat, marigold, bajra (millet), jowar (sorghum) and other crops, though part of a different constellation of relations, also had something to say about water quality. Some farmers in Ibrahimpur – without access to their own tube wells and pumps – had also used pond water for irrigation[3]. Using this water entails 'trial and error'[4], if the crops grow well, it follows that the water quality was fine. But one farmer told of a case where, after irrigating with pond water, the plants turned black[5]. They concluded that the water was to blame and so stopped using this water. In this trial-and-error approach, the responsiveness of crops signals water quality issues to farmers.

Finally (returning to the phenomena that opened this chapter) I read the presence of a different kind of vegetal life – algal blooms on the surface of Ibrahimpur pond – as another sign of poor water quality (see also Figure 5.2 below). In doing so, I was drawing from my understanding of algal blooms as a sign of eutrophication. But the bloom only lasted a few days. Had the water quality shifted in that time? Was it some other churning of pond ecological processes? My ability to understand these changes over time was limited.

Intra-actions[6] of plants and water create meaningful signs for human observers. Reading plant health can be used to attest to the quality of a particular water, or to the transformations of water quality taking place in wastewater infrastructure.

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[3] Before the pond was 'rejuvenated' as part of the constructed wetland project, and such abstraction was no longer allowed.
[4] Group Interview (GI) 1, 6 – Ibrahimpur (IBM)
[5] GI 1 - IBM
[6] Water fills microbial, plant and animal bodies, transports microbes and molecules, and is the medium of biochemical reactions. Karen Barad's concept of intra-action seems appropriate for thinking about these relations and the ways that they produce water quality knowledge. "Individuals do not pre-exist their interactions; rather, individuals emerge through and as part of their entangled intra-relating" (Barad, 2007, p. ix).

Figure 5.2 - Algal bloom on the surface of Ibrahimpur pond. Photograph by the author, 2019.

Biosensing

The different ways that plants signal water quality speak to a broader set of more-than-human communications. The potential for more-than-human relations to generate knowledge about land or waterscapes is recognised most explicitly in environmental sciences through the concepts of biosensing and bioindicators (Li, Zheng and Liu, 2010; Scaramelli, 2013; Johnson, 2017; Gabrys, 2018; Gramaglia and Mélard, 2019). Biosensing methods determine air, water or soil toxicity through paying attention to the presence or health of living beings. The use of biological indexes to indicate water quality is a common practice as part of the package of water quality tests developed to fulfil the Water Framework Directive in the European Union (Hering *et al.*, 2010). In comparison to chemical monitoring techniques, biosensing offers a different way of understanding water quality. Biosensing methods integrate across a wide range of potential chemical and physical stressors; allow for a different temporality of monitoring (with living bodies functioning as archives of past harm); and offer a form of water quality data that is more tangible for non-experts (Sarkar and Dixon, 2021).

Li Li, Binghui Zhang and Lushan Liu give an indication of how a range of bioindicators have been developed for river ecologies:

> “Periphyton, benthic macroinvertebrates and fish are the most common indicators in river biomonitoring, which can be used separately or contemporaneously… Commonly used biomonitoring approaches include diversity, biotic indices, multimetric approaches, multivariate approaches, functional feeding groups and multiple biological traits.“ (2010, p. 1510)

Virender Singh, M. P. Sharma, Shailendra Sharma and Saurabh Mishra (2019) compare six different bio-indexes based on benthic macro-invertebrates, developed in the central Himalayas, and find that they are applicable for the river Ujh in Jammu and Kashmir. In a similar vein, Dani Benchamin, Sreejai R. and Beena S. Kurup (2021) correlate caddisfly diversity with water quality parameters in the Kallada River, Kerala. While these studies indicate the potential for biosensing to be a valuable tool for water quality monitoring in India, Singh et al. note that “bio-assessment based monitoring of water bodies is not regularly performed in India” (2019, page 80). This way of knowing water quality is not given official validation.

The development of biosensing methods has captured the attention of social researchers as well. As Emily Johnson summarises, “biosensing appropriates and enrolls nonhuman life in cognitive and communicative endeavors” (2017, p. 15) where “it is the labor of living itself that produces knowledge of a changing world” (2017, p. 10). For the environmental monitoring kits investigated by Johnson – or the clams whose agency in water quality monitoring is explored by Christelle Gramaglia and Delaine Sampaio da Silva (2012) – an analysis hinging on non-human labour and enrolment seems appropriate. Biosensing, in Johnson’s telling, is an example of the kind of Anthropocene biopolitics we should hope to avoid. Knowledge is generated by appropriating nonhuman labour and knowingly subjecting nonhuman beings to trauma (Johnson, 2017, p. 10). Certainly the example of clams placed into highly polluted waterways raises ethical questions about submitting other creatures to expected harm, questions that should never be seen as resolved (Haraway, 2016).

Other analyses of biosensing offer a more hopeful reading of these practices. Christelle Gramaglia and François Melard describe the selection of conger fish as bioindicators of pollution in the Gulf of Fos, France as a form of cosmopolitics which worked towards situated scientific knowledge (2019). Perhaps most significant for this optimistic reading of biosensing is the work of Jennifer Gabrys (2012, 2018). Thinking with moss and lichens, Gabrys suggests that bioindicators don’t merely provide a more integrated – and potentially cheaper and easier – way to measure air, soil or water quality, they can also shift how pollution is conceptualised. Firstly, bioindicators might shift our frame of reference from individuals to ecologies; from atomised damage to "sprawling affiliations that are worked and reworked through environmental pollutants" (2018, p. 354)[7]. Working and thinking with bioindicators might also undermine articulations of pollution based upon thresholds (of which more shortly), offering the potential to "generate alternative and speculative engagements with pollution" (2018, p. 354). Perhaps biosensing, like any other knowledge practice or technology, has effects that depend on where it is used, by who, and for which ends.

Plants of various kinds have already indicated that biosensing is important for knowing water quality. But other examples from these waterscapes shed more light on the ethics of biosensing and how it may or may not contribute to situated water quality knowledge.

E. coli

A plastic tray glowing brightly under a UV light is not immediately suggestive of anything 'biological'. Yet, sitting on the bench in the laboratory at NIH in Roorkee, this apparatus is part of a hybrid technology that mobilises *Escherichia coli* (henceforth, E. coli) as a bioindicator.

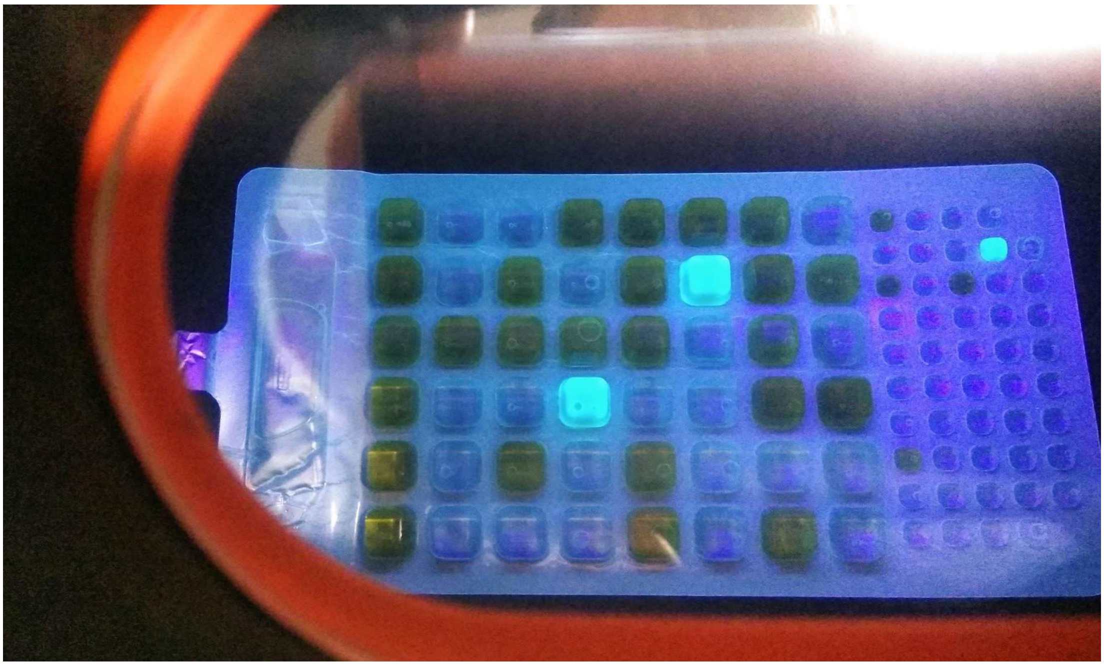

Figure 5.3 - Glowing blue cells in Colilert tray. Photograph by the author, 2020.

E. coli is a bacterium that was first identified in 1885, from faecal samples. Its presence within the human microbiome (Eckburg *et al.*, 2005) suggested a potential for E. coli as a water quality indicator (Ashbolt, Grabow and Snozzi, 2001). Though most strains of E. coli are not harmful to people (and

[7] This is particularly apparent when working with the symbiotic assemblages of lichens.

some are beneficial), the presence of human gut bacteria in water used for drinking indicates flow patterns that could spread water-borne diseases. In the first decade of the 20th century, E. coli was introduced for water quality testing in London, UK. The exact testing method has changed alongside changes in technology yet testing for E. coli remains a standard part of water quality standards worldwide (Ashbolt, Grabow and Snozzi, 2001). Making visible the presence or absence of E. coli brings it into a testing apparatus that signals the risk of sewage pollution.

E. coli testing both relies upon and reveals the abundance of microbial life in water. Testing methods rely on propagating living E. coli bacteria. The Colilert® process was the method of analysis for testing water from both Ibrahimpur and Berambadi. A customised reagent powder is added to the sample. The mix is then poured into a standard clear plastic container, resembling an icetray, and incubated for 24 hours. In this time, a chemical compound in the reagent is metabolised by E. coli bacteria, using a specific enzyme (*beta-glucuronidase*) which only E. coli produces[8]. Using this tailor-made food source, E. coli are able to multiply, while other bacteria starve. This metabolic process also releases a molecule (*4-methylumbelliferone*) which, under a UV light, emits a fluorescent blue glow (see Figure 5.3) (*Colilert*, no date). Counting the number of glowing 'wells' allows an estimate of the E. coli numbers in the water sample to be calculated. The Colilert® test, with its propagation of E. coli life and colorimetric reactions, makes one fragment of waterscape microbial life visible.

While E. coli's material presence is certain, its ability to represent the pollution of a particular wastewater flow is ambiguous. The use of E. coli as an indicator is backed up by an assumption that E. coli is a gut bacterium; that it does not survive long outside of this intestinal niche. Microbial ecologists have discovered that this assumption is not always accurate, particularly in tropical climates. This evidence is summarised in a 2001 World Health Organisation publication[9]:

> Many members of the total coliform group and some so-called faecal coliforms … are not specific to faeces, and even E. coli has been shown to grow in some natural aquatic environments… Hence, the primary targets representing faecal contamination in temperate waters are now considered to be E. coli and enterococci. For tropical waters/soils, where E. coli and enterococci may grow, alternative indicators… may be preferable.
> (Ashbolt, Grabow and Snozzi, 2001, p. 305).

[8] Life is never quite so perfect. "Since *most* non-coliforms do not have these enzymes, they are unable to grow and interfere. The *few* non-coliforms that do have these enzymes are selectively suppressed by the Colilert Test's specifically formulated matrix" (*Colilert*, no date) (emphasis mine).
[9] Since 2000, knowledge of environmental E. coli has continued to develop (see, for example, van Elsas *et al.*, 2011; Jang *et al.*, 2017).

The work of Javier Arce-Nazario (2018) on water supply systems in Puerto Rico, illustrates the socio-political consequences of misapplied standards. The use of E. coli to diagnose unsafe water systems is a 'misreading of Puerto Rican ecology' (Arce-Nazario, 2018, p. 467). On the island, E. coli may be found in streams without any pollution, unlike in the mainland USA – where Puerto Rico's water quality standards are devised. As more about E. coli lifeways is understood, its part in a standard testing assemblage should be questioned. 'While compliance methods [in Puerto Rico] provide an apparently objective view of the distribution of risk, they draw definitions of environmental risk from a narrow perspective' (Arce-Nazario, 2018, p. 476). In the case of Puerto Rico, this meant designating community-managed water supplies as unsafe.

At Ibrahimpur and Berambadi, environmental E. coli increases the likelihood of recording high E. coli concentrations or failing to meet water quality standards – potentially creating the impression of a malfunctioning infrastructure. This is not to say that a high E. coli count is no cause for concern. But translating this count into meaningful water quality knowledge is not straightforward. This correlation rests on a simplification of E. coli ecologies. Against assumptions that environmental monitoring technologies can be easily translated from place to place, examining the varied ecologies of E. coli shows that such translations may be difficult.

BOD

Among the many parameters relevant to water quality, one of the most ubiquitous is 'organic matter', which includes any chemical compounds released by living organisms. The decomposition of organic matter is carried out primarily by microbes that require oxygen for respiration. Hence, when excess organic matter (for example, sewage) is added to a water body, oxygen levels will decrease, as bacteria feeding on the organic matter use up the available oxygen. Biochemical Oxygen Demand (BOD) testing methods recreate this metabolic process within a testing bottle, kept at a fixed temperature within a lab for several days (Jouanneau *et al.*, 2014). By measuring the decline in dissolved oxygen content over a period of time, the *demand* for oxygen is determined. This serves as a measure of the potential impact of organic matter on water ecologies. The BOD test is one of the most widely used methods in water quality assessment (Jouanneau *et al.*, 2014) as low oxygen levels in water make water bodies uninhabitable for fish and other aquatic life. Indeed, in classifying and prioritising rivers in need of remediation, the BOD of water samples is the sole metric used by the

Indian Central Pollution Control Board (Central Pollution Control Board, 2018; Lele, Jamwal and Mahesh, 2021)[10].

Through measuring oxygen depletion, BOD testing methods track the labour of microbial communities. However, the diversity and vulnerability of microbial communities creates variability in BOD results. In cases where the community within a water sample has been disturbed, for instance through wastewater disinfection, a 'bacterial seed' is needed to enable the breakdown of organic matter, with the presence of this introduced bacteria leading to a higher BOD result (HACH, 2015). In addition BOD values can be altered if compounds such as pharmaceuticals inhibit bacterial activity, or a large community of nitrifying bacteria are present in the water (Hammer, 2013, p. 60). A choice must be made between using the variable microbial community already present in the sample or choosing a specific set of microbes for the degradation which ensures results are replicable, but doesn't match ecological conditions, and hence it doesn't capture the harm caused by organic matter at the location the water in question was sampled from (Jouanneau *et al.*, 2014). Reviews of the BOD method highlight that it is not a highly reliable method due to this microbe-induced variability (Jouanneau *et al.*, 2014). Evaluating BOD test results requires accounting for microbes as agential subjects.

Everyday biosensing

While these technical methods use microbial metabolism to generate water quality information, there are other more immediate ways to know water quality. While they may stretch the bounds of what is normally considered 'biosensing', these are also determinations of water quality made through more-than-human intra-actions with waters. At one household where we were discussing water quality, I was offered a glass of water to drink, to judge for myself that it was good. As water is used not only for drinking but also preparing food, it is no surprise that sensory information is so important. Local women interviewed in Ibrahimpur and Berambadi determine water quality based on the taste, smell and appearance of the water. Taste was the most frequently invoked of these senses. This was often expressed simply with the explanation that good quality water is good tasting. But water might also have a bitter, salty, rusty or unpleasant taste[11]. An unpleasant smell was also sometimes part of the problem of poor-quality water, both for domestic water and the water in the pond at Ibrahimpur. Interviewees noted that cattle also use their sense of smell to reject bad water, with people joking that cattle were more intelligent than people at making this judgement[12]. Yellow

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[10] Whether or not this constitutes a good approach to prioritisation is another question (see Lele, Jamwal and Mahesh, 2021).
[11] GI 5,6 Berambadi (BER). GI 9, 10 IBM
[12] GI 1 IBM

coloured water at Ibrahimpur was a sign of bad quality, while in Berambadi borewell water was preferred over water pumped from the Kaveri River due to the rusty[13] colour of the river water. Women reported sore throats, headaches and other health issues that had come from drinking certain waters[14]. These experiences link judgements of poor water quality to certain colours, tastes or smells of water.

Sensory judgements are inseparable from culturally specific understandings of good and poor water quality. In translating conversations to English, interpreters suggested that one of the problems in Berambadi water was that it was *tasteless*, and in Ibrahimpur that the taste was very light, or the water lacked taste[15]. This way of judging bad quality water is outside my own culturally shaped sensory understanding. Amitangshu Acharya explores how the spread of reverse osmosis systems for home purification of water in middle-class Indian households has altered notions of what good quality water tastes like (Acharya, 2019)[16]. Sensory judgements of water make water quality simultaneously embodied and culturally situated.

During another group interview in Ibrahimpur, I was shown a tin cup filled with water, so that I could observe the thin pale film on the inside of the vessel. Multiple interviews described a yellow film, coating containers and utensils, that developed when water from some wells was left overnight[17]. Several discussions at Berambadi described a similar oily film that borewell water developed when left for several days[18]. Both of these changes are likely to indicate microbial action (Department of Environmental Quality, 2016). Bacteria make themselves visible gradually as they metabolise iron and other components in the water. Such bacterial communities are not necessarily harmful but go against an aesthetic of clean water.

Boiling water together with dhal (lentils), or with tea and milk, was considered by many people to provide a clear indication of water quality. When asked why water from a borewell was good, one (male) respondent in Berambadi replied "dhal cooks well in it"[19]. But in some water, dhal doesn't cook

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[13] ಕೆಂಪು – *kempu*

[14] There was some discussion at Berambadi as to whether some of these health issues might be caused by the chlorine dosing that was used to clean out the village water storage tanks.

[15] GI 3 IBM, GI 1,3,6 BER

[16] The fact that 'good tasting water' is a reference point that might change over time doesn't make it any less valid for guiding people's preferences. But the case of reverse osmosis shows the complications of water quality. Highly pure water (with good quality and good taste) may lead to health issues, due to a lack of essential minerals (Acharya, 2019).

[17] IBM - GI 1,4,5,7,9

[18] BER - GI 1,2

[19] BER GI 3

properly, or doesn't taste right[20]. When dhal didn't cook well in Ibrahimpur, women tried using water from another well, using lentils as an experimental apparatus to confirm that water was the problem. And, in another key cooking task, water from one shallow hand-pump made milk curdle in tea[21]. Water interacts with lentils or milk in specific ways depending on its quality. These interactions with cooking materials or containers were *constitutive* of water quality problems; how could water be good if it has an oily film? or if the lentils don't cook right?

Ecologically situated knowledge

The stories presented above indicate that, whether acknowledged or not, more-than-human relations underpin the generation of water quality knowledge; "knowledge practices themselves are more-than-human relations" (Nustad and Swanson, 2022, p. 17). To understand knowledge production as more-than-human entails revising our understanding of the other beings and objects that are our partners in knowledge making. This argument aligns with the legacy of STS scholarship, including Actor Network approaches (Latour, 1987; Lave, 2015). Donna Haraway argues that developing situated knowledge requires:

> granting the status of agent/actor to the "objects" of the world. Actors come in many and wonderful forms. Accounts of a "real" world do not, then, depend on a logic of "discovery" but on a power-charged social relation of "conversation". (Haraway, 1988, p. 593)

The notion of research as a conversation captures the messiness of more-than-human relations. The film in a cup of water, or the plant that is growing healthily, has something to say about water quality, but my fluency in reading these signs was limited. Conversations are also always prone to miscommunication or misunderstanding[22]. For instance, the E. coli might not be saying quite what we think it is. The voice of the microbes used to determine BOD might be drowned out by disinfectants. Paying close(r) attention to the more-than-human relations that already generate water quality knowledge is a step towards situated knowledges. At the same time, developing knowledge tuned to water justice requires attention to the forms of water quality degradation that are harder to perceive due to time lags (Murphy, 2013) or minor chronic impacts. Understanding these issues requires developing a broader set of more-than-human relations, with other living beings as well as technologies.

[20] BER GI 3, IBM GI 3,7

[21] IBM GI 7 – the same water also didn't wash clothes properly.

[22] Treating research as a conversation also marks a step away from ANT analysis that focus on the enrolment of diverse beings and apparatuses by scientists. The implications of foregrounding 'enrolment' in actor network approaches has been the focus of several critiques (Ingold, 2011, pp. 89–94; Lave, 2015).

The concept of situated knowledge marks a recognition that knowledge is partial, embodied and particular to knowing subjects (Haraway, 1988, pp. 582–583). Following Haraway, understanding the situated nature of all scientific constructions is not merely the grounds for contesting particular knowledges. It is a requirement for making a *better* science, where “partiality and not universality is the condition of being heard to make rational knowledge claims” (Haraway, 1988, p. 589). Generating situated knowledge requires a “critical practice for recognizing our own ‘semiotic technologies’ for making meaning” (Haraway, p. 579). This practice encompasses the challenging task of reflexivity. Some invocations of situated knowledge frame it largely on these grounds (Rose, 1997). Yet, if knowledge is produced through more-than-human collaborations, then a different kind of situating practice is also required. If (as shown above) plants and microbes are ‘semiotic technologies’ for making sense of water quality, then understanding their ecological specificities is another way that knowledge might be situated.

This is important for understanding the potentials of biosensing. The analytical potential of bioindicators relies on the ability to translate ecological knowledge between places. For example, caddisfly larvae require clean water (Benchamin, R. and Kurup, 2021) or E. coli does not survive outside of the gut. But these translations have limits. Like many other forms of knowledge, biosensing works in the tension between universalism and particularism. Universalism is “the belief that certain principles, concepts, truths, and values are undeniably valid in all times and places” (Rogers, Castree and Kitchin, 2013, para. 1). Such a belief can easily lead to a reductionism that dismisses other ways of knowing (Haraway, 1988, p. 580; Sundberg, 2014). In contrast to universalism, biosensing must instead rely on careful generalisation, built upon ecologically situating more-than-human relations (Gramaglia and Mélard, 2019; Liboiron, 2021, pp. 152–153).

Making water quality meaningful

The growth (or ill-health) of crop plants, the taste of food, or a health issue caused by drinking water are all water relations that don’t just signal water quality but are constitutive of good or bad water quality in these particular contexts. On the other hand, some of the biosensors described in the previous section are merely indicators of water quality. The growth of canna plants in the wetland, or E. coli in a testing apparatus gave (uncertain) indications about water quality. E. coli is an imperfectly communicated signal that there might be water quality issues. Similarly, water with high BOD or nutrients indicates the potential for oxygen depletion and other harmful ecological effects. It is only through water quality standards or other techniques of comparison that these parameters enable judgements to be made about water quality.

This suggests that it is necessary to take a step back from the details of water quality sensing, and to locate these methods within a broader knowledge formation. In a resonant analysis, Caterina Scaramelli describes how River Monitors understand water quality in the Mystic River, Boston through an "emotional or sensorial connection with living water beings like herring, water lily, and E. coli bacteria" (Scaramelli, 2013, p. 159). Yet, as Scaramelli explains, such knowledge is mediated by factors such as "State parameters, laboratory practices [and] political commitments" (ibid., p. 159), all components of a complex knowledge formation. This section examines social practices that supported the water quality understandings of local residents as well as the State and scientific practices that aided project teams in their efforts at making water quality meaningful. A historical analysis of these techniques emphasises that notions of adequate water quality may not translate smoothly from place to place.

Standards

The design process for the Berambadi constructed wetland was guided by a particular target for the outflowing water: 30mg/l of BOD. This is a threshold derived from a discharge standard set by the Central Pollution Control Board, an Indian State agency. A discharge standard is one that puts a limit – or, framed differently, sets a target – on the quality of water being discharged into a body of water, or onto land. Achieving this threshold at Berambadi was one of the ways of affirming wetland performance. Publications from the project compared the results to this standard:

> "The effluent quality of both systems met the discharge standards set by CPCB (MOEF and CC, 2017) with BOD5 and COD less than 30 mg/L and 250 mg/L respectively"
> (Jamwal *et al.*, 2021, p. 4)

On top of this, project members described the wetland to me as meeting these discharge standards. This figure, 30 mg/l, and its use in the context of the Berambadi project speaks to a complex and contingent history of water quality standards. Standards work to make water quality meaningful between logics of water use and pollutant harm.

In the development of Dominant water quality science the use of water was paramount (Liboiron, 2021, p. 67). This focus on usefulness was tied to an ideology of making the "maximum use" of resources (ibid., p. 70). In this way, standards are shaped by culturally specific imaginaries of useful or healthy water (Wilson *et al.*, 2019). Alongside the logic of use, water quality standards may also address the harm that water would cause when discharged, either to human health or to a broader ecological community[23]. By focusing on harm, water standards might move away from the anthropocentrism inherent in use-based approaches. This ecologically attuned approach to water quality standards is seen, for example, in the EU Water Framework Directive, which aims for all water bodies to achieve 'good ecological status'[24]. Contemporary water quality standards encompass a multitude of ways that water is used or valued, and both human-centred and more-than-human ethical concerns. Tracing the history of water standards shows how these ideas of water quality evaluation came about and reveals the underlying logics of standard making.

Colonial history

Setting water quality standards is just one approach to the ethico-political regulation of water quality. In Europe and the United States[25] prior to the formulation of water quality standards, legal concepts related to water rights were used to adjudicate conflicts caused by increasing water pollution from industries (Paavola, 2002; Rosenthal, 2014; Liboiron, 2021). A key normative principle in these determinations was that of 'best use'. The requirements for any particular industry to pay damages or limit pollution was dependent on whether the economic activities generating this pollution were more valuable than the uses of water which had been disrupted (Paavola, 2002). By the late 19th century, as growing urban populations produced more and more sewage, this legal approach became increasingly limited (ibid.). As with earlier legal approaches, there was a desire to regulate water pollution, without creating excessive complications or costs (Liboiron, 2021). In this context we see the co-production of water quality science and standards in the United Kingdom, Germany and United States (Hamlin, 1990; Paavola, 2002; Kneitz, 2012; Liboiron, 2021).

In the UK in the 19th century a wide range of parameters and philosophies were used to judge water qualities, with sensory perception through smell and taste often forming part of the analysis for drinking water (Hamlin, 1990; Liboiron, 2021). Regulation required a simplification of water quality standards. Research in the UK and USA narrowed in on organic matter as the main pollutant of concern, measured through BOD. The development of BOD as a method in late 19th and the early 20th centuries, was initiated by UK Royal Commissions on River Pollution and on Sewage Discharge (Royal Commission on Sewage Disposal, 1915; Jouanneau *et al.*, 2014), and accompanied the drafting

[23] The division between a logic of use and of harm is a porous one. For example, harm to fish becomes a limitation on the *use* of water bodies for fishing, or the usefulness of drinking water depends on a limited degree of harm caused by this water.
[24] An aim which existing European water governance and politics is far from achieving (Carvalho *et al.*, 2019; Linton and Krueger, 2020)
[25] Most of the historical literature on the co-evolution of water quality science and standards focuses on the European and United States context.

of standards for sewage discharge that used this metric. The Eighth Report by the Commission on Sewage Disposal summarises:

> "we found as a result of prolonged observations on a number of streams that the most reliable chemical index of the nuisance-producing power of a polluted stream is the amount of dissolved oxygen taken up in 5 days"
> (Royal Commission on Sewage Disposal, 1915, p. 10).

From the many water quality indicators available (Hamlin, 1990), oxygen demand was the parameter said to most reliably index the 'nuisance-producing power', the tendency of oxygen depleted waters to kill fish and produce bad smells as organic matter decomposed aerobically or anaerobically. In this way, the complexities of water pollution are gently circumscribed[26].

Bad smells and oxygen depletion also indicate a gradual breakdown of some kinds of pollution within the river; at some point downstream the water was no longer impacted. This was referred to as the 'self-purifying' capacity of rivers (Liboiron, 2021). Understanding this purifying capacity was a key focus of water quality research in the early 20th century. Streeter and Phillips used the Ohio River as the basis for their experiments on oxygen depletion (ibid.). Similar work was carried out by British bacteriologist Ernest Hanbury Hankin in Allahabad, India with a focus on coliform reduction (Kochhar, 2020). Ecological relations within these specific rivers provided the basis for a way of thinking about water pollution in general. By 1938, Streeter could write that:

> "It was not until the early years of the present century… that a true conception began to be held concerning the biochemical reactions involved in the self purification of streams, together with their extent, limitations and modes of action. Today there is no longer any doubt as to the actuality of this phenomenon, as it has been measured by methods which now are reasonably precise and simple in application, and its effects are known to be definite and to a considerable extent predictable in accordance with well-established laws."
> (Streeter, 1938, p. 747)

A key outcome of this experimental work was the notion of assimilative capacity, which builds upon the concept of self-purification to suggest there is some threshold below which pollution is

[26] Such simplifications continue to be valuable for governing water quality. As mentioned in the previous section on BOD, though the Central Pollution Control Board monitors many different parameters, when they classify rivers into priority classes for remediation it is solely BOD that is used as the metric (Central Pollution Control Board, 2018; Lele, Jamwal and Mahesh, 2021).

acceptable as the 'receiving environment' can assimilate it[27]. Pollution becomes a binary category, only a concern if concentrations are above the threshold. This model – with its framing of pollution as a definite phenomenon following 'well-established laws' – could be applied to any water body. This meant replacing a complex physical, chemical and aesthetic spectrum of pure to highly polluted water, with a single line of demarcation. Subsequent generations of struggle over pollution, water quality and health have deepened the ways in which water quality is regulated and made the restoration of ecological health a goal for many water bodies. Still, the threshold concept continues to underpin water quality standards, even as it only makes sense for some kinds of pollutants[28] (Liboiron, 2021).

Thinking with this history adds another layer of insight to water quality politics. In her analysis of arsenic-contaminated tube-wells in Bangladeshi waterscapes, Farhana Sultana specifies that "safe tube-wells are those which produce water with less than 50 micrograms of arsenic per liter" (Sultana, 2013, p. 338). It was this threshold that enabled health workers to mark tube wells in red or green paint, as safe or unsafe. The knowledge practices that defined this threshold extend well beyond the Bengal delta. Yet, as the product of ongoing knowledge practices, this threshold has its own contingent history. The harmful effects of high concentrations of arsenic have been well determined, but the health impacts of lower doses of arsenic remain an area of scientific dispute (see, for example, Shao *et al.*, 2021). The impermanence of flaking red paint on waterspouts is not the only way in which clear lines between safe and unsafe water might be unmade.

Indian history

This history provides a framework for a basic understanding of water quality standards in India. Philippe Cullet and Joyeeta Gupta (2009) note that the Law of Manu, a Hindu legal text dating back to 200 CE or earlier, "imposed a system of social reprimands and punishments for those who polluted the water" (p.160). Skipping forward to recent centuries, Vandana Shiva (2016) argues that "prior to

[27] Putting this concept into practice meant that rivers were to be put to work cleaning up or diluting pollution, at least within particular 'sacrifice zones' (Keeling, 2005; Kneitz, 2012; Liboiron, 2021). This argument is still being made today! (Willcock *et al.*, 2021)). As Max Liboiron (2021) notes, in the United States and Canada, this is settler colonialism in action, as access to Indigenous Land and water is viewed as an entitlement.

[28] With a century of further research and the synthesis of thousands of novel organic chemicals, many additional pollutants are now incorporated into water quality standards. Many of these pollutants make biological relations in ways that don't match the threshold model, and yet, as Liboiron notes "The threshold model of harm is formidable in its resilience" (Liboiron, 2021, p. 62). The key issue with these water quality approaches is a lack of specificity (Liboiron, 2021). Contaminants have widely different properties and relations. Not all contaminants are degraded in the same way as organic matter, instead, some compounds are highly stable, or accumulate. And while some compounds have no impacts below a certain concentration, that is not the case for other compounds for which there is no such threshold (ibid.). In these cases, water quality standards act as a weighing, calculation or legitimation of harms.

the passage of the Water Act of India in 1974, almost all judicial decisions were in favor of polluters" (p.119). This reflects the colonial legal framework influenced by UK law, and a similar prioritisation of industrialisation and economic development to that seen in the United States (Paavola, 2002). The passage of the 1974 Water Act was partly spurred by the 1972 Stockholm Conference on Human Environment (Central Pollution Control Board, 2010), which was itself an indicator of the growing force of concerns about environmental pollution. The preamble of this Act sets out an aim to "provide for the prevention and control of water pollution and the maintaining or restoring of *wholesomeness* of water" (ibid., p.1).

Under the system established by the Environmental Protection Act 1986 the Central Pollution Control Board (CPCB) sets minimum discharge standards, which states can strengthen if desired, through their state-level pollution control boards[29]. These standards are tailored to a wide range of different industries and industrial processes, including coal power stations, cashew seed production and sewage treatment plants[30], alongside a 'General Standard' for those processes (such as constructed wetlands) that do not have a specific standard (Central Pollution Control Board, 2010)[31]. The CPCB specifies that State boards shall "take into account the assimilative capacities of the receiving bodies, especially water bodies, so that quality of the intended use of the receiving waters is not affected" (CPCB, 2010). In this sentence, the reference to assimilative capacities points to the continuation of pollution logics described previously. This guidance also indicates a focus on the use of waters.

While discharge standards have a specificity towards industry, spatial location and receiving environment (divided into inland surface water, public sewers, land for irrigation or marine/coastal areas) there are still many issues with this approach to ensuring good water quality. Commenting on the Water Framework Bill, Veena Srinivasan et al. (2016) write that "water quality regulations in India are weak and fragmented" (p. 7). Sharachchandra Lele, Priyanka Jamwal and Mahesh Menon (2021) suggest that standards "vary inexplicably" (p. 3). There are no standards that specify desired states for a water body, only for water being put to use (Misra, 2021)[32]. Lele et al. (2021) trace these problems

[29] Alongside the CPCB discharge standards, separate use standards are developed by the Bureau of Indian Standards and include standards for drinking water and irrigation.
[30] The total list contains over 60 different industries. This specificity of allowances for each industry gives credence to Vandana Shiva's framing of water quality standards as 'permission to pollute' (Shiva, 2016, p. 120).
[31] An appendix to this table states that "these standards shall be applicable for industries, operations or processes *other than* those industries, operations or process for which standards have been specified in Schedule of the Environment Protection Rules, 1989" (italics added). A total of 33 parameters are included.
[32] 'Designated Best Use' classifies lakes and rivers into one of five classes of suitable use, ranging from drinking water and bathing to fisheries to industrial cooling (Central Water Commission, 2017), but this is a categorisation of current conditions rather than a desired state.

to a lack of independent and accountable governance in state-level Pollution Control Boards, and ultimately question whether an improved process of judging and regulating water quality is possible in "an era of single-minded promotion of economic growth and 'ease of doing business' by the state" (p. 8).

Besides the issues described above, there is an ambiguity in the current Indian water quality legislation[33]. I could not find any description of how these standards account for variability over time. Is water required to meet the standard every time that it is tested, or only on average over time? Some water quality legislation prescribes this, specifying that standards must be met on 95% of sampling occasions, for example[34]. In describing the Berambadi wetlands as meeting water quality standards, project participants seemed to be drawing on average concentrations. My analysis of both wetlands in terms of percent exceedance gives a different picture. None of the parameters meet the surface water discharge standard 100% of the time. Nitrate-nitrogen (84% probability) and COD (94%) come closest. For both BOD and suspended solids, there are roughly even odds that it will meet or not meet the standard at any sampling. Ammonia-nitrogen meets the standard only 15% of the time. A lack of specificity allows contradictory claims to be made about adherence to standards.

Table 5.1 - Percent adherence to CPCB discharge standards at Ibrahimpur and Berambadi

Parameter	Threshold for discharge to inland surface water (mg/L)	Percent of Ibrahimpur outflow samples under threshold	Percent of Berambadi outflow samples under threshold
BOD	30	6%	48%
COD	250	n/a	94%
Nitrate-nitrogen	10	65%	84%
Ammonia-nitrogen	50	100%	15%
Phosphate	5	88%	6%
Suspended solids	100	n/a	45%

Given these political histories of standard making, a key question for evaluating the appropriateness of water quality standards is how such standards, parameters and threshold values are derived. An opaque regulatory process makes understanding how standards were developed by the Central Pollution Control Board next to impossible (see Dharmadhikary, 2017). Timothy Karpouzoglou's interviews with CPCB staff suggest that the default condition is that standards are "dictated by the

[33] Anand (2022) also describes Mumbai effluent standards as worked through ambiguities.
[34] The relevance of these different ways of measuring depends on whether the pollutant in question causes acute or chronic harm.

'international literature', and not by 'baseline studies'" (Karpouzoglou, 2012, p. 106). The preface of the Indian Drinking Water specification (IS 10500, 2012) traces this directionality of water quality knowledge; revisions were made to "align with the internationally available specifications on drinking water" (p. i), including EU, USEPA and World Health Organisation standards. The dissemination of knowledge and concepts reflects an assumption of universal water quality knowledge. This may be appropriate for drinking water and other human uses of water but is less suitable for regulating the harm that water pollution may cause to specific water bodies and their ecologies. This can be seen by examining how Indian standards engage with two water quality metrics introduced earlier: BOD and E. coli.

BOD as a standard

The history of BOD standards suggests that this metric embeds a focus on river waters and their processes. As already described, BOD testing methods were developed as part of efforts to control river pollution from sewage. Dilution is assumed, as wastewater flows into a river or stream. This assumption was incorporated into the Royal Commission's recommendations for BOD standards (1915). Dilution assumptions are also carried through into Indian CPCB discharge standards. These standards prescribe 30 mg/l of BOD as a discharge standard to any surface water body anywhere in India. At the same time, State pollution control boards are instructed to take "into account the minimum fair weather dilution available" in a particular stream (Central Pollution Control Board, 2010, p. 16). This is important for urban water bodies, as the level of dilution is often close to zero (Lele, Jamwal and Mahesh, 2021). Yet, this specification was not part of how the Berambadi project engaged with the standard, in effect treating the drains receiving wetland outflow as if they were rivers.

Rather than dilution of flows validating BOD standards, a different hydrological relation was dominant for these constructed wetlands; the evapotranspiration of water, amplified by the plants in the wetland. As the evaporated water does not contain nutrients or organic matter, concentrations in the remaining water, and of the wetland outflow is increased[35]. Dilution assumptions indicate an attunement of BOD standards to streams, rivers and other flowing surface water. BOD standards have been developed to align with the hydrological and ecological processes of rivers, while the hydrology of wetlands and other water bodies are significantly different.

[35] This evaporation impacts how wetland performance is judged. The results presented in the 'efficiency' section assume no evaporation takes place. In a vegetated wetland in summer that's a poor assumption. Unfortunately none of the wetlands had continuous flow measuring equipment that could measure evaporation. When flow sampling did take place, it was only at either the inlet or the outlet, and not both at the same time. Therefore, this 'no evaporation' assumption was the only method available.

An additional detail of the BOD testing method demonstrates how characteristics of particular waterscapes become universalised in water quality testing. As oxygen declines asymptotically the choice of five days for the test rather than three, four, seven or more days is somewhat arbitrary. Sources suggest that the selection of five days for the test corresponds to the maximum length of English rivers, as after five days, any organic pollution would have reached the ocean (Robbins, 2007, p. 142; Jouanneau *et al.*, 2014). Hence, using this BOD method to measure water quality continues a genealogy of water quality methods that springs from historical specific issues with (English) rivers. In 1996 the CPCB shifted Indian standards from five days at a controlled temperature of 20 degrees, to three days at the higher temperature of 27 degrees (Central Pollution Control Board, 2010). This alteration of the method gives a comparable result (as metabolism rates increase with higher temperature). I haven't been able to determine the reasons for this shift, perhaps it is better suited to climatic conditions in Indian laboratories, or a speedier result was needed. Given the geographical specificity of the original method, the actions of the Central Pollution Control Board could be figured as an undoing of colonial universalisms, even if motivated by practical rather than ideological concerns.

Yet the laboratories that conducted water quality testing for Ibrahimpur and Berambadi still use the 20 degrees and five days combination. In reporting the Berambadi results, this is described as following the *Standard Methods for the Examination of Water and Wastewater*, a reference text that is the joint work of three United States technical societies, the American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF). *Standard Methods* is a benchmark for "accurate, proven" methods, promoting a universal approach to conducting water quality testing (American Public Health Association, 2005). Using a five-day BOD method is a necessary universalism for results to be accepted in globalised networks of academic publishing.

E. coli as a standard

Standards also help to understand the persistence of E. coli testing, despite the World Health Organisation's recommendations that other indicators would be preferable. Two decades on from this recommendation, E. coli was part of the water quality testing in both project's wastewaterscapes and many others. Despite its ambiguities, E. coli is part of Indian water quality standards, defined by Pollution Control Boards at national and state levels (Central Pollution Control Board, 2010; Bureau of Indian Standards, 2012). As already described, these standards are drawn with reference to UK and US standards. In this way, as knowledge follows pathways laid down by colonialism, the behaviour of E. coli bacteria in one climatic zone is universalised. Besides the solidity of national standards, another factor nudging towards E. coli testing is the technology available for it. The Colilert® method described above is an easy to implement method requiring a simple set of equipment and reagents, all produced by an American company (*Colilert*, no date). The simplicity of this test reflects the development that has gone into it because of the widespread use of E. Coli as a water quality testing parameter. In contrast, testing for some of the other bacteria that the World Health Organisation recommends is done through microbial assays that require more specialised equipment and skills (American Public Health Association, 2005). Constellations of knowledge, technology and power have rooted E. coli testing firmly in the practices of a variety of actors. E. coli testing follows a well-worn groove determined by legal and technological constellations, which create and legitimise a particular way of producing water quality knowledge.

Beyond standards

Water quality standards provide prescriptive answers to the question of what counts as good water quality. They specify which parameters and thresholds determine if wastewater is 'treated' and suitable for release into 'the environment', if a river or stream is in 'good condition' (Carvalho *et al.*, 2019) or if water is safe for a particular use. These answers embed ethico-political judgements and reflect particular histories of water pollution. At the same time, as Marianne de Laet and Annemarie Mol (2000) note, "Standards… not only *create* but *require* uniformity" (p. 243). Such uniformity is not available across the diversity of Indian waterscapes. Rather than relying on the "binary boundaries" of standards (ibid., p. 243), there are other ways of handling water quality measurements. If determining adequate water quality started from the circulations of wastewater drain, pond and groundwater hydro-ecologies would BOD and E. coli have emerged as key metrics? Thinking carefully about wastewater requires a shift in focus away from what standards prescribe.

Judging water quality improvement by standards and thresholds does not say much about how this water impacts on waterscape ecologies. The task for critical water studies is to go beyond struggles to set and force adherence to thresholds. Instead, we should recognise that thresholds and standards are not always the best way to treat water quality (de Laet and Mol, 2000; Liboiron, 2021). Standards become goals in themselves, detached from pollutants' impacts on specific places. This brings into focus the major advantage of standards from the perspective of these research projects; they provide a simple answer to difficult questions of ecological entanglement. But different answers might be required to orient water quality knowledge towards more-than-human flourishing.

Efficiency

During a visit to the Berambadi wetland, the head teacher at the school asked me: "How is the efficiency of the system?". Efficiency is an internal comparison between water quality at the inlet and outlet of the constructed wetlands, expressed as a percentage reduction. It is a particular logic for making water treatment meaningful, and one that many of the scientists and other stakeholders associated with these projects found good to think with. Berambadi project reports described how "both [wetlands] showed significant TSS and organic matter (BOD_5 and COD) removal efficiency" (Ellis *et al.*, 2020, p. 45). At Ibrahimpur, the final project report makes no reference to water quality standards, results are presented as a percentage reduction in pollutants; a measure of wetland efficiency (National Institute of Hydrology, 2021). Treatment efficiency is also near ubiquitous for the presentation of results in published constructed wetland literature (Kadlec and Wallace, 2008). To take one example, Sutar et al. (2019) write "the removal of COD and BOD were 66% and 72%, respectively—which shows significant treatment efficiency of the [constructed wetland] bed" (p. 161). Efficiency calculations are a simple but powerful way of making water quality results meaningful, in the context of wastewater treatment.

Using the water quality data for both locations, I made my own efficiency calculations (see Table 5.2). For the Ibrahimpur wetland, results are presented both with and without the upstream settling chamber. These results show that the settling chamber contributed an equal or greater reduction in BOD and COD. The average efficiency of wetland alone was 22% and 25% for these parameters. The treatment efficiency also proved much more variable than had been expected. Across sampling days, the performance of the wetland could shift dramatically. Figure 5.4 and Figure 5.5 present temporal trends, plotting BOD, COD and a measure of nitrogen and phosphorus from each wetland over time. At Ibrahimpur, the wetland never achieved above 75% efficiency in reducing BOD or phosphate. Dissolved organic nitrogen only once exceeded a 25% reduction. For Berambadi, removal efficiency was more consistent. BOD and COD both had efficiencies between 50 and 75% most of the time, with maxima above 80% in each wetland. Efficiencies for total nitrogen and phosphorus were less impressive[36].

[36] The temporal patterns in these efficiency results also suggests that canna health was not a reliable signal of wetland performance (as discussed in the first section). The Ibrahimpur wetland, while producing a solid reduction in Biochemical Oxygen Demand in May, had performed equally well the previous November and December, when the canna lily was small and sparsely distributed. Predicted performance reductions due to canna rust at Berambadi also could not be seen when analysing the water quality results, partly due to the high variability between sampling dates. Hence, judgements about wetland performance based on canna aesthetics produce a different conclusion than those from technical analysis. These somewhat contradictory conclusions appeared to co-exist side-by-side within project evaluations.

Table 5.2 - Efficiency of constructed wetland pollutant removal

Site	Parameter	Mean efficiency of wetland treatment[37]	
	Location	*Wetland only*	*Including grit chamber*
Ibrahimpur	BOD	25%	48%
	COD	22%	74%
	Nitrate–N	-298%	-377%
	Ammonia–N	-2%	11%
	Phosphate	35%	40%
Berambadi	*Location*	*Wetland one (unplanted)*	*Wetland two (planted)*
	BOD	64%	56%
	COD	57%	59%
	Ammonia–N	11%	1%
	Nitrate–N	-136%	-68%
	Phosphate	14%	1%
	Total Nitrogen	9%	11%
	Total Phosphorus	17%	5%

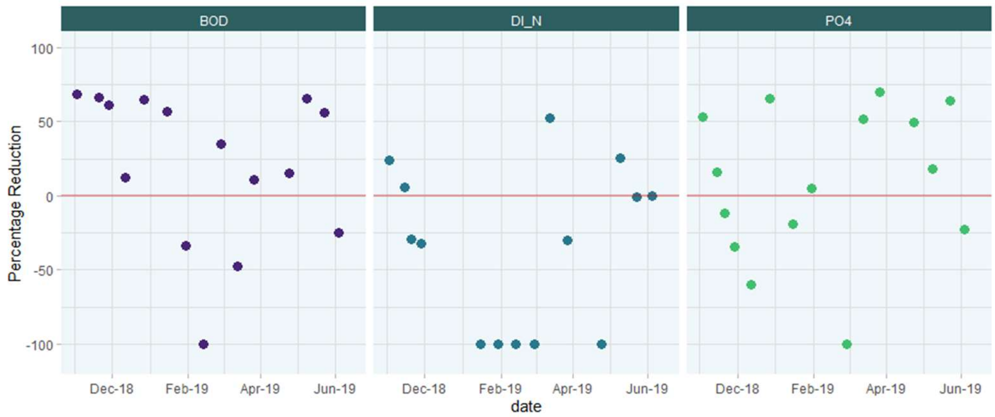

Figure 5.4 - Ibrahimpur wetland efficiency for BOD, Dissolved inorganic nitrogen and phosphate[38]

[37] The percentage reduction is calculated as: % reduction = (mean inflow - mean outflow)/mean inflow. As outflow concentrations were sometimes higher than the inflow, negative percentages are possible. For instance, a percentage reduction of -100% represents a doubling in outflow concentration relative to the inflow. These results are calculated using average inflow and outflow, which is a further interpretive choice made in knowing and presenting water quality results. An alternative method, calculating efficiency at each sampling date then averaging those efficiencies, gives a different result.

[38] These plots have been truncated; values lower than -100% have been plotted at -100% for chart legibility.

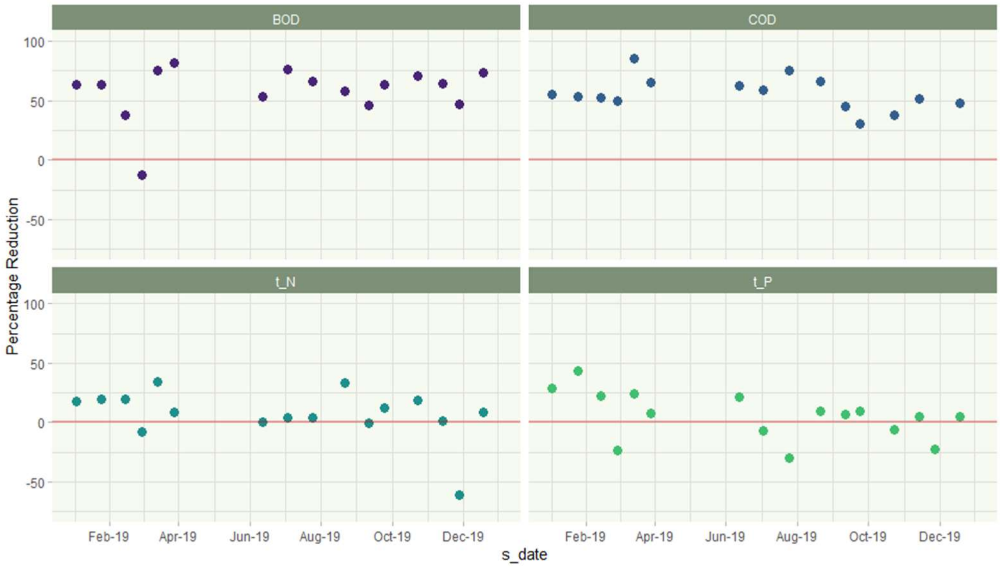

Figure 5.5 - Berambadi constructed wetland efficiency for BOD, COD, total nitrogen and total phosphorus

Working between the scientific team's uses of efficiency and my own efficiency analyses demonstrates the affordances and limitations of this metric. Efficiency is an excellent metric for comparison. Firstly, these efficiency metrics implicitly compare to a situation with no wetland. Efficiency tells you that what you've done is better than nothing. The constructed wetlands did produce some improvements in water quality. Statistical tests of probability provide a robust way to evaluate these shifts, essentially asking if positive efficiencies could just be the result of random variability. I used a paired t-test was used to statistically compare inflow and outflow concentrations. Only BOD and COD in Berambadi wetlands 1 and 2, and phosphate and total phosphorus in Berambadi constructed wetland 1 showed a statistically significant[39] decline. The hypotheses that the wetland at Ibrahimpur did nothing to reduce BOD, COD and phosphate could not be discounted[40].

Secondly, efficiency results published in the constructed wetland literature give comparability between different wetland locations and configurations. An interview with one member of the Berambadi project team suggested that based on this comparison, the Berambadi wetland was not performing. But another team member, by focusing on to the highest efficiency results, was able to

[39] Statistical significance is another tool for making sense of wastewater treatment, but one that was not always applied in how results were reported. Presenting results without clarifying whether the results are significant validates small shifts which (from a statistical perspective) could have been the result of random fluctuations.
[40] Due to the composition of water flowing to the Ibrahimpur wetland, the inflow quality can vary rapidly, as a yard is cleaned of cow dung, or water from a tube well is switched on for washing kitchen utensils. While flows coming out of the wetland are more stable the inflow variability leads to unevenness and variability in efficiency results, this is part of the reason for these statistical results.

suggest the wetland was performing as expected. Published results set the bounds of expectation for wetland performance. Efficiency allows comparison between diverse wetlands, with no guarantee that this comparison is meaningful. Kadlec and Wallace (2008) write:

> "It is very easy to compare the amounts of a pollutant in the inlet and outlet streams of a wetland, and to compute the percentage difference [i.e. efficiency]. Unfortunately, this information is of very limited use in design or in performance predictions, because it reflects none of the features of the ecosystem." (p. 170)

Efficiency also circumvents the need to think about potential impacts arising from outflow water quality. While a higher efficiency will always be preferable, efficiency as a metric is determined as much by the quality of inflow water as it is by the outflow. This means that a wetland with very high efficiency could still be discharging water with significant concentrations of contaminants. Doing 'better than nothing' does not guarantee any reduction in harm. The focus on efficiency produces a form of water quality knowledge that is disconnected from the effect of the water on the waterscape.

Social and political meanings

While standards and efficiency were universal measures that helped to make sense of water quality for scientific (as well as local) audiences, the meaning of water quality in Ibrahimpur can't be separated from cultural judgments about water pollution. During my social survey in June 2019, I asked which components of wastewater were the most significant. The results of this survey are presented in Figure 5.6. Human waste stands out as a primary concern. The sewage overflowing from soak pits and adding to wastewater flows may not have been significant by volume, but it brought about significant material-semiotic changes to water quality. As a pile of sanitation literature has explored – and everyday experience will attest – human excrement has a strong cultural valence (Jewitt, 2011). This is particularly true in India (Coffey and Spears, 2017). Cultural judgements on pollutants are combined with hydrogeological knowledge; as Ibrahimpur wastewater flows into the pond and from there into the shallow groundwater (60-70 ft), both water sources now are widely considered to have bad quality water[41]. These concerns exceed what can be sensed about the water, or what quality standards might indicate.

[41] IBM GI 1,4,5,8

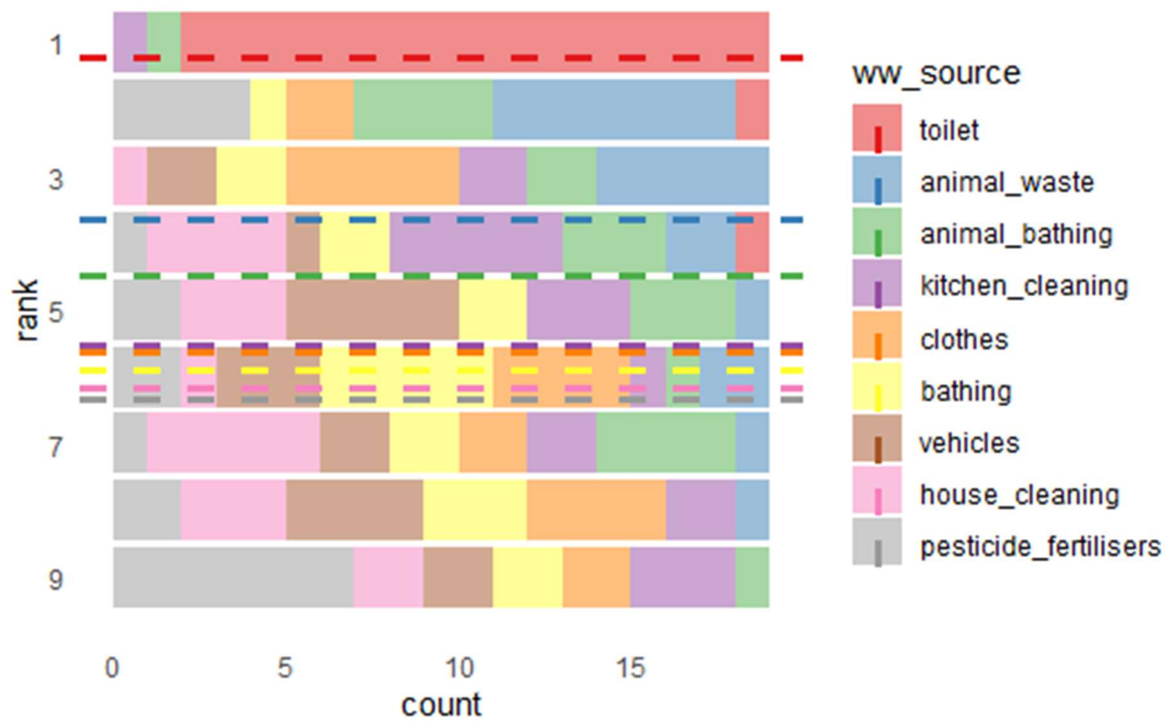

Figure 5.6 - Ranking of wastewater components. Count refers to the number of households ranking a source at a particular rank. For example, for rank 1 (most important), 17 out of 19 households chose toilet water, one household animal bathing and one kitchen cleaning. A horizontal dashed lines show the average rank of each source.

Standards and efficiency metrics are both techniques of comparison. Other forms of comparison are also used to make water quality meaningful for those living around these wetlands. For instance, observations of water quality are shared through conversations, building up an understanding of water quality that is socially meshed. Gathering water from outside taps each morning, women in Berambadi can discuss the water quality with their neighbours[42]: "When we are out to collect water at the tap, we discuss if we notice something". One woman in Ibrahimpur recalled how visiting relatives had told her the water from her well was good[43]. In these conversations, water quality is compared across different locations and over time.

Such social comparisons are necessary in a context where other ways of knowing water quality are unreliable. Several households recounted stories of external testers coming to check water quality. One interview suggested that this water quality testing was conducted by people working for a reverse osmosis water purification company who had judged that the water quality wasn't good[44] (presumably in comparison with water treated by reverse osmosis filters). Other conversations suggested a government department had come to tests the water two years prior, and that a

[42] BER GI 2,5
[43] IBM GI 2
[44] IBM GI 10

chemical dosing of the hand pump water had taken place[45]. Besides indicating that standards had been met, the water quality data (including data on groundwater and other water sources) generated in the Berambadi project was not presented back to local people[46]. These external testers provided patchy water quality information, with the enabling-yet-simplifying logic of standards serving more to mark the expertise of testers (Mitchell, 2002) than to respond to community concerns. As one respondent noted, when asked when further testing might happen, 'nobody calls them, they come by themselves'[47].

At one of the wealthier households in Berambadi a woman told us that she received information about water quality by asking the panchayat officers and shared this information with other people[48]. The panchayat staff also suggested that the water officer informed people of water quality and recommended when to boil water[49]. However, households in Berambadi who did not belong to the dominant caste said that they had not received any information from the Panchayat[50]. In Ibrahimpur, many respondents expressed that nobody had told them about water quality[51]. When "each and every person is saying that the water is not good"[52] perhaps this expert knowledge was seen as unnecessary. At the same time, it indicates how the sharing of water quality knowledge aligns with the turbulence and stratification of social interactions.

A respondent from one of the Lingayat[53] households noted that 'even if we complain to the panchayat [about bad water quality], they do not take any action'[54], while another household described how they were told by the panchayat to send a letter 'to higher authority' and suggested that the panchayat would only act if many people complained[55]. Grappling with the question of how to make water quality *politically* meaningful, people realised that power would come from converting individual knowledge of water quality into collective action.

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[45] IBM GI 4,5
[46] As indicated by interviews with project participants.
[47] IBM GI 4
[48] BER GI 7
[49] BER Panchayat staff interview
[50] BER GI 2,5
[51] IBM GI 9,10,11
[52] IBM GI 3
[53] The dominant caste in Berambadi
[54] BER GI 3
[55] BER GI1

Historically situating water quality knowledge

My critique of standards and efficiency metrics rests on a questioning of the uniformity or universality that these measures assume, and require to be effective (de Laet and Mol, 2000). The first section of this chapter challenged assumptions and enactments of universalism through close attention to water ecologies, in this section it is historical translations and hydrological specificities that emerge as equally important for situated knowledge of water quality. In both cases we see the influence of universalism, the belief that certain concepts can be 'valid in all times and places' (Rogers, Castree and Kitchin, 2013, para. 1). As Max Liboiron (2021) argues, the question is how to generalise appropriately. Giving more attention to ecological relations as well as histories of water quality methods are both avenues for generalising carefully. If knowledge arises in more-than-human relations, then understanding the positioning of beings and technologies involved in these practices is just as important as the positionality of human researchers.

Zwarteveen and Boelens (2014) map the divergence between situated and 'universal' knowledge to more or less equitable water orders:

> "much water knowledge speaks 'as if' from nowhere, from a value-free and god-like position, by someone without interests or background, representing the universal good… we instead see meanings, discourses and (the production of) truths as internal to inequitable water orders, rather than external: they come about through situated perspectives that need to be made as explicit as possible." (p. 148)

Understanding knowledge as situated rather than universal highlights the values and interests that contribute to the creation of particular methodologies for knowing water quality. The creation of water quality standards can be read away from a 'value-free' position, to instead see how these standards were shaped by a desire to make the 'maximum use' of water, and a regulatory approach that aimed to be conducive to industrial growth. The interests that have shaped contemporary ways of knowing water quality often run contrary to multispecies water justice.

A historical analysis also uncovers the "radical historical specificity" (Haraway, 1988, p. 578) of particular techniques, revealing them to be the product of particular scientific and political configurations that were far from inevitable – and hence, far from universal. While water science may present its knowledges as both essential and highly generalisable, there is contingency and hence contestability in the methods and concepts used to judge water quality.

While tracing the processes producing waters of varying qualities is already a complicated undertaking, adding a critical analysis of the techno-political processes through which water quality is made meaningful contributes another layer to the politics of water. Making situated perspectives explicit is an important step towards countering water injustices. To develop situated knowledges is, in Haraway's account, to be working towards a "more adequate, richer, better account of a world, in order to live in it well" (ibid., p. 579).

Conclusion: knowing and making waterscapes differently

Water quality standards – and their threshold logic – position wastewater discharge as a practice that doesn't constitute pollution, so long as the threshold values aren't exceeded. This logic does more than offer a way of evaluating constructed wetland performance. Since constructed wetlands never remove all the nutrients, organic matter or other contaminants in wastewater streams, a threshold model of pollution is an enabling logic without which constructed wetlands would not be acceptable as water treatment infrastructure[56]. Ways of knowing water quality make some forms of infrastructure seem logical and discount others.

This point illustrates a broader political significance of water quality knowledges. This is encapsulated in the concept of *co-production* (Jasanoff, 2004; Forsyth, 2008; Aubriot *et al.*, 2018), which recognises that scientific knowledges and technologies do more than just measure a pre-existing reality. Instead, in the words of John Law, these knowledges "participate in the social world, being shaped by it, and simultaneously shaping it" (Law 2004, page 12). Within hydrosocial research, such processes of co-production have been explored from the large scale of river basins and mega-projects (Carse, 2012; Bouleau, 2014) to the affective landscapes of small scale development interventions (Sultana, 2011). If social and ecological histories shape water quality knowledge, these knowledges in turn mould infrastructure projects and refashion land and waterscapes.

These processes of co-production extend beyond infrastructural form. Ways of knowing water quality both reflect and inform the ethics and politics of waterscapes. For instance, Indian standards are oriented towards maintaining the useability of water for people, while efficiency metrics are also silent on downstream ecological impacts. In this context, the resultant pollution of waterscapes can be read as a practice of human exceptionalism (Haraway, 2008; Tsing, 2014; Srinivasan and Kasturirangan, 2016). The standards and technical practices deployed in Ibrahimpur and Berambadi

[56] If discharging sewage into water bodies wasn't viewed as acceptable, alternative approaches are available, including as sewage treatment that aims for total evaporation of water, application of treated water onto land, or toilet designs that avoid water entirely.

embed human exceptionalism into these waterscapes. While my account has highlighted more-than-human relations as central to generating water quality knowledge, this entanglement does not automatically translate into an ethical concern for the other-than-human beings who also inhabit waterscapes (Srinivasan, 2022a). In other words, more-than-human relations are currently a means but not a motive for tracking water pollution. If situated knowledge requires acting in "critical, reflexive relation to our own as well as others' practices of domination" (Haraway 1988, p. 579), this awareness should surely extend to domination within more-than-human relations. My critical evaluation of water quality has hence aimed to unpick the co-production of water quality knowledges and human exceptionalism.

In making sense of water quality in these waterscapes, I have found inspiration in broader analyses of pollution and toxicity. A key argument here is that dominant ways that pollution is understood *do not work* (M. Murphy, 2017; Gabrys, 2018; Liboiron, 2021; Theriault and Kang, 2021). Knowledge practices like those which I have described above do harm by allowing some pollution and making the historical roots of toxicity invisible. On top of this, they don't generate the kinds of politics that are needed to live well amidst pollution (Liboiron, Tironi and Calvillo, 2018). Hence, a critical analysis of water quality knowledge might provide an opening to reflect on the broader politics of toxicity that is enacted in these waterscapes.

As Liboiron et al. (2018) argue, toxic harm "can be understood as the contravention of order at one scale and the reproduction of order at another" (p.335). This suggests that critical studies of pollution need to move beyond viewing toxicity as solely the outcome of contaminants in water/air/soil. Nicholas Shapiro, Nasser Zakariya and Jody Roberts (2017) suggest that toxicity "often functions as a proxy for a range of cultural, economic, or infrastructural instabilities that are, indeed, something 'toxic' but are far more complicated and difficult to identify" (p. 581). A water quality parameter which illustrates this clearly is nitrate. Studies from India, Vietnam and Sub-Saharan Africa show that, even at concentrations less than the typical drinking water standard of 10 mg/l, exposure to nitrates is correlated to significant decreases in adult height – a proxy measure for broader health (Damania *et al.*, 2019). Groundwater sampling at both Ibrahimpur and Berambadi showed that nitrate levels in tube-wells were often near or above 10 mg/l and few of the wells had concentrations less than 2 mg/l (Goyal and Singh, 2018; Ellis *et al.*, 2020), a level at which harms were reported in Vietnam. These elevated nitrate levels are not unique to these two villages, nitrate pollution is widespread across India (Sarkar and Dixon, 2021). Returning to the definition of toxic harm offered by Liboiron et al. (2018), this disruption of human health, plus groundwater and freshwater ecologies, is historically linked to the reproduction of capitalist agriculture through the innovations of the Green Revolution

(Aga, 2021), whose harmful socioecological effects are becoming more apparent each year. Reading elevated nitrogen levels through this lens suggests that the socioecological processes that drive the pollution of surface and groundwaters in these waterscapes require something other than technological solutions. A critical politics of toxicity must consider the macro-toxicities of social and ecological domination (Shapiro et al. 2017, p. 578).

One way of approaching water quality differently might begin from Michelle Murphy's (2017) concept of *alterlife*, a condition where the susceptibilities and potentials of future life are profoundly shaped by "community, ecological, colonial, racial, gendered, military, and infrastructural histories" (p. 497), so that "studying alterlife requires bursting open categories of organism, individual, and body to acknowledge a shared, entangling, and extensive condition of being with capitalism and its racist colonial manifestations" (p. 498). Alterlife is a critique of epistemologies sustained by the consistent erasure of constitutive violence (p. 498). For Murphy, recognition of alterlife is "an invitation to consider what infrastructures and concepts have to be dismantled to make room for another way of being and knowing to emerge" (Murphy, 2017, p. 10), Living in the ongoingness of water pollution requires recognising the violence included within devices such as water quality standards, and acting on this, working from entangled but differentially situated positions. These calls to dismantle certain concepts, to reclaim phenomena from violence-enabling epistemologies and to recognise a shared entanglement across bodies, resonate with the critiques of standards and metrics presented above, and suggest a way forward towards situated water quality knowledge, and multispecies water justice.

6 Models and motives: Interpreting changes in water quality

Introduction

As a cupful of water in Ibrahimpur makes its way from a shallow aquifer to a kitchen, to the street-side drains and through the constructed wetland, its material properties are transformed. Improving water quality is a central aim for constructed wetland infrastructures. To track water quality changes, data was generated by members of the project teams at Ibrahimpur and Berambadi. I generated data myself at Loch Leven. While the previous chapter looked at static measurements of water quality, this chapter takes this data as a starting point for thinking about water quality in flux[1]. Rather than simply measuring changes in water quality caused by the constructed wetlands, what I and others working on these projects were called to do was to explain or interpret these changes. We were aiming to account for why certain trends appeared and not others.

This chapter argues that making such interpretations is always a partial and political process. Interpretations draw upon models of hydraulic, ecological and social dynamics, as well as particular ways of representing water quality data. A critical analysis of interpretation calls for reflection on which models are chosen (Paxson and Helmreich, 2014). My method for exploring interpretation and its politics relies on juxtaposition. I first investigate how interpretation is practised in a publication from the Berambadi project. My analysis demonstrates how different models of ecological, hydraulic and social processes are used to develop an interpretation suited to the aims of the paper. I show how this interpretation is congruent with the broader constructed wetland literature. At the same time, I aim to critically evaluate how these models may simplify or flatten more-than-human relations.

In the second section of this chapter I embrace my position as an engaged participant in these waterscapes. In this section I draw upon a range of methods, observations and theories to justify a different set of hydraulic, ecological and social models. I use these models to offer my own interpretations of water quality changes over time and space. Such an interpretation practice repositions people, other living beings and water, compared to the Berambadi paper interpretation.

[1] This means that the direction and magnitude of change in water quality parameters is the focus, rather than the value of these parameters (and the ecological significance of this value).

Comparing these different interpretations makes visible the different objectives and outcomes of hydrosocial interpretation.

I build my interpretations upon a different set of models for understanding hydraulic, ecological and social forces. These models suggest that flows of water are varied and that much of this variability stems from hydrosocial processes. In examining ecological processes, I argue for a non-functional account of plant and microbial doings. And in the social domain I conduct an interpretation of changes in water quality through the frame of 'the project' (Li, 2015). These models reposition people, other living beings and water, compared to the Berambadi paper interpretation. Juxtaposing these two analyses demonstrates how models and ideologies shape all practices of explanation and generate interpretations with different political effects.

The interpretation of water quality changes cuts across multiple domains of knowledge. This is not unique. Hydrosocial scholarship has attempted to develop 'balanced' accounts where water quality and quantity is the result of heterogenous forces (see, for example, Ranganathan, 2015; Rusca *et al.*, 2017; French, 2019). More broadly, new materialist accounts have generated a lively debate about how to account for agency, events and transformations in more-than-human worlds (Bennett, 2009; Abrahamsson *et al.*, 2015; Lemke, 2018; Gandy, 2022b). In the final section of this chapter I explore what is at stake in interpreting differently. I suggest that the simplified interpretations of constructed wetland science normalise relations of domination between humans and over wetland ecologies. Finally, I consider the limitations of interpretation and ask whether water justice might be better served by more responsive interpretive practices.

Interpretation in Constructed Wetland Projects

Interpreting ecological action

In April 2021, the Berambadi project team published a paper in the journal Ecological Engineering; *Evaluating the performance of horizontal sub-surface flow constructed wetlands: A case study from southern India* (Jamwal *et al.*, 2021). Interpretation of water quality changes is central to achieving the aims of the paper. The first of these aims is to make sense of changes in water quality through reference to ecological processes.

At Berambadi, canna lily was planted in one of the two parallel wetlands, while the other was left empty. Comparing these two set-ups was a key emphasis of the paper. Average inflow and outflow concentrations for a range of pollutants are compared to see changes in the percentage removal efficiency. The aim of interpretation was to link changes in water quality to the influence of the plants, to unravel plant influences. For example, a comparison of the percentage removal of BOD and COD showed that the planted wetland had a "slightly higher" efficiency (Jamwal *et al.*, 2021, p. 4). As the authors explain, "this can be attributed to release of oxygen through the roots of *Canna indica* which facilitates the decomposition of organic matter by aerobic microbes." (p. 4). Turning from organic matter to nutrients, the authors note that "the net increase in nitrate-N concentration observed in the planted [wetland] was significantly lower indicating uptake/assimilation of nitrate-N by plants" (p. 6). In both cases, they interpret variations between the two wetlands as signs of plant vitality.

Measuring the contribution that plants make to water treatment is a perennial theme in constructed wetland studies (Brix, 1994a, 1997; Yang *et al.*, 2007; Fang *et al.*, 2019; Kumar *et al.*, 2020; Zheng *et al.*, 2020). To take one example, Yang et al. (2007) found that nitrogen retention improved from 59% to 76%, when comparing a non-planted control wetland to one planted with *Canna indica*. This is a finding backed up by many constructed wetland studies comparing planted and unplanted wetlands, as reviewed by Zhang et al. (2014)[2].

The experimental design of Berambadi – two parallel wetlands, one planted and the other left as bare gravel – was a continuation of this mode of analysis. It was an infrastructural configuration designed to allow a particular interpretation of constructed wetland processes. However, the plant processes highlighted in the paper – root zone oxidation and nutrient uptake – were ultimately just hypotheses. Neither oxygen release nor plant nitrate uptake were directly measured in these wetlands. They were suggested by the project team because of their inclusion in previous constructed wetland literature. The interpretation drew not only upon a physical experimental set-up but also on models of plant functionality in constructed wetlands developed by constructed wetland science.

Historically, constructed wetlands were treated as a 'black box' (Brix, Schierup and Arias, 2007; Kadlec and Wallace, 2008; Kumar and Zhao, 2011). A key impetus of wetland research has been to determine how they work – and how they might work better. Lab-based or small-scale experiments, with multiple wetlands running different set-ups, are key to this research, though these are abstracted from 'real-world' wastewaters. It is at this lab scale that direct measurements of processes such as root zone oxidation (for example, Tanner, 2001; Taylor *et al.*, 2011) or plant nutrient uptake

[2] Many of these studies also compare different plant species, aiming to find which species provides the most efficient wastewater treatment.

(Wu *et al.*, 2011; Ramprasad and Philip, 2016; Clairmont and Slawson, 2020; Grebenshchykova *et al.*, 2020) can more easily be conducted. For the Berambadi team, internal processes could be inferred by the differences between inflow and outflow, based on these generalised understandings of ecological processes. While no longer exactly a black box, the wetland is still not transparent.

What added complexity to ecological interpretation at Berambadi was that the plants did not stay healthy. The canna lily grew quickly. But after a few months the signs of a parasitic fungal infection of canna rust became visible, encouraged to spread by the wetland's humidity and dense clusters of leaves. As the authors summarise "after 102 days of planting *Canna indica*, yellow pustules were observed in the leaves of the plants accompanied by premature drying and falling of the leaves" (Jamwal *et al.*, 2021, p. 7). The paper goes on to suggest that this infection has important implications for interpretation. For example, "the infection could have inhibited growth and development of the canna lilies resulting in reduced nutrient uptake and subsequent poor nutrient load reduction" (p. 7). A chart indicating the variability of nutrient removal over time is presented as part of an interpretation that treatment efficiency had dropped after the canna rust infection. If the vitality of plants is significant for pollutant reduction, then less than expected improvement in water quality might be interpreted as a case of reduced vitality.

Figure 6.1 - Canna rust on a leaf from Berambadi. Photograph by the author, 2020.

The limited role of plants serves to bring Berambadi microbial communities into focus. Having calculated that wetland plants contributed a maximum of 18% towards the removal of any wastewater contaminant, the authors take this as an indication that biofilms play a primary role in pollutant removal (ibid., p. 7). Microbial communities are also part of their explanation for increasing nitrate-nitrogen concentrations in both wetlands. The conversion of ammonia to nitrate indicates the presence of a 'nitrifying community' (or functional group) of bacteria (p. 4).

The influence of microbial communities on constructed wetland performance was not something that Berambadi researchers investigated explicitly. However, their conclusions align with an understanding in constructed wetland literature that microbial[3] life is central to water quality transformations. Kadlec and Wallace (2008) report that "microbes are involved in a large proportion of wetland transformations and removals" (p. 61). Microbial research on wetlands attempts to deepen the ability to interpret constructed wetland results and to suggest ways to create better performing wetlands. This research makes use of molecular genetics and other techniques to map taxonomic or functional groups[4] of bacteria (see, for example, Chen *et al.*, 2015; Bernardes *et al.*, 2019; Truu *et al.*, 2019; S. Wang *et al.*, 2019). Faulwetter et al. (2009) summarise that the "removal of a particular pollutant is typically associated with a specific microbial functional group" (p. 987). For instance, microbes in the nitrifying 'functional group' are those that transform ammonia to nitrate. The concept of functional group resolves the diversity of microbial life within a wetland through a classification system focused on pollutant removal mechanisms. These functional groups offer a semi-tautological way to interpret constructed wetland performance.

Hydraulic interpretation towards design principles

A second, but no less important, aim of the Berambadi paper is to contribute towards the design of similar constructed wetlands in south India. The project team converted results to a form where they could serve as design principles. As the authors write, "for effective deployment of constructed wetlands… confidence in the translation of design principles to the field is essential" (Jamwal et al. 2021, p. 2). Developing these design principles requires models of constructed wetland hydraulics and kinetics.

[3] A note on terminology: microbial, as used in this section is not a technical term in biology. 'Microbes' include members of the kingdoms of bacteria, archaea and protozoa including fungi, plants and some microscopic animals.

[4] Taxonomic unit is the generic term for a taxonomic categorisation, ranging from the specificity of species to the more general categories of genus, family, order, class and phylum. I'll further discuss the mapping between functional and taxonomic groups of bacteria below.

One model the authors work with for this task is the first-order removal rate constant. The equation used to calculate removal rates through this model is:

$$ln\frac{c_i}{c_0} = kt$$

This expresses a simple idea, that the percentage pollutant reduction over any equal period will be constant – or, expressed more mathematically, pollutant concentrations reduce exponentially. The authors note that "the contaminant decay rate depends on design parameters (HRT, HLR), inflow characteristics, physical, chemical and biological processes, and environmental conditions (temperature, rainfall)" (p.8). In other words, these decay rates are a guide to what performance you might expect building a similar wetland in a similar climate, to treat similar wastewater.

Calculating a removal rate is a way to interpret water quality changes that relies on a succession of averaging and abstracting techniques. First, there is an averaging of both the inflow and outflow concentrations over time, flattening any variability in the constructed wetlands performance and abstracting it from the inflowing wastewater. Second, to convert this percentage reduction into a removal rate, we need to know the time that water takes to flow through the wetland (*t*, in the equation above). Another model is required here, an understanding of how water flows through the wetland. Guiding the flow of water is a key part of constructed wetland design (Kadlec and Wallace, 2008). A well-designed horizontal-flow wetland (the wetland type at all three sites) encourages water to distribute across the width and depth of the wetland and to flow smoothly from the inlet to the outlet. This model is known as 'plug flow'. A result of this flow pattern is that all water spends a similar amount of time within the wetland. The average time water takes to travel through a wetland is described as the Hydraulic Residence Time (HRT)[5]. HRT was an important parameter in the design and evaluation of the Berambadi and Ibrahimpur wetlands[6]. This parameter can be calculated in various ways. The Berambadi project team calculated the HRT by filling the wetland with water to calculate the pore volume and taking flow measurements over several days to determine an average

[5] The use of Hydraulic Residence Time does not automatically imply 'plug flow'. My contention here that plug flow was the dominant model used to understand wetland hydraulics at Ibrahimpur and Berambadi is also based on conversations with project teams.
[6] A longer HRT leads to improved treatment performance as there is more time for biological processes to break down pollutants, as well as a slower flow, which allows for more settling of suspended matter. The principle here is that wastewater treatment is largely a matter of time.

flow rate. The residence time was calculated as the flow rate divided by the internal volume. With a calculated HRT of 3.7 days, the removal rate constants could be calculated[7].

Turning to constructed wetland literature, while there are many other papers that take the same rate-constant approach (Braskerud, 2002; Konnerup, Koottatep and Brix, 2009; Luo *et al.*, 2019), there is also a caution about this mode of interpretation. Richard Kadlec (2000) argues that plug flow is a poor model for how water flows, no matter how well-designed the wetland. The structure of filter material, biofilm and plant roots within the wetland means that there is an uneven resistance to flow. Water flows faster through paths of less resistance, and this motion in turn maintains these paths as 'preferential flow paths' within the wetland. Simultaneously, in other zones of the wetland water and organic matter stagnate. If clogging of the wetland occurs, then water can also flow more quickly across the surface of the wetland bed, rather than within it. As a result, the time that some water takes to pass through the wetland can be significantly less than what HRT calculations and conceptual models suggest. This has significant implications for the transformation of water quality. To generate rate-constants, a conceptual smoothing-out and simplification of both pollutant and flow variability was required.

Interpretation towards social dynamics

The interpretations of plant disease covered earlier lead, in the Berambadi paper, to a conclusion about the management of constructed wetlands:

> "Proper maintenance of wetland vegetation, which includes regular harvesting of plants, inspection for pest infestation, weeds and pathogen infections, is essential to enhance performance of plants in contaminant removal" (p. 7) and hence "to achieve and sustain improved/ long term performance of constructed wetlands" (p. 9) (Jamwal *et al.*, 2021)

Though they do not state this, one implication of this argument is that 'proper maintenance' was not carried out (or was not possible) in the Berambadi project. This suggests the low treatment performance, brought about by the canna rust infection, ultimately has a social cause.

Social interpretations are more specific than interpretations based upon hydraulic or ecological processes. But this interpretation of constructed wetland under-performance as a failure of

[7] To calculate these rate constants the Berambadi team also included concentrations from intermediate sampling points. In this way, an assumption of uniform flow is used to map between space (distance along the wetland) and time (used to calculate a rate-constant).

maintenance aligns with other research on constructed wetlands in India. A report reviewing different 'Natural Treatment Solutions' in India argues that poor operations and maintenance is a major cause of constructed wetland failure (Wintgens *et al.*, 2016, p. 135). Based on research at four constructed wetland sites in Telangana and Karnataka, India, Friedrichsen et al. (2020) point out that local understandings of constructed wetland processes may hinder maintenance. They suggest that perhaps the best – and certainly most techno-optimistic – solution is to design constructed wetlands so that no maintenance is required. These discussions reflect broader questions about how to ensure that decentralised water infrastructure is maintained, particularly in contexts where state funding is not available or reliable (see, for example, the 'community water' literature: Mesa *et al.*, 2014; Birkinshaw, Grieser and Tan, 2021). Interpretations of infrastructural performance hinging on maintenance are commonplace, but, as I will explore further below, simplify the social complexities of infrastructure (Larkin, 2013).

Interpretation as a question of models

The paper from the Berambadi project suggests a scientific motor in action. Accumulated knowledge of constructed wetland processes propels interpretation[8], and drives towards the "scaling up" (Jamwal *et al.*, 2021, p. 9) of constructed wetlands in southern India. The Berambadi project team's interpretation of water quality changes pulls together hydraulic processes in the wetland (the basis of rate constant calculations), ecological processes (used to explain variations in treatment performance) and interpretations of the social arrangements required for constructed wetland performance. Sustaining water quality improvement involves particular arrangements of hydraulic, ecological and social forces and relations.

The specific case of interpretation from the Berambadi project is congruent with the broader constructed wetland literature. Interpretation in constructed wetland science unfurls a web of interactions between water, microbial communities, plants and filter materials so that wetland design can be adapted to create more efficient and robust wetlands. It is also oriented towards predicting wetland performance, so that new wetlands can be designed to meet required standards. These models might be built on an understanding of particular physical processes, formalised to allow for mathematical modelling, or they might be more abstract (Rousseau, Vanrolleghem and De Pauw, 2004; Kumar and Zhao, 2011; Samsó, Meyer and García, 2015). Social interpretation also relies on particular models to account for constructed wetland failures.

[8] Each 'can be attributed to' or 'suggests' in the paper has a citation from previous constructed wetland literature.

Identifying and probing these models is part of a critical practice of interpretation. One way to approach this task is through Henri Lefebvre's triadic conception of space (Lefebvre, 1991). Alongside spatial practice and representational space, Lefebvre describes *representations of space* as "conceptualized space, the space of scientists, planners, urbanists, technocratic subdividers and social engineers" (ibid., p. 38). The ecological, hydraulic and social models described above are representations of waterscape space. Such representations are "abstract, but they also play a part in social and political practice" (p. 41). Divergent representations offer distinct interpretations of water quality changes, and these interpretations have practical consequences. Lefebvre emphasises that representations of space are built upon knowledge that is neither fixed nor neutral.

> "representations of space are shot through with a knowledge (savoir) – *i.e. a mixture of understanding (connaissance) and ideology* – which is always relative and in the process of change." (p. 41) [emphasis mine]

Lefebvre's characterisation of knowledge as a mixture of understanding and ideology aligns with the work of anthropologists and STS scholars. In their paper on microbial life – spanning from cheese to astrobiology – Paxson and Helmreich (2014) caution against taking microbial (or any other) science "at face value" (p. 169). A critical engagement with such knowledge is required, tracing the social context in which interpretation takes place. Paxson and Helmreich suggest viewing such science as producing not bare truth but instead "model ecosystems" (p. 170).

Following on from the discussion of situated knowledge in the previous chapter, I am committed to a scientific project that doesn't just critique scientific models but works to develop models and interpretations that are better aligned with water justice. In the following section I lay out my approach to interpreting changes in water quality in the three constructed wetlands. Working across the three sites and their water quality patterns, I mobilise different models for interpreting the flow of water, the ecological relations of plants and microbes, and the social actions of people. I reinforce these models with a varied set of methods and observations.

Hydraulic flows and simplifications

Interpreting flows and wastewater transformations within the wetlands

Charts such as the one below (Figure 6.2) tell a simple story about water quality changes through the wetland. Results from the two Berambadi constructed wetlands show a consistent pattern across different parameters. When plotted along the 'treatment chain' – from the inlet to the last sampling points inside the wetland – the concentration of key pollutants (BOD, COD, total nitrogen and total phosphorus) decreases. The decline is steeper for BOD and COD, more modest for both nitrogen and phosphorus. So, perhaps the most significant patterning of water quality here is that the constructed wetlands are working. However, compared to results in the constructed wetland literature, these pollutant declines indicate poor performance. Water quality transformations in the Ibrahimpur wetland were also surprisingly limited, as shown in Figure 6.3. Accounting for these results is where I begin my work of interpretation.

These chart offers further possibilities for interpretation. By plotting each data point, rather than only the average, we see the variability of water quality over time, as shown by the cloud of dots surrounding the mean value. While the span of values reduces along the Berambadi wetland for BOD and COD, for total nitrogen and phosphorus the variability does not seem to decline. The Berambadi chart also contains a surprising pattern: concentrations sampled at the outlet are equal or higher than those at the final sampling points inside the wetland.

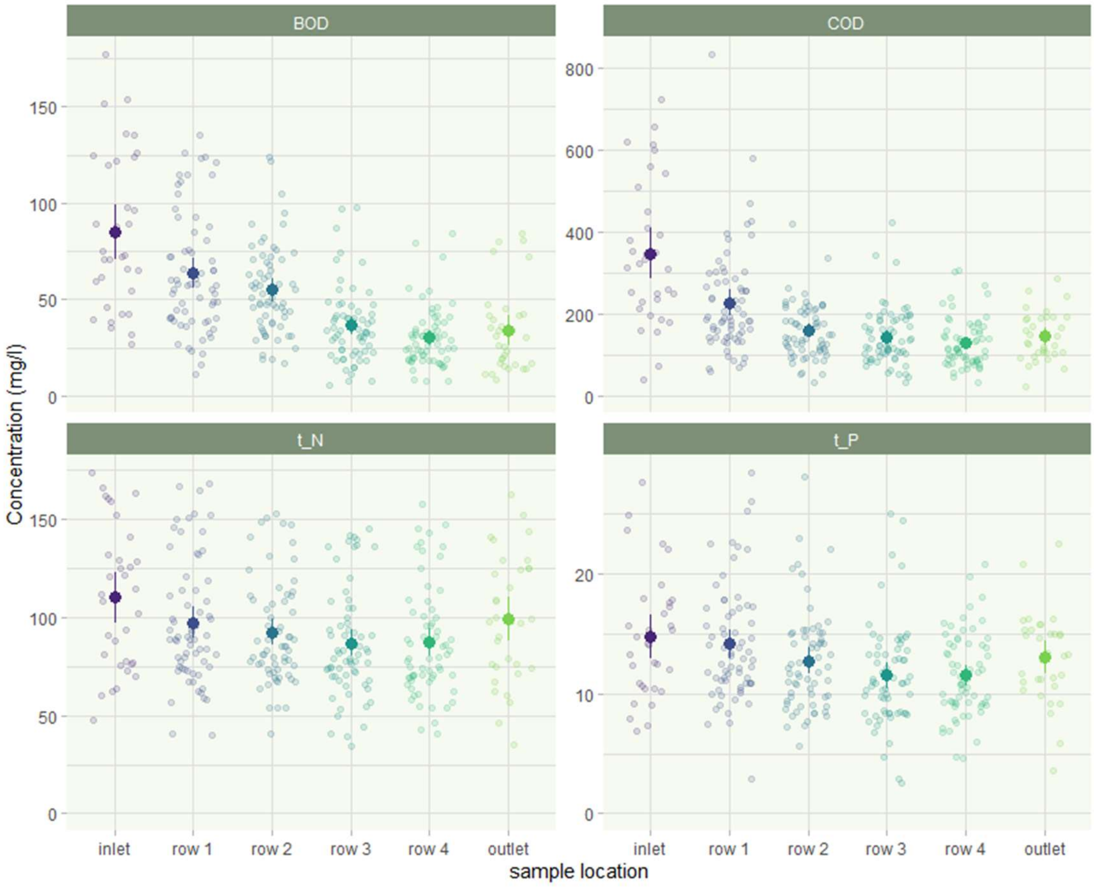

Figure 6.2 - Concentrations of four water quality parameters at Berambadi wetland. t_N and t_P are total nitrogen and phosphorus. The filled dot shows the mean concentration at each sampling location. The vertical line shows the 95% confidence interval for each mean, under an assumption that the data is normally distributed. A wider line shows a greater variability of data. Fainter unfilled dots scattered around each line show individual data points. These are plotted to allow the variability and messiness in the data to be part of

the presented results. The horizontal scatter of these points is random. Rows within the constructed wetland combine the values from two parallel sampling points in each wetland, for a total of four sampling locations across the two wetlands.

To begin my interpretation of these patterns, I want to highlight a significant assumption that makes these charts legible as narratives of water quality transformation. The x-axis of these plots orders results from the inlet of the constructed wetland, through intermediate sampling points within the wetland, to the outlet. All three wetland sites have similar 'treatment chains', though without sampling within the wetlands at Ibrahimpur and Loch Leven. The assumption written into such a chart in each case is that wastewater flows through the wetland smoothly from entrance to exit. However, conducting interpretation based on this assumed flow pattern risks overlooking some of the complexities that matter for interpreting wetland performance.

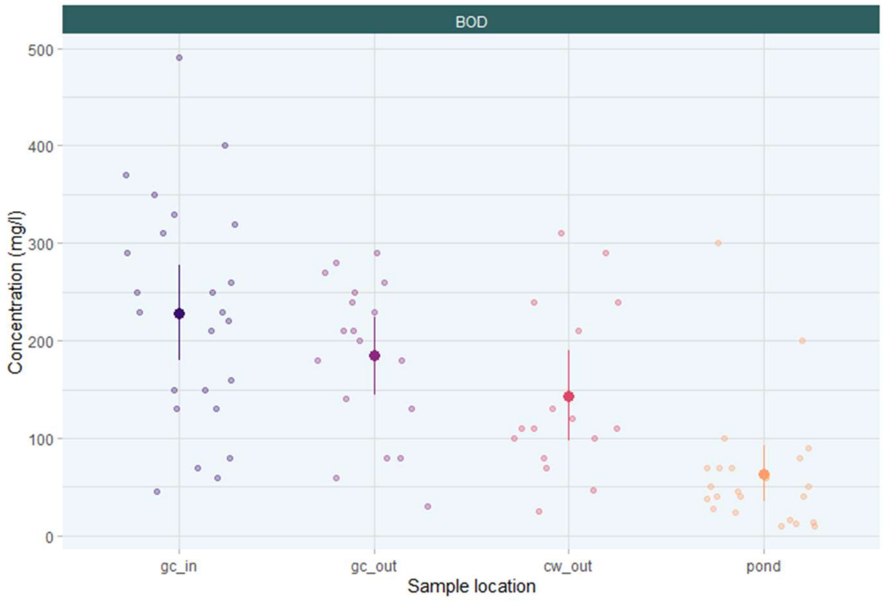

Figure 6.3 - BOD chart showing limited declines at Ibrahimpur wetland

First, making the hydraulic residence time calculations used by Berambadi and Ibrahimpur project teams implies a steady inflow to the wetland. Design drawings of the Ibrahimpur wetland show 31 cubic metres of water flowing into the wetland each day. However, shifting from design to reality, flow to these wetlands was highly variable. Water came from different sources with their own rhythms. At Ibrahimpur, the predominance of household uses of water gives wetland inflows a diurnal pattern, highest in the morning and evening (see Figure 6.4). This pattern is also influenced by the availability of electricity to drive electric pumps[9].

[9] During my visit in June 2019 there were frequent cuts to electricity in the evenings.

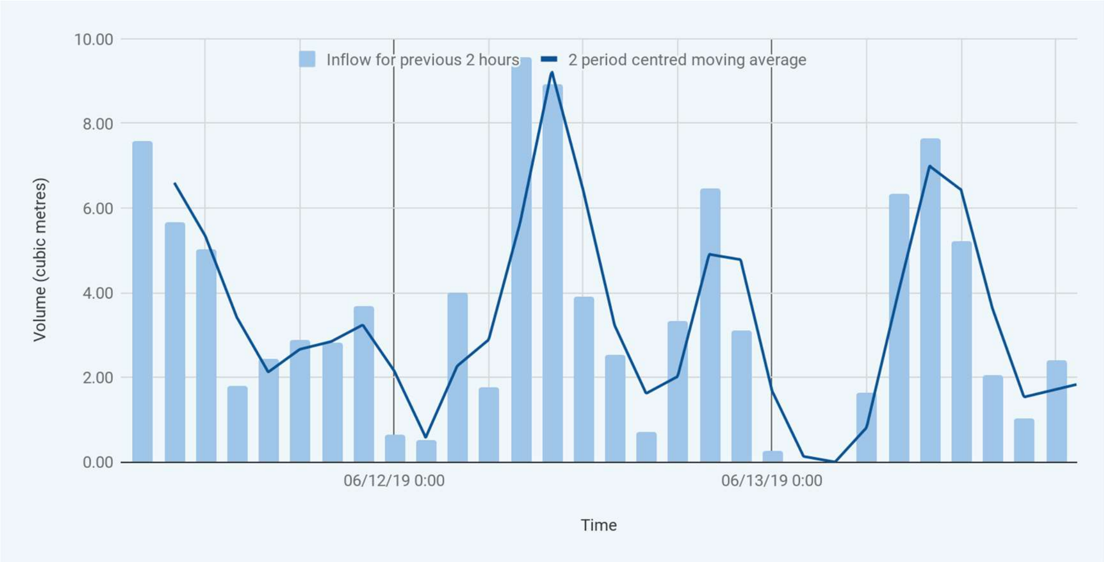

Figure 6.4 - Constructed wetland wastewater inflows at Ibrahimpur, reflecting shifting intensities of water use

For Berambadi, variability of the wetland flow pattern is tied to school opening times. The wetland receives inflow only during the five hours of school operation, with inflow generally beginning around 10am and finishing at 3pm[10]. There is no inflow while the school is closed over the weekend. This means that water entering the wetland at the end of the week would have several extra days of treatment, as no flow follows it. On top of this, water use varies daily. Measurements of outflow volumes made over 6 days in November and December 2019 showed that the outflow from wetland one and wetland two varied between 195-418 and 180-326[11] litres per day.

In the previous section I described how the plug-flow model represents a significant simplification of constructed wetland hydraulics. To develop a more detailed model of how water was flowing through each wetland, I employed experimental methods. Hydraulic tracer studies are a common way to evaluate flow patterns through diverse bodies of water. By adding a chemical to the wetland inflow and measuring its concentration (or a proxy indicator) at the outlet over time, information can be generated about the paths that water is taking through the wetland. Inflow and outflow electrical conductivity values recorded during the three days I conducted tracer studies at Ibrahimpur and Berambadi are shown in Figure 6.5 and Figure 6.6[12].

[10] This was judged by audio from the camera trap recordings used for habitat analysis, where it was possible to hear when water was flowing out of the wetland into the sump.
[11] These results from the second wetland may be less reliable due to leakages from the tank.
[12] More details of this method are included in the methodology chapter.

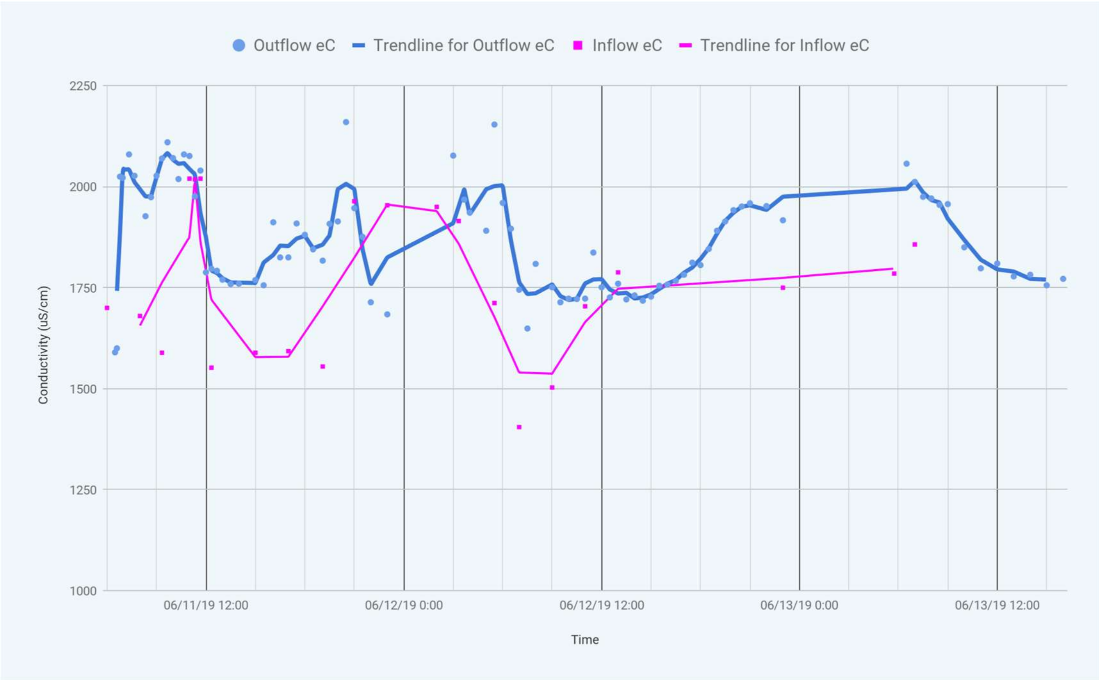

Figure 6.5 - Electrical conductivity during the tracer experiment at Ibrahimpur wetland

The results of these tracer studies at Ibrahimpur and Berambadi do not give a comprehensive picture of flow patterns in the wetlands. There are several limitations to the method: using a salt tracer means that density effects might influence these results[13] and there are also issues with fluctuating background EC readings. However, these experiments do give enough data to question the plug flow assumption. For example, there is no sign of a smooth peak after several days that this hydraulic model would suggest. In both tracer experiments, an elevation in electrical conductivity was detected at the wetland outlet soon after the addition of the tracer. This suggests that some of the flow is short circuiting through the wetland. The Berambadi tracer study also suggests that water is bypassing intermediate sampling points, reaching high levels at the outlet of the wetland without registering in the intermediate sampling points. Flow may pass along the walls of the wetland cell. This is one interpretation of the uptick in concentrations at the wetland outlet at Berambadi compared to intermediate sampling points[14]. Rather than water progressing smoothly through the wetland, some of it jumps ahead to the outlet without treatment.

[13] Water with salt dissolved into it is more dense than other wastewater, so it may sink to the bottom of the wetland and remain in place there rather than flowing along with the rest of the water.

[14] Yet importantly, it is not the only possible interpretation. Jamwal et al. (2021) suggest that this increase "could be attributed to either re-suspension and dislodging of suspended particles and biofilms or short-circuiting of inflows in the constructed wetlands" (p.6).

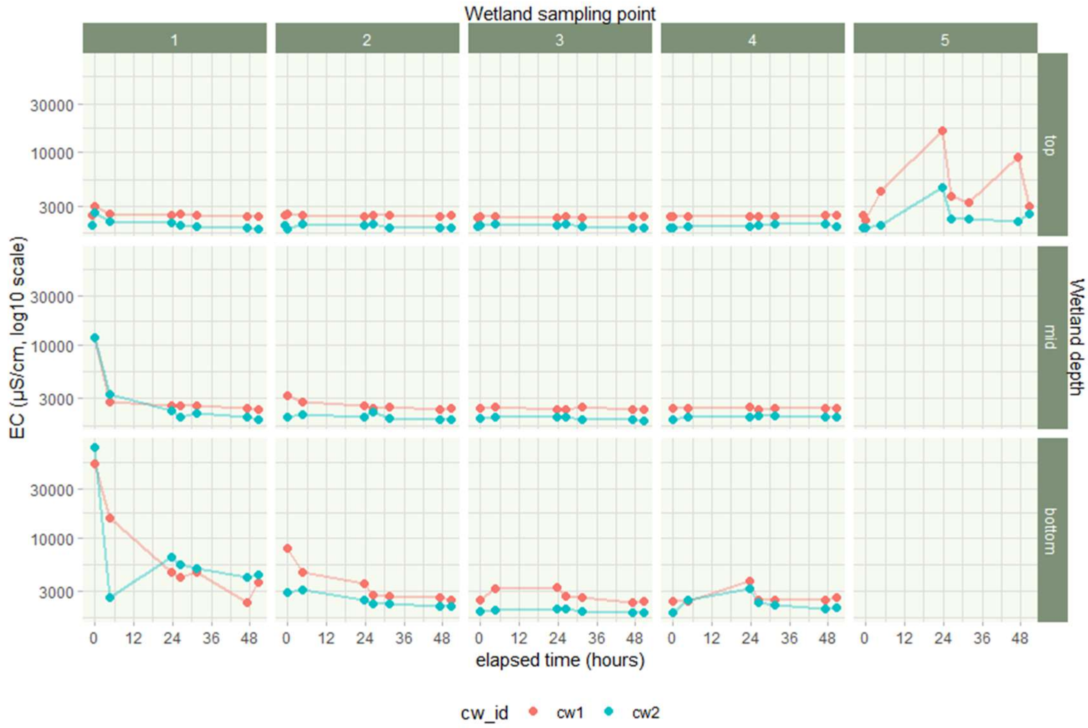

Figure 6.6 – Electrical conductivity during the tracer experiment at Berambadi. Each cell of the chart gives the time series for a particular sampling depth and distance along the wetland. Column 5 is the outlet, where no depth profile was present.

Besides these tracer experiments, some characteristics of wetland flow could be determined through observation of the wetland. The Ibrahimpur wetland had clogging visible at the inlet, which grew in extent over subsequent visits (Figure 6.7). Silt was passing through the grit chamber and was deposited onto the wetland surface. As a result, the deeper parts of the wetland were clogged with sediment, and not contributing to water flow. This clogging was verified by a vertical hydraulic conductivity test[15].

[15] The testing pipe was buried in the wetland at a 20cm depth near both the inlet and outlet. After water was poured into the pipe, a hydraulic head of approx. 1m did not decline over several hours. See methodology chapter for further description of this method.

Figure 6.7 - Clogging and surface flow around canna and reeds at Ibrahimpur. When first constructed, this wetland was clean bricks and stones, with no mud. Photograph by the author, 2020.

Conducting tracer experiments and other observations was part of my process of questioning and developing a different model of water flow through the wetland. This model of short-circuiting and variable flow makes certain interpretations easier: it provides a satisfying explanation for the uptick of concentrations at the outlet of Berambadi wetland and offers a way to account for less-than-expected treatment performance. But it also makes other interpretations – such as deriving a rate-constant to inform design – impossible.

Determining the composition of flows to the wetland

The way of presenting data in Figure 6.2 and 6.3 overlays results across the months of sampling. This is a representation that highlights only some dynamics of water quality transformation. Variability at each sampling point appears as a cloud of dots. Displaying results along a time series gives a better understanding of some of this variability. There is often a close linkage between inflow and outflow at each sampling date. As shown in Figure 6.8, at Berambadi it is largely the inflow concentration of nitrogen that drives the outflow concentration. There is a similar alignment between inflow and outflow concentrations of BOD at Ibrahimpur. The variation in inflow was outside the scope of the Berambadi project team's interpretation work and was not visible in how they presented water quality results. However, rather than setting aside this variability using averages, it can be used as an opening to another area for hydrosocial interpretation: explaining how the composition of inflows shapes their material properties.

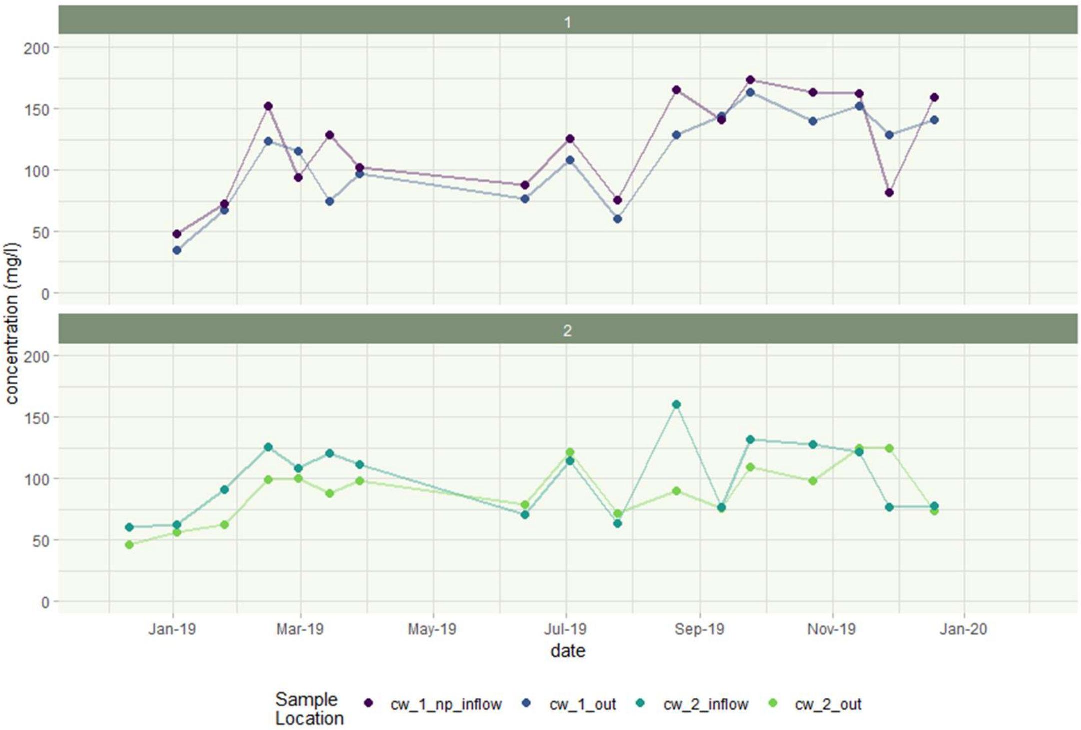

Figure 6.8 - Total nitrogen concentrations over time in the Berambadi constructed wetlands

At Ibrahimpur water flows to the wetland through open drains that are often simply a contour between the road and houses. This arrangement meant that it was possible to understand wastewater inflows through drainage mapping, which explored both the composition and motion of wastewater.

As water is put to varied household uses, the wastewater drains aggregate a mixture of different waters and other materials. Observations of water use suggested that the greatest volume of water comes from cleaning activities: washing of clothes and kitchen items, cleaning out yards, and bathing of both people and animals. Sewage is not supposed to be part of the wastewater mix carried by Ibrahimpur drains. Yet concern that this was happening was raised in social surveys and interviews, and during the mapping, leakage was occasionally evident from latrine pits[16].

[16] The sewage situation is partly the legacy of the Swachh Bharat Abhiyan, the Indian Government mission for a 'Clean India' which included among its goals the eradication of open defecation (Coffey and Spears, 2017). The key policy lever was a subsidised program of toilet building. However, the standard designs used for the toilets had issues, making the pits difficult to empty (Sagar, 2017). Though electricity poles around Ibrahimpur advertised the number of latrine-emptying services, it seems these were not employed as frequently as necessary. The result was that sewage was part of the wastewater that reached the constructed wetland.

Figure 6.9 - Ibrahimpur catchment and drainage mapping. Cartography by author, based on data from site walks, embedded photographs by author, 2019-2020.

It is not only human practices that generate Ibrahimpur wastewater; other water users also contribute. An NIH report on the Ibrahimpur wetland project gives statistics on livestock, the most visible co-inhabitants of Ibrahimpur, and provides water balance calculations. These numbers give some sense of the importance of these cows and buffalo in shaping wastewater flows[17]. NIH statistics (Goyal and Singh, 2018) suggest a total of 2394 bovines, compared to a surveyed human population of 2170 people in 223 households. The households interviewed in the scoping survey almost all had between one and eight livestock, with only one household not having any, and one larger household having 35 livestock. NIH calculations input a water requirement of 85 litres per animal per day for livestock, following Indian government guidelines. Based on these numbers, the total volume of water used by livestock in Ibrahimpur is greater than for human residents (Goyal and Singh, 2018). As these cattle are generally housed within the village, they contribute significantly to the water, nutrients and organic matter in Ibrahimpur wastewater flows. Some of the manure they produce is collected and dried to use for fuel, but plenty still reaches the wastewater drains. On top of this, the chopped straw which cows are fed is the ideal material for clogging the grit screen (see Figure 6.10). While I didn't investigate these dynamics, any changes to the number of cattle or where they are kept during different times of the year will have a significant effect on the wastewater quality in Ibrahimpur.

Figure 6.10 - Ibrahimpur grit screen clogging, with dried solids on right showing the predominance of straw. Photograph by the author, 2020.

The area of the village that contributes water to the constructed wetland is illustrated in the drainage map (Figure 6.9). As the images surrounding this map show, the simple lines of the mapped drainage

[17] I say 'gives some sense' because this report relies on simplified assumptions and averages livestock numbers across the seven villages of the panchayat. As a result, I don't put much faith in these numbers.

system are, on the ground, a terrain where flows are interspersed with zones of stagnation. Water carries sediment and other materials, and various plants sprout and grow. Ibrahimpur sits on a hill, and so wastewater and rainwater travel out of the village in several directions. This wastewater catchment is also an approximation of the rainwater catchment for the wetland. I used this as the basis for a rough calculation of rainwater volume (see Figure 6.11)[18]. The seasonal pattern of rainfall, drawn from NIH statistics (Goyal and Singh, 2018), means that over the year rainfall goes from playing almost no role in the wetland to being extremely significant. These calculations show that during the monsoon, rainfall inflows are more than double the wastewater flows, while the volumes are equivalent when summed over the full year. Whether it is the diurnal pattern of household water use, shifts in the numbers or location of livestock, or the annual arrival of the monsoon, the varied temporalities of wastewater flows combine to produce significant variations of inflow water quality.

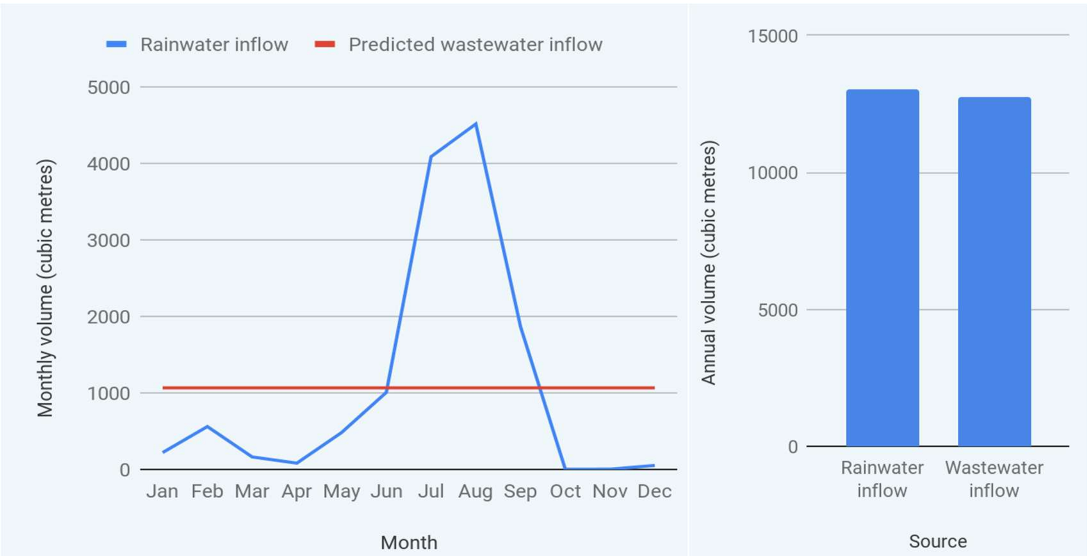

Figure 6.11 - Rainfall and wastewater inflows to Ibrahimpur constructed wetland and pond

Dilution, evaporation and other unruly flows

The other two wetlands, at Berambadi and Loch Leven, receive inflow through piped systems, which offer less opportunity to trace how wastewater is constituted. Berambadi wetland's inflow is made up of sewage and handwashing water from a toilet block, pre-treated through septic tanks. The two parallel wetlands receive flow from different septic tanks, which accounts for differences in inflow concentrations between the two wetlands (visible in Figure 6.8). Changes in inflow composition also come from occasionally leaking taps, which dilute the sewage flows to some degree. While less

[18] This calculation relies on several simplifying assumptions. The simple 'rational method' was used for converting rainfall to runoff (Peel and McMahon, 2020). Rainfall runoff depends on the permeability of roads and yards, which has altered over time as dirt and mud plaster is replaced with concrete. There are also interplays between rain and household uses that are not captured in this rough calculation. For example, some of the washing down of yards and animals that contributes to wastewater flows is not necessary after rains.

complex and variable than Ibrahimpur, Berambadi inflows were still shaped by social patterns of water use and the difficulty of containing water within the plumbing. These factors provide a partial and speculative interpretation of the variations over time seen in Figure 6.8.

Figure 6.12 - Soluble reactive phosphorus concentrations at Loch Leven

At Loch Leven, the wetland receives water pre-treated by a rotating baffle sewage treatment system, which is connected to the dozen or so households at the site. This wastewater comes from domestic uses and household appliances. These add up to an average household water use of 165 litres per person per day in Scotland (Scottish Water, no date). Variations in the volume or quality of this flow over time – especially as more people began working from home during Covid-19 lockdowns – can only be speculated[19]. Domestic wastewater is the most regular water source, but observations showed it was not the only flow of water into the wetland. Rainfall directly onto the wetland makes a small contribution, but more importantly, the area around the wetland is soil which is easily saturated by rainfall. This creates inflow to the final section of the wetland, which is unlined. In November and December 2020, inflow into the second cell of the wetland was visible, overflowing the plastic liner. Water quality testing of this water indicated, unsurprisingly, that it had much lower levels of organic carbon and phosphorus. This water was diluting the treated water sampled at manhole two. An interplay of dilution (due to rainfall) and concentration (due to evaporation) offers one way to interpret the variation in outflow phosphorus concentrations, as shown in Figure 6.12. Concentrations at the first and second manholes (the green and blue lines) appear to have a seasonal

[19] Unlike at Ibrahimpur, there was no way to measure flow rates into the Loch Leven wetland

pattern, in contrast to more-or-less static inflow (red line). However, there are also layers of ecological process that might be relevant to this interpretation, as the next section will explore.

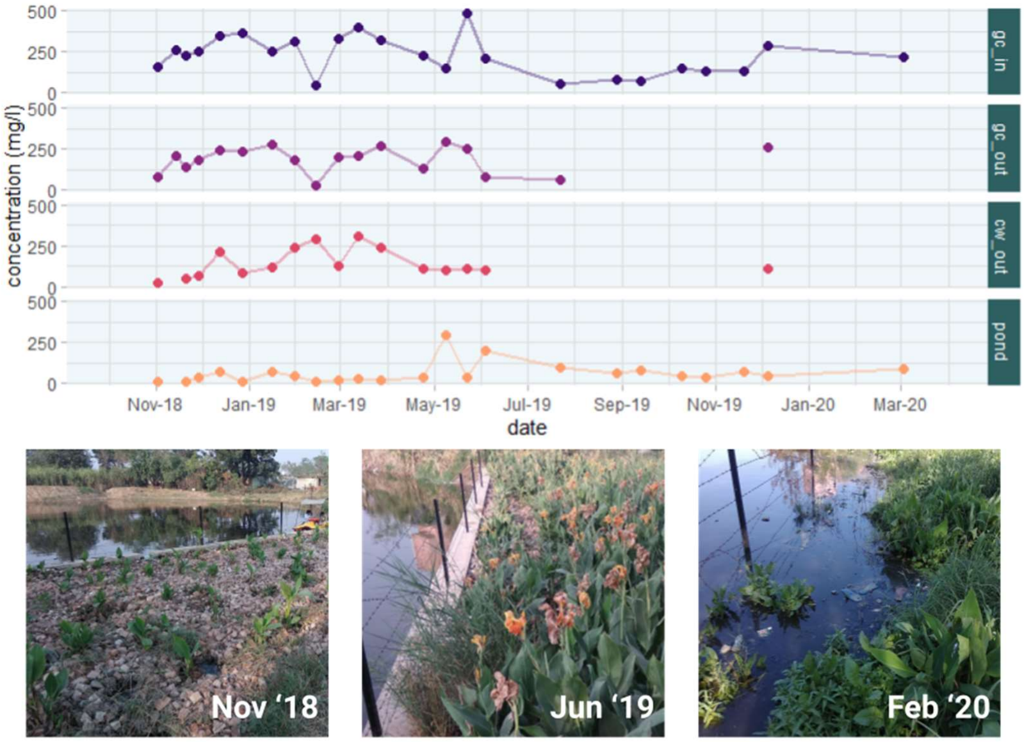

Figure 6.13 - Development of vegetation and flooding at Ibrahimpur, with charts of BOD showing the resulting gaps in the data due to flooding. Photographs by the author, 2018-2020.

After passing through the wetland, the water in the Ibrahimpur wetland was stored in a pond. However, as the wetland was being built, the level of a road alongside the pond was raised. Then the owner of a neighbouring field built a concrete wall on the other side of this road. The road and wall blocked the former outlet of the pond. As a result, the pond had no outlet lower than the constructed wetland level. During the hot, dry months before and after the monsoon, the water level in the pond was controlled by evaporation. However, with the arrival of the monsoon in 2019 and 2020, and over the winter months in 2020, the water level rose until the surface of the constructed wetland was submerged. The result was that the wetland effectively ceased to function. Water bypassed the wetland either by flowing around the wetland, if the grit screen was clogged, or by passing quickly over the wetland. Making sense of water quality data at Ibrahimpur wetland is difficult without knowing this history. Project staff attributed the flooding issues to the construction of the wall, which was out of their control. This was coupled with a stated belief that local people were using too much water. In contrast, people living around the wetland described this flooding as a consequence of the project as a whole – as highlighted by requests for me to do something about it. After all, even before reaching the level of the wall, water was constrained by the road which was built up during pond rejuvenation. This hints at some of the political significance of how waterscape processes are interpreted.

Paying greater attention to the constitution and flow of wastewater simultaneously makes different interpretations possible, while demonstrating the limits of interpretation in a context where so much is in flux. These limitations can be illustrated by presenting the same water quality data as in Figure 6.2 in a different arrangement. Figure 6.14 separates out the water quality data by giving each sampling date its own row. This chart shows that the pattern of nitrogen or BOD transformation through the wetland might be totally different from one month to the next. Accounting for such changes is beyond my capacity to interpret.

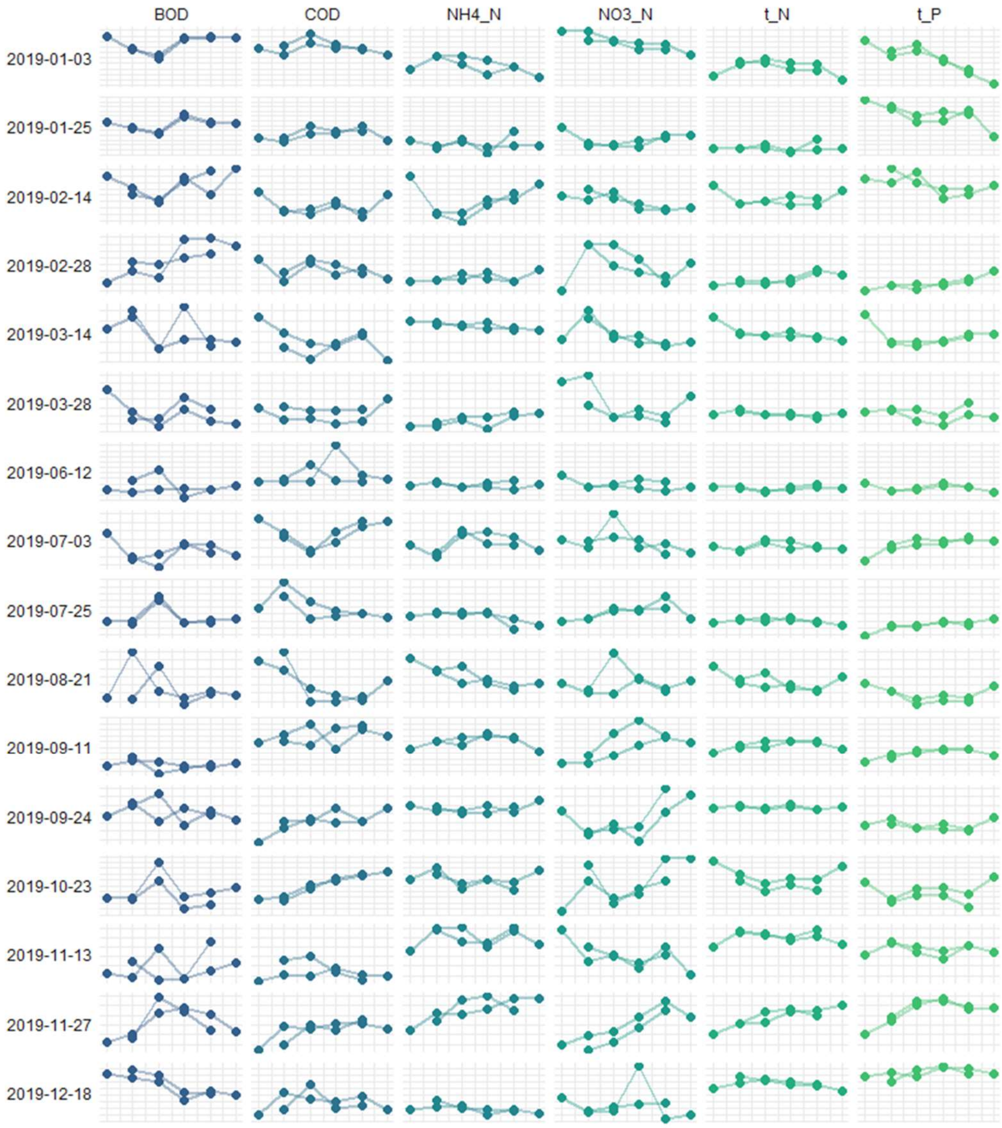

Figure 6.14 - Normalised water quality data from Berambadi constructed wetland to illustrate the temporal variability of water quality within the constructed wetlands. Each grid of the image contains data from the two sampling rows of the first constructed wetland, for one water quality parameter and sampling date. This figure is intended to be read illustratively, rather than for information, hence the axes have been removed.

Ecological relations, functions and capacities

An exploration of constructed wetland hydraulics provides one avenue to interpret surprising patterns of water quality of the Ibrahimpur, Berambadi and Loch Leven wetlands. However, in cases where there is a divergence of inflow and outflow concentrations an additional domain of interpretation needs to be included. In common with the Berambadi project interpretation, I was drawn to considering the doings of plants and microbial communities. For example, at Loch Leven, dissolved inorganic nitrogen[20] concentrations were variable in the inflow from the septic tank. Spikes in concentration were detected in February and August 2021 (see Figure 6.15). Water quality readings from manholes one and two within the wetland show a similar pattern over time. However, it can also be seen from this chart that the efficiency of nutrient removal is higher in August. This is one example of a potential fingerprint of ecological processes.

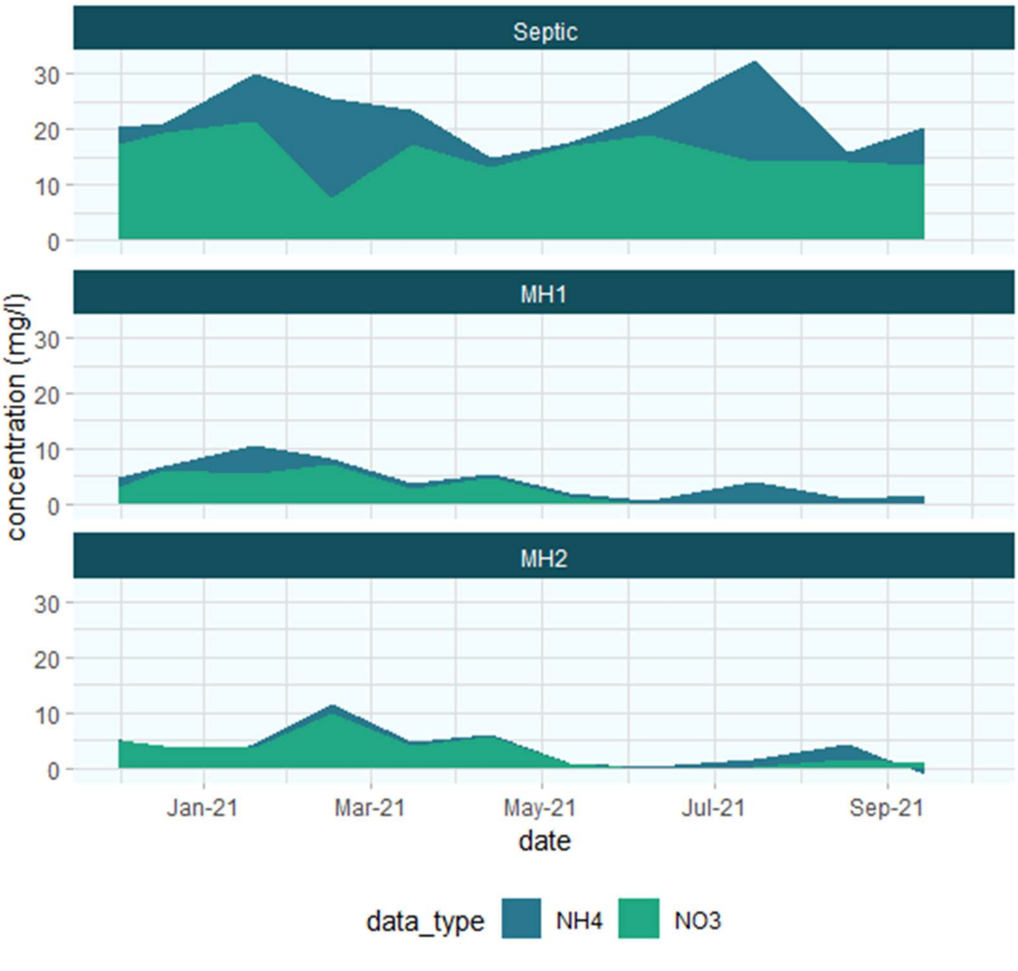

Figure 6.15 - Time-series of dissolved inorganic nitrogen at Loch Leven

[20] The combination of nitrate and ammonia

Constructed wetland science attempts to unpack the 'black box' of constructed wetland ecologies, through experiments and models (Kadlec and Wallace, 2008; Kumar and Zhao, 2011). The key agents in these approaches are species of plants, and microbial functional groups. I have previously described how the Berambadi project relied on understandings of ecological processes drawn from constructed wetland literature to interpret differences in removal efficiency. Figure 6.16 summarizes treatment processes collated from constructed wetland literature (Kadlec and Wallace, 2008; Choudhary and Kumar, 2020; Kataki *et al.*, 2021). These treatment mechanisms degrade, transform or sequester carbon-rich organic matter, forms of nitrogen and phosphorus, and pathogenic organisms. Alongside the contributions of plants and microbes are several abiotic processes involving the filter media of the wetland. There is a tendency for such lists to present only positive ecological processes that contribute to water quality improvements. This is a model of ecological interaction that downplays the processes which act *against* or obliquely to pollutant removal.

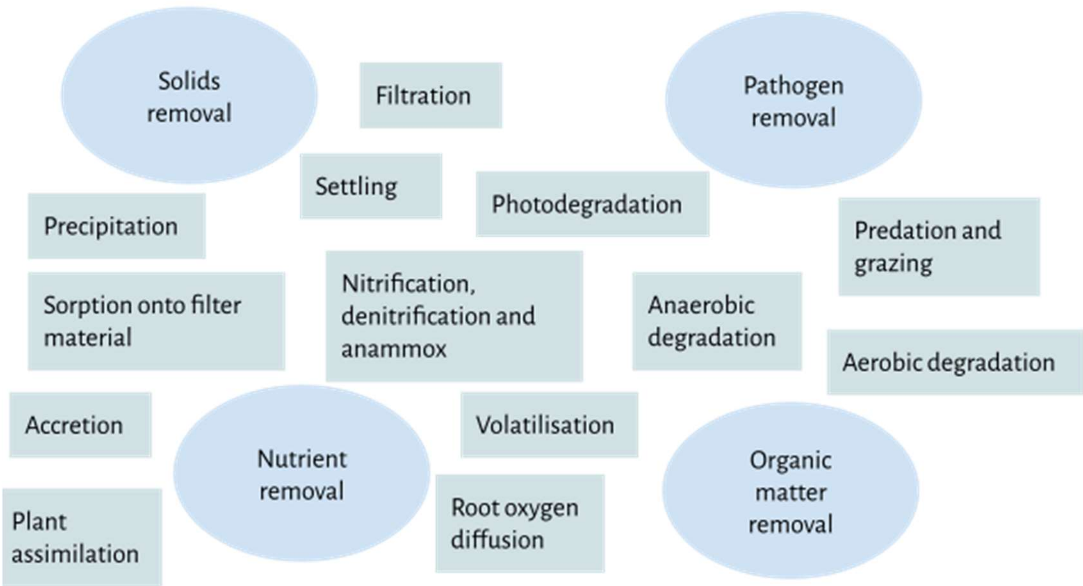

Figure 6.16 – Pollutant removal processes in constructed wetlands. Prepared by author.

One way to read this figure is as a compendium of microbial, plant and geological labour. This is the work that Nature carries out in constructed wetlands (Perkins, 2007; on non-human labour see Battistoni, 2017; Randle, 2022). But, if we are trying to account for failures in treatment, perhaps we need to realise that microbes and plants are in important ways not labourers.

An important ideological manoeuvre in dominant science[21] is the mashing of ecological and economic modes of explanation, such that other-than-human beings are expected to act rationally

[21] On the use of this term, see Liboiron (2021, p. 18)

to maximise their utility. As Carla Hustak and Natasha Myers (2012) argue, part of how such models become prevalent is through a focus on particular temporalities of ecological life:

> "Practices that fall outside the domain of reproduction or survival, including organisms' improvisations and playful experiments, do not record themselves in evolutionary memory; deemed irrelevant, they are rendered invisible in these broad sweeps of time." (p. 95)

Through such evolutionary readings, we are encouraged to see the actions of other-than-human lifeforms as shaped by a "reductive, mechanistic and adaptationist" logic wholly oriented around survival (Hustak and Myers, 2012, p. 77; see also, Schrader *et al.*, 2015). The result of these functional perspectives on ecology is a model of constructed wetland processes that presents only a limited slice of a more complex reality – a narrow set of plant and microbial relations. Is it possible to instead model other-than-human beings as involved in their own forms of thick hybridity (Lulka, 2009) outside of human networks? My approach to interpretation starts by exploring different models for plant and microbial doings[22]. In doing so, the aim of interpretation is not only to understand water quality changes, but to use this interpretation to unsettle dominant ways of interpreting more-than-human doings.

Plant capacities

Recent geographical and anthropological scholarship on plant-human relationships (Head and Atchison, 2009; Head, Atchison and Phillips, 2015; Fleming, 2017; Myers, 2017; Durand and Sundberg, 2022; Lawrence, 2022) affords the opportunity to develop a different interpretation of plant doings in the constructed wetlands. Head et al. (2015) draw upon botanical research to articulate a set of four relational plant capacities (p. 399). They explore these capacities empirically through a focus on the political ecology of invasive rubber vine plants in the Northern Territory, Australia. First, plants carry out photosynthesis and related biochemical processes. This is a 'distinctive materiality' (p. 403) of vegetal metabolisms. Second, plants have various capacities for motion. Third, botanical research is increasingly highlighting plants' capacities for sensing and communicating[23]. Finally, plants have 'flexible bodies' (p. 404): a plasticity of form over their lives as well as indeterminate boundaries between individuals and collectives. The distinctive and inventive

[22] My use of the term 'doings' in this section is an attempt to bring a sense of intention that is absent from the term 'processes', as well as a greater capaciousness compared to 'actions' or 'activities'. This choice is inspired by the work of Abrahamsson et al. (2015)

[23] Related to this is a branch of vigorous debates about plant intelligence, which I will leave aside in this section (Marder, 2012; Head, Atchison and Phillips, 2015, p. 404; Sopory, 2019; Taiz *et al.*, 2019; Calvo *et al.*, 2020).

ways that plants enact capacities of materiality, mobility, form and communication are my starting point for attuning to plant doings.

Metabolic materiality

The plants in the constructed wetlands make use of affordances including sunshine and nutrient-rich wastewater. As the canna lily, reeds and other plants within each wetland create energy from the sun (photosynthesis), they breathe out water from their leaves (transpiration). This creates a pressure gradient that draws water and nutrients up from the wetland, through their roots. Plant growth enfleshes nutrients, building them into the architecture of roots, rhizomes, shoots and leaves.

Figure 6.17 - *Glyceria maxima* at Loch Leven. Photograph by the author, 2021.

Thinking with this metabolism, perhaps the low levels of nutrient reduction in Berambadi are a sign of insufficient plant vitality; but an alternative possibility exists. As plants draw up water from the wetland and transpire it out to the atmosphere, the relative concentration of nutrients in the remaining wastewater is increased. As a result, based on nutrient concentration alone, plants may appear to be worsening water quality[24]. High outflow concentrations do not need to be interpreted as a sign of limited plant activity. They could result from positive and negative influences on water quality cancelling each other out. The methods used at Berambadi, as well as the other two wetlands, could not untangle this web of material fluxes between water, plants, and atmosphere.

Sensing, mobility, flexible bodies

Turning to how other plant capacities shape changes in water quality, we can begin by thinking with the roots and rhizomes of wetland plants. At Ibrahimpur, Dinesh explained during my March 2020 visit that they would use reed rather than canna for a subsequent wetland. Reed's deeper roots were expected to provide better water quality improvements. Dinesh presented rooting depth as a species trait. However, Kadlec and Wallace (2008) suggest that differences in root depth are a characteristic of plants in 'relatively clean waters' (p. 76). In nutrient-rich water, such as in a constructed wetland, "roots are predominantly in the upper 20–30 cm of the media" (p. 76) regardless of the plant species. What's going on here? Plants are sensing the affordances of nutrient rich water and adjusting their development in response. The mobility and flexibility of plant roots result in different growth patterns in different circumstances. A mesh of shallow roots has implications in turn for the performance of constructed wetlands. First, the water that travels through deeper levels of the wetland will not be in contact with plant roots. If roots don't reach to where most water is flowing, then the vitality of the plants becomes irrelevant to interpretation. Meanwhile, at the surface of the wetland, a thick mat of roots encourages clogging and surface flow over the wetland, as was seen at the Ibrahimpur wetland (see Figure 6.7 above). Rather than acting as static nutrient absorbers, the sensitive motions of plants shape the flow and transformations of water over time.

I was also drawn to thinking about plant sensitivity through attempting to trace seasonal patterns of nutrient removal. Seasonal cycles are most relevant for Loch Leven, because of the cold winter; on one sampling date the wetland was still partially covered in snow. Relations between climate and water treatment have been examined in detail in the literature. Research primarily examines how microbial growth and metabolic rates reduce at low temperatures (Faulwetter *et al.*, 2009)[25]. Plants also sense the seasons and respond to them. Both the reeds and willow in Loch Leven wetland had a seasonal pattern of growth, one that has developed in relation to Northern climates over

[24] To address this requires measuring the inflow and outflow from the wetland simultaneously, which was not possible for any of the three wetland sites. Calculations can then be performed to look at the mass of nutrients (or other pollutants) entering and leaving the wetland, rather than the concentration.
[25] Faulwetter et al. also report that this influence is frequently less significant than expected "numerous studies … have shown that seasonal temperature variation did not always significantly affect COD and BOD removal" (p. 995).

evolutionary time (Head *et al.*, 2014). These patterns include a vertical shifting of nutrients and energy between plant roots and aboveground stems and leaves, another example of the flexibility of plant bodies.

However, my attempts to trace seasonal patterns were not particularly successful[26]. The basic dynamic is that the lack of plant growth and the breakdown of reeds over the winter and spring contributes to nutrient outflow. Nutrient removal is then intensified during summer growth. This seems to be the pattern in Figure 6.12 above of phosphorus at Loch Leven. But this dynamic is complicated by other interactions. The thick mat of dead leaves that covers Loch Leven wetland in winter insulates the wetland below. The breakdown of dead plants contributes nutrients to constructed wetlands, but also carbon which may aid in denitrification (Kadlec and Wallace, 2008). These processes blur the distinction between active live plants and inert dead matter. Seasonal responsiveness alters constructed wetlands nutrient outflows, but the net effect was not always easy to determine.

More-than-plant interactions

The final layer in this examination of plant capacities is to consider the web of relations between plants and microbial life in constructed wetlands. Plant roots, rhizomes and stems provide the architecture for a diversity of other beings to establish within the wetland (Calheiros *et al.*, 2019; Zuo, Zhang and Yu, 2020). Meng et al. (2014) report that "many studies have shown that microbial density, activity, and diversity are enhanced in the plant rhizosphere" (p. 319). These symbiotic relations contribute to pollutant removal as plants provide a carbon source for some microbial processes (Kadlec and Wallace, 2008; Chen *et al.*, 2015), while bacteria and fungi are increasingly recognised as crucial for plant nutrient uptake (Calheiros *et al.*, 2019). Plant-microbe interactions play an important role in the transformations of organic matter and uptake of nutrients within the wetland (Wu *et al.*, 2017; Nguyen *et al.*, 2019; Man *et al.*, 2020).

At the same time, this symbiosis does much more than just determine pollutant outflows. By passing exudates and oxygen from their roots into the surrounding matrix, plants are continuously reshaping microbial assemblages (Chen *et al.*, 2015; Sun *et al.*, 2019; S. Wang *et al.*, 2019). Different plant species support distinct microbial communities (Zuo, Zhang and Yu, 2020). These microbial communities, in some wetland environments, become a driver of future vegetation development

[26] This interpretation was limited by the fact that I only sampled over one year. On top of this, as flow monitoring wasn't possible, I couldn't separate ecological processes from the hydraulic variability described above.

(Lamers *et al.*, 2012). Recognising these thick knots of interspecies relationships figures constructed wetlands in a very different way to interpretations of only functional processes.

Vegetal conclusions

Engaging with the conversation of vegetal more-than-human studies, this section has aimed to think about plants differently. This approach points to the ways that plants are creatively making and remaking relations. Observations of the plants at each wetland highlight how plants exceed the standard functional accounts offered in the representational space of constructed wetland design and research. Nutrient rich water is an affordance to plants, but one they might respond to differently depending on the situated context of climate, growth stage, and on the specificities of relations between plants, bacteria and fungi. Whether it is evaporation or the creation of different flow channels in the wetland, plants are also reshaping the hydrology of constructed wetlands. The resulting picture is tangled. More-or-less healthy plants grew in all the wetlands, and this growth alone is evidence that the plants must have taken up some nutrients. But definitive signs of plants' nutrient absorbing capacities were not evident in the water quality data. Rather than concluding plants having a limited impact, I suggest it is the multitude of plant doings that make it difficult to say what their impact on water quality was. Plant doings may support or subvert the water quality transformations occurring in a constructed wetland. Attuning to plants' relational capacities redirects straightforward water quality interpretation.

Microbial functionality or sociality

An earlier section described how microbial processes within constructed wetlands can be modelled as the result of different functional groups carrying out biochemical processes. From a microbial point of view, these processes are about harnessing chemical potentialities to fuel life processes of respiration, movement, repair and reproduction. There is a biochemical specificity to these processes. Bacteria are conducting chemical synthesis, crafting complex enzymes, in order to facilitate molecular deconstructions (Rajta *et al.*, 2020). These processes represent the creativity and responsiveness of bacteria over evolutionary time. At the same time, a reading of microbiology outside of the constructed wetland literature offers a more expansive way of understanding microbial life in constructed wetlands.

First, there is room for a critical perspective on 'functional group' models of microbial life. Part of my justification for describing functional groups as 'semi-tautological' in the previous section was that evidence suggests that functional groups might have little to do with taxonomic affiliations (Louca, Parfrey and Doebeli, 2016). Furthermore, classification into functional groups is often carried out for bacteria alone. However, the microbial life in constructed wetlands goes beyond bacteria to include archaea, fungi, ciliates, rotifers, amoebae and algae (Vymazal, Sládedek and Stach, 2001; Meng *et al.*, 2014, p. 317). With a focus on nitrogen dynamics, Truu et al. (2009) argue that:

> "The diversity of microorganisms involved in the nitrogen cycle is much greater than that which has currently been studied in constructed wetlands. It is possible that archaeal nitrifiers, denitrifying fungi, aerobic denitrifying bacteria and heterotrophic nitrifying microorganisms may play an important role in N-cycling in constructed wetland systems" (p. 3967).

Finally, even if microbes have the genomic capacity to carry out a metabolic process, it doesn't automatically follow that this process is being carried out[27]. In other words, microbes can be classed in a functional group yet not engage in this group's sole defining function. While microbiological research can offer important insights into constructed wetland design, the diversity of microbial life makes interpreting the performance of a specific wetland using microbiological community data extremely uncertain.

There is another way that dominant models of microbial action in constructed wetlands might be stretched. As microbial communities develop on the filter material and on the roots of wetland plants, they form a biofilm. From a functional perspective of pollutant removal, this film reduces the pore spaces within the wetland, improving the physical filtration of suspended particles. As described by Maiga et al. (Maiga, von Sperling and Mihelcic, 2017) "in wetland environment[s], parts of submerged plants and their associated biofilms form "sticky traps" for particles (p. 8). This physical filtration can remove pathogenic organisms and particles of organic matter (Kadlec and Wallace, 2008; Maiga, von Sperling and Mihelcic, 2017). But there is a less functional perspective on these assemblages. Microbial research on biofilms suggests that, far from being just a sticky mass of bacteria, biofilms are one expression of the 'social life of microbes' (West *et al.*, 2007)). West et al. (2007) describes how biofilms form through 'many forms of cooperation' (p. 62) between bacteria of different lineages. Biofilms are 'intricate architectures' (p. 62), perhaps reflecting a specialisation of roles (p. 63). Watnick and Kolter (2000) go as far as to suggest that the best analogy for a biofilm is a human city. This understanding of microbial sociality raises all kinds of questions about the microbial lives within constructed wetlands. How microbes relate to other beings, microbial and otherwise; how they develop and dissolve multispecies architectures; how they adapt to and reshape their changing milieu become relevant to water quality transformations. Bodelier and Dedysh (2013)

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[27] Thanks to Andrew Singer at UKCEH for pointing this out.

note that "the diversity and functioning of microbial communities in wetland systems is highly under-explored" (p. 1). What seems to emerge from this research is that microbes have a richer set of relations than constructed wetland models – focused on interpreting or predicting treatment performance – entertain.

Given the complexity of bacterial relations it seems fair to say that the model of 'functional groups' does not capture many life processes of wetland microbes. Why does this matter? First, because those life processes might be just as significant for interpreting the wetland operation as the narrow functionality of pollutant removal metabolism. Rather than their 'functional group', what might be more important for understanding the contribution of microbial beings in constructed wetlands is how they interact with plants; whether they work with other microbes to produce a sticky biofilm; how susceptible they are to viruses and so on. Biofilms and symbiotic relations puncture the clean boundaries between individuals and species that informs functional understandings of constructed wetlands[28]. Interpreting water quality changes through microbial 'functional groups' builds a model of knowable microbial life only through significant simplifications.

Social interpretation from maintenance to projects

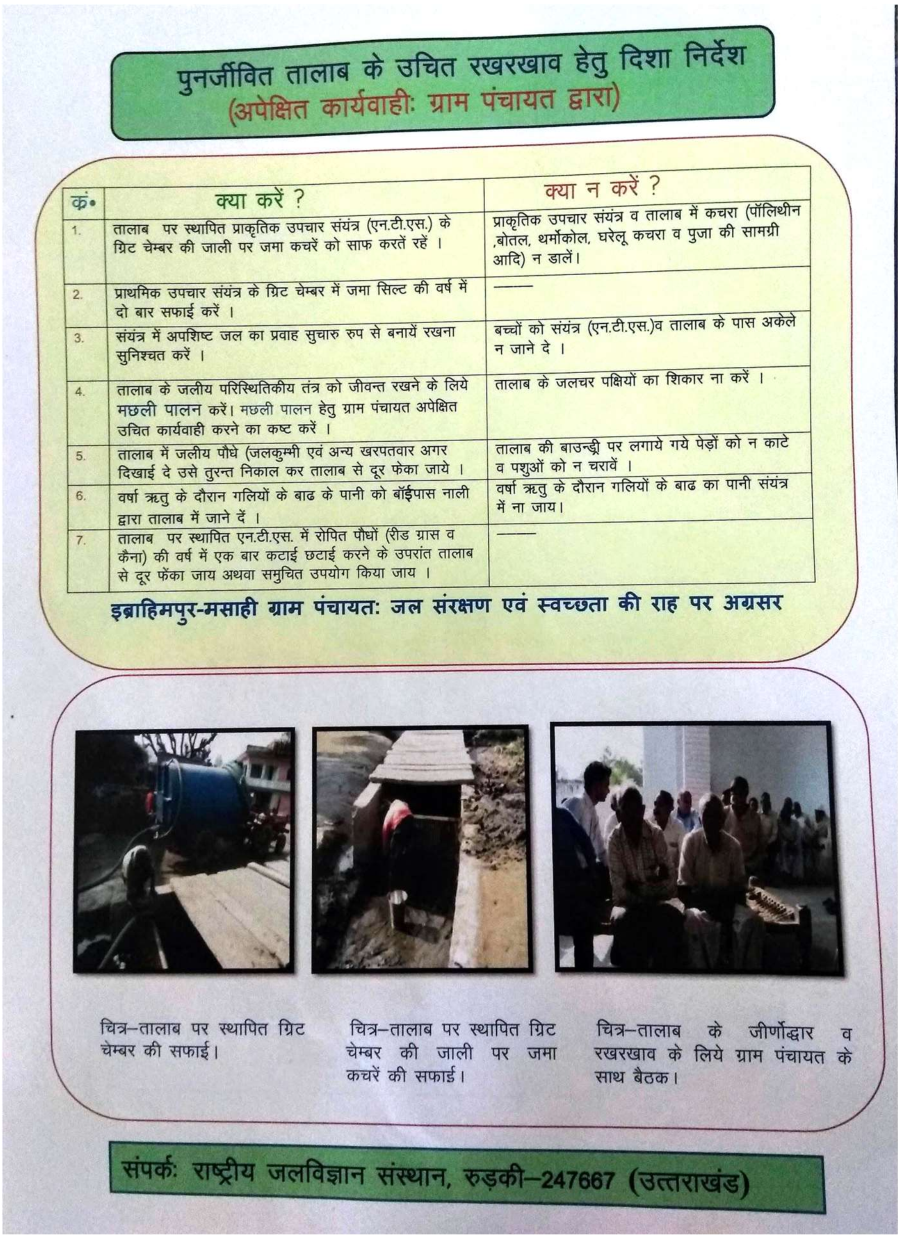
Maintenance issues

Maintenance is central to the performance of infrastructure, as social research has repeatedly emphasised (Barnes, 2017; Silva-Novoa Sanchez, Kemerink-Seyoum and Zwarteveen, 2019; De Coss-Corzo, 2020). For Ibrahimpur and Berambadi wetlands, this understanding was reflected in maintenance guidelines that detailed the work required to keep the wetlands operating successfully.

The Ibrahimpur researchers produced the maintenance guide shown in Figure 6.18 and translated in Table 6.1. Maintenance work included several tasks aimed at directing flows of water, as well as cutting the plants and keeping waste, children and flood waters out of the wetland. Regular clearing was prescribed to ensure that the grit screen at the inlet to the wetland was not clogged. However, upon arriving at the wetland with the research team, we regularly found the grit screen almost fully clogged. It appeared that unclogging only occurred when researchers visited the wetland for water quality sampling. On one occasion this involved Dinesh asking around for a spade, so that he could clear off the front of the grit screen himself. While running counter to the expectations set out in the

[28] More generally, this boundary or skin is fundamental to liberal understandings of individuals and species (Povinelli, 2021).

maintenance guidance, this division of work wasn't untypical. When things went wrong in these projects, it was the scientific teams who were called upon to do the required maintenance. As one interview respondent in the Berambadi team pointed out, while these projects were being used to generate scientific findings, members of the project teams had an interest in keeping everything working well.


पुनर्जीवित तालाब के उचित रखरखाव हेतु दिशा निर्देश
(अपेक्षित कार्यवाही: ग्राम पंचायत द्वारा)

क्र•	क्या करें ?	क्या न करें ?
1.	तालाब पर स्थापित प्राकृतिक उपचार संयंत्र (एन.टी.एस.) के ग्रिट चेम्बर की जाली पर जमा कचरें को साफ करतें रहें ।	प्राकृतिक उपचार संयंत्र व तालाब में कचरा (पॉलिथीन ,बोतल, थर्मोकोल, घरेलू कचरा व पुजा की सामग्री आदि) न डालें।
2.	प्राथमिक उपचार संयंत्र के ग्रिट चेम्बर में जमा सिल्ट की वर्ष में दो बार सफाई करें ।	———
3.	संयंत्र में अपशिष्ट जल का प्रवाह सुचारु रुप से बनायें रखना सुनिश्चत करें ।	बच्चों को संयंत्र (एन.टी.एस.)व तालाब के पास अकेले न जाने दे ।
4.	तालाब के जलीय परिस्थितिकीय तंत्र को जीवन्त रखने के लिये मछली पालन करें। मछली पालन हेतु ग्राम पंचायत अपेक्षित उचित कार्यवाही करने का कष्ट करें ।	तालाब के जलचर पक्षियों का शिकार ना करें ।
5.	तालाब में जलीय पौधे (जलकुम्भी एवं अन्य खरपतवार अगर दिखाई दे उसे तुरन्त निकाल कर तालाब से दूर फेका जाये ।	तालाब की बाउन्ड्री पर लगाये गये पेड़ों को न काटे व पशुओं को न चरावें ।
6.	वर्षा ऋतु के दौरान गलियों के बाढ के पानी को बॉईपास नाली द्वारा तालाब में जाने दें ।	वर्षा ऋतु के दौरान गलियों के बाढ का पानी संयंत्र में ना जाय।
7.	तालाब पर स्थापित एन.टी.एस. में रोपित पौधों (रीड ग्रास व कैना) की वर्ष में एक बार कटाई छटाई करने के उपरांत तालाब से दूर फेंका जाय अथवा समुचित उपयोग किया जाय ।	———

इब्राहिमपुर-मसाही ग्राम पंचायत: जल संरक्षण एवं स्वच्छता की राह पर अग्रसर

चित्र–तालाब पर स्थापित ग्रिट चेम्बर की सफाई।

चित्र–तालाब पर स्थापित ग्रिट चेम्बर की जाली पर जमा कचरें की सफाई।

चित्र–तालाब के जीर्णोद्धार व रखरखाव के लिये ग्राम पंचायत के साथ बैठक।

संपर्क: राष्ट्रीय जलविज्ञान संस्थान, रुड़की–247667 (उत्तराखंड)

Figure 6.18 - Original version of the Ibrahimpur maintenance guide. Photograph by the author, 2018.

The social arrangements envisioned by project teams at the outset, with maintenance work taken up by local people, were not realised in either Indian project. This suggests that one way to account for the limited changes in water quality through the Ibrahimpur wetland is a 'lack of maintenance'. This is similar to the interpretation made by the Berambadi project team. However, this interpretation elides the question of who should be responsible for maintenance and downplays the responsive work of maintenance. Rather than providing a satisfactory analysis in its own right, 'lack of maintenance' is an explanation that works best as a starting point to consider other social forces and assemblages.

Table 6.1 - Maintenance tasks at Ibrahimpur wetland, as translated by NIH staff

	What to do?	What not to do?
1.	Clean the bar screen (regularly)	Do not throw any solid waste in the NTS* or pond
2.	Silt collected in primary treatment system should be cleaned twice a year	
3.	Flow of wastewater through the treatment unit should be maintained continuously	Do not allow the children to go near the treatment system and pond alone
4.	To sustain the ecosystem of the pond, carry out fish culture. For fish culture the Gram Panchayat is expected to do necessary action.	Do not hunt the birds in the pond
5.	If aquatic plants like hyacinth are seen in the pond, they should be immediately removed and should be disposed of at a far-off place	Do not cut the trees planted at the boundary, do not let the animals graze there. [Plans to plant trees around the edge of the pond were cancelled, making this advice unnecessary]
6.	The excess water during the monsoon season should be diverted to the pond through the bypass drain	The flood water during the monsoon should not enter the treatment system
7.	Wetland plants in the NTS should be pruned once a year, and disposed of in a far-off place	

* 'NTS' is an abbreviation for 'Natural Treatment System'

Interpreting with the project model

A particular set of social relations makes maintenance a problem. Through her research on development in Indonesia, Tania Murray Li (2005, 2007, 2015) articulates the concept of 'the project' to describe this social assemblage. Projects are a mode of governance that "enrol government officials, politicians, transnational donors, NGOs, scientists, and villagers; they form them as subjects, and engage them in a particular set of practices" (Li 2015, p.2). This description resonates with how the Ibrahimpur and Berambadi wetlands were designed, funded and monitored by assemblages of scientists and engineers, working at government and charitable institutions. Li offers the following definition of a project: "a time bound intervention with a fixed goal and budget, framed within a technical matrix which renders some problems amenable to intervention, while leaving others out of account" (Li, 2015, p.1). While Li's account focuses on Indonesia, she suggests that such a model is also relevant in "many other parts of the global south" (p. 1)[29]. The project concept provides a different model for the social interpretation of water quality patterns at Ibrahimpur and Berambadi, one that moves beyond maintenance practices to foreground structural dynamics.

This model enables me to make three different manoeuvres. First, to reframe the 'problem' of maintenance. Second to directly interpret water quality charts as indicative of project dynamics. Finally, to understand projects as an assemblage through which the power relations and tensions of state, caste, capitalism and patriarchy are enacted.

The first point is simple. It was the fixed end date of both projects that made continued maintenance a crucial question – one that neither the Berambadi nor Ibrahimpur project could resolve tidily. In these 'time-bound interventions', relations between project teams and local people were hence oriented towards establishing 'local ownership' of the wetlands. This ownership was enacted through the staging of handover ceremonies where the keys and maintenance guides to the system were transferred. Ownership, in these cases, was intended to convey responsibility. However, as described above, symbolic handovers of responsibility were not followed by a straightforward shift in labour. When viewed from inside the project, ensuring continued water quality treatment could only be a question of local maintenance. Li suggests that "thinking about rural development in terms of projects has become so routine that alternative ways of thinking and acting are scarcely considered." (Li, 2015, p.1). Issues of constructed wetland maintenance, as they appeared at each site, are an indicator of this routineness at work. In these cases, the project model sustains its own mode of interpretation.

Thinking with the project model also allows water quality charts to be interpreted in different way. Rather than reading patterns of water quality fluctuation, we can turn to reading the chart itself as a project artefact. First, the timespan of the charts, slightly over a year at both sites, speaks to the limited timeframe that is typical of project interventions. Once the constructed wetlands were built, only a short time was left in the duration of each project. Second, although each project did collect other forms of data, the water quality data collated in charts and tables was the primary approach to understanding the impact of the constructed wetlands. This choice speaks to how projects frame issues within a 'technical matrix'[30]. The very existence of the data that allowed me to create the charts

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[29] Research such as the work of Marcus Taylor and Suhas Basme (2021), describing a climate-resilience project in South India, supports this assertion.

[30] I should note that NIH did ask me to contribute a 'social impact assessment'. Given that the project started before I was involved, it seems fair to assume that this social research was not seen as critical to the project design.

is not typical for rural Indian waterscapes. In this interpretation, each line on the water quality charts points towards a 'project model' at work.

Most significantly, the project model encourages us to explore the power relations that underlie waterscape and water quality transformations. As Li emphasises, the project system needs to be historicised, understood as the result of particular social and political developments[31]. It is a way of doing things that was not always dominant (Li, 2015). To understand this history in the context of my study locations requires tracing ongoing social processes including state formation, capitalist value extraction, and colonialism. To do this task justice is beyond the scope of this thesis, but I can trace some of the outlines. This tracing indicates the power relations that have brought the project model to its current dominance.

A helpful place to start this tracing is by asking what problem the Ibrahimpur and Berambadi projects aim to solve. These projects engaged with a web of social, political and ecological relations primarily through engineering design. The "practices of problematisation and rendering technical" (Li, 2015, p. 2) are the condition of possibility for projects, as well as a cause of their failures (Li, 2015, p. 3). In the case of Ibrahimpur and Berambadi wetland projects, this problematisation hinged on discourses of water scarcity (Mehta, 2003; Bharucha, 2019). Most residents of Ibrahimpur and Berambadi rely upon agricultural work, which makes 'water scarcity' an economic as well as social concern. Water scarcity is symptomatic of a complex trajectory of politics and agricultural development in India, which includes the colonial development of irrigation infrastructure (Hardiman, 1998; Mosse, 1999; Beattie and Morgan, 2017; Tozzi, Bouzarovski and Henry, 2022), the growing exploitation of groundwater following the 'green revolution' (Birkenholtz, 2009; Subramanian, 2015), and the (still actively contested) liberalisation of Indian agriculture (Narasimha Reddy and Mishra, 2010; Aga, 2021; Nielsen, no date). Hence, responding to water scarcity, these constructed wetland projects are attentive to the structural imperative to realise capitalist value, a common thread running from colonial domination (Moore, 2015; Patnaik and Patnaik, 2021) to today's reformulations of political power. These water conservation projects develop within the stresses of marketised and crisis-prone agricultural economies (Deshpande and Shah, 2010; Narasimha Reddy and Mishra, 2010).

What are the political affordances that facilitate project transformations in these waterscapes? In the past decades in India, rural politics has been partly reshaped by a process of decentralisation, where local panchayat councils were given greater powers and budget. The implications of these shifts are

[31] In the case of Indonesia, Li points to how active debate characterised Indonesian rural politics in the late period of Dutch colonisation, as well as in the 1960s. In the 1960s this political contestation was violently suppressed by General Suharto's government (with the support of the United States) (Bevins, 2020).

highly variable, depending on the power relations, caste politics, and sometimes specific individuals within each of the approximately 250,000 gram panchayats in India (Fischer and Ali, 2019). The outlines of the panchayat system in legal form do not map neatly to realities on the ground[32]. To give one example, while a local woman had the role of elected Gram Pradhan at Ibrahimpur, her husband was more frequently involved in project discussions. While the exact power relations involved in local governance were not always clear to me, the support of the panchayat was crucial for each project to proceed. At Berambadi it was hoped that the panchayat would provide some financial support to maintain the infrastructure once it was completed. At Ibrahimpur, flooding pulled NIH staff and the panchayat into negotiations over further engineering works to solve these problems, and who would pay for these. Overall, my impression is that the panchayat and local people navigate top-down projects such as these and their politics regularly[33]. Strategies include leveraging these projects for work opportunities, a refusal to engage with the project (through funding its upkeep, for example) or actions against project infrastructure. Projects are shaped in response to changing political constellations. In turn, they offer political subjects a variety of responses. Interpreting through the project model brings to light how hydrosocial relations are mediated through economics and politics, differentiated through caste, class and gender hierarchies and lived within the catastrophes of capitalism and colonialism.

The critical theorisation of the project provides an alternative mode of interpretation, both contextualising and moving beyond concerns about a 'lack of maintenance'. While these projects are subject to acts of repurposing, refusal and resistance, it is also the case that more broadly "the process of planning and implementing projects both expresses and creates a divide between experts and targets of expertise" (Li 2015, p. 7). In creating this divide, projects represent a hierarchical and non-democratic approach to shaping waterscapes. Hence, while the water quality charts above may indicate improvements in water quality, they also indicate the difficulties of moving towards visions of water justice grounded in democratic deliberation.

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[32] Though similar arrangements have a long history in India, the current system of panchayat raj was instituted by a constitutional amendment in 1992. In many areas, this political landscape has provided the opportunity for marginalised castes to increase their political influence (Chhotray, 2011). Fischer and Ali (2019) use a case study to highlight how the outcomes of panchayat governance can depend on specific individuals. The fact that I am reporting from the literature here, rather than first-hand, is an indication of the difficulty I had in uncovering these dynamics at the Indian study sites due to the limited time spent at each site, lack of language skills and limitations in my understanding of the social and political context as an outsider.

[33] For example, the Swachh Bharat Abhiyan scheme had reshaped village wastewaterscapes a few years prior to these projects. Such Indian Government 'missions' seem to fit the project mould neatly.

Conclusion: the politics and possibilities of interpretation

Juxtaposing interpretations

When changes in water quality are integrated over time and space, the result is a patterning of water quality. This patterning is an important component of waterscapes. This chapter has examined interpretations of the water quality changes that occur as water passes through three constructed wetlands.

To briefly recap the preceding sections, I first investigated how interpretation is practised in a publication from the Berambadi project. Interpretation of water quality changes is central to achieving the aims of the paper. Some of the interpretation in the paper aims to make sense of water quality patterns through reference to ecological processes. Understandings of these processes are drawn from the wider constructed wetland literature. The paper also interprets the performance of the Berambadi wetlands through a particular model of constructed wetland hydraulics and kinetics, again drawing on approaches from constructed wetland science. Finally, the paper gestures towards a social interpretation of constructed wetland performance, through discussions of maintenance. Through this multifaceted interpretation, the paper both explains water quality patterns at Berambadi and puts forward recommendations for other constructed wetland projects. Based on this analysis, I set out a theoretical framework that positions models and representations as foundational to interpretation practices.

I then offered my own interpretations of water quality changes across the three constructed wetland sites. The interpretations are built upon a different set of models for understanding hydraulic, ecological and social forces. These models suggest that flows of water are varied, that this variability stems from hydrosocial processes and that acknowledging such variability makes certain forms of interpretation impossible. In examining ecological relations, I argue for a non-functional account of plant and microbial doings. And in the social domain I conduct an interpretation of water quality patterns through the frame of 'the project' (Li, 2015). These models reposition people, other living beings and water. Juxtaposing these two analyses demonstrates how models and ideologies shape all practices of explanation and generate interpretations with different political effects.

The politics of interpretation

The processes of water quality degradation and remediation in these waterscapes are far from unique. The variations in water quality over time and space explored in this chapter exemplify the patchy patterning of water quality across all waterscapes. Turning to similar research helps to draw out the tensions in interpreting water quality patterns across different domains of analysis. Describing the patterning of water quality in Lilongwe, Malawi, Maria Rusca and co-authors aim for an account of water that balances material and socio-ecological relations, including broader social, political and economic processes; the goal is to provide a "multifaceted understanding"[34] (Rusca *et al*., 2017, p. 139, see also, 2022). Their conclusion points to the influence of two disparate things on water quality; the political decisions of planning policy and the material-semiotic 'force' of water pipes (Rusca et al. 2017, p. 144). Such an analysis leaves open the potential for different responses to address inequitable drinking water. Actions to reform pipes or to mend urban planning processes will both reshape future patterns of water quality. Following an urban political ecology framework, the materiality of pipes and the politics of planning decisions are "different moments within a broader socio-ecological totality" (Rusca et al. 2017, p. 144). In a similar fashion, Adam French (2019) argues that an interpretation of the water level and outflow of Lake Paron, Peru requires both a historical-material analysis of political dynamics and a sensitivity to the emergent agency of socionatural actors. However, tracing emergent agencies across an ever-expanding range of actors is far from straightforward. Malini Ranganathan's assemblage-oriented analysis of flooding and urban development in Bengaluru leads her to ask: "What does it mean to say that sewage, concrete, and capital are also flood-inducing agents?" (Ranganathan, 2015, p. 1315). We are left with what she describes as "vexing questions" (p. 1315). Hydrosocial interpretation requires making non-innocent choices about which moments or actors to pay attention to.

The Berambadi project team's interpretation could be characterised as a mode of interpreting that foregrounds technical and biophysical factors. Such approaches are coupled with an assumed generalisability of constructed wetland performance. Interpretation in one location serves to inform constructed wetland design or operation more broadly. For example, within the Berambadi project, attributing the performance of the wetland to a lack of plant vitality led to a suggestion that wetland planting could perhaps be omitted when "scaling-up" constructed wetlands in southern India (Jamwal et al., 2021, p. 9). Such generalisations are not unreasonable but need to be approached carefully. In my own analysis, this mode of interpretation was a tempting one to turn towards. Hydraulic explanations seemed parsimonious for explaining many key water quality patterns. It is easy to draw out recommendations based on these biophysical interpretations. For example, building a more distributed wetland inlet structure at Ibrahimpur might have reduced clogging. These interpretations build upon or develop well-established representations of wetland space to

[34] This approach is underpinned by an argument that "by following the process of abstraction through which water is produced as a commodity, many urban political ecologists have failed to attend to the material properties of water" (ibid., p. 139).

suggest how wetlands might be better designed and operated. But this mode of interpretation has more subtle effects. In their technical orientation, such interpretations present waterscapes as knowable or predictable[35]. Each variation in water quality, intended or not, is explained in alignment with constructed wetland science. One result of this is that such interpretations stabilise scientific expertise and its divide between those who are the bearers and subjects of expertise (Li, 2007). Furthermore, the functional ecological explanations which I critique and aim to work beyond in this chapter are indicative of a particular ethic of more-than-human relations. Other-than-human beings are positioned as functional components or labourers. Such an interpretation denies the responsiveness of other-than-human beings. In this way, technically focused interpretations sustain relations of domination on two fronts: between humans and over other-than-human beings.

Interpreting differently

All interpretation relies on models, which are ideologically inflected representations of a more complex reality. This chapter has emphasised the simplifications required for making the technical interpretations favoured in constructed wetland science. As Timothy Mitchell (2002, p. 34) cautions, these simplifications are often part of the stabilisation of expertise. They may also normalise inequitable or dysfunctional social arrangements. In contrast, my accounts of wetland life in this chapter aimed to animate plants and microbial life and in doing so, to embrace complexity and uncertainty. Bringing together ecological science, observation and more-than-human scholarship has worked to complicate constructed wetland models.

One tool I adopted for this task was Sebastian Abrahamsson and colleagues' conceptual model of "affordance-response", which they suggest offers a way to work around 'agency' and its baggage (Abrahamsson *et al.*, 2015). As these authors argue, Western modes of thought create a bifurcation between a social world of free action and material world of events where events are caused by external forces (p.13). This dichotomy constrains interpretations of constructed wetland performance. Following this arrangement makes it difficult to see any contingency or creativity in how non-human beings contribute to shaping the waterscape. At the same time, it limits our understanding of how human actions are also moulded by structural constraints. In the preceding sections, highlighting how plants are responsive to the affordances of constructed wetlands is my attempt to remove them from a functionalist logic. I used alternative models of ecological relationality to challenge narrowly functional ecological accounts (Schrader *et al.*, 2015) and to

[35] For example, hydraulic models position water as fluid whose motion can be precisely represented through a mathematical equation. However, the accuracy of these models rests on how well waters' relations can be estimated, a much more difficult problem for flow through a rocky, plant and microbe-filled medium.

approach living beings as "inventive practitioners who experiment as they craft interspecies lives and worlds" (Hustak and Myers, 2012, p. 106). To take another example, the project system is a response to the political and economic context of 'development' while offering different affordances for scientists, local politicians, and village residents. Such a model has potential for developing the balanced interpretations that hydrosocial scholarship aims for.

At the same time, my interpretations are intentionally partial and uncertain. There were some changes in water quality that I was not able to interpret with any confidence. Instead, I believe it is important to accept some degree of uncertainty. It is on these grounds that I am troubled by the turn to 'functional group' explanations of microbial performance. Such interpretations all too readily close down the need to acknowledge dynamics that remain unknown or surprising. I take seriously the notion that the full "vitality of matter is well beyond human knowledge and control" (Wakefield, Chandler and Grove, 2022, p. 8)[36]. In this way, predictability and uncertainty become key to the politics of interpretation. As David Lulka argues, "thick hybridity forces society to embrace environmental uncertainty" (Lulka, 2009, p. 378). In response to such uncertainty, ecological knowledge can also be oriented towards an experimental approach[37]. Examples of this already exist in the constructed wetland literature, for example, experiments that introduce different microbial life (Q. Wang *et al.*, 2019; Hu *et al.*, 2021; Tondera *et al.*, 2021) or change wetland conditions in ways that are expected to alter microbial communities (Ouellet-Plamondon *et al.*, 2006; Song *et al.*, 2020; Yuan *et al.*, 2020) and seeing what impact this has. Reckoning with uncertainty suggests a different role for interpretation, as an ongoing responsiveness and exploration. Rather than being explained away, unexpected patterns of water quality could serve as an invitation for ongoing engagement. In the Ibrahimpur and Berambadi waterscapes the project model forecloses possibilities for such ongoing responsiveness. However, even if it is a remote possibility in these locations, I believe it is still valuable to imagine interpretative work as an ongoing practice characterised by continued responsiveness to a waterscape whose processes we can never fully understand. Feminist science scholars might describe such an approach as the cultivation of response-ability. Donna Haraway (2016) describes this as "a praxis of care and response" (p. 105), of "collective knowing and doing" (p. 34), which aims to learn more each day. Such response-ability is a foundation for ethical engagement in waterscapes.

Ultimately, as this chapter has demonstrated, there are always ways to interpret differently. These interpretations might be used to generate political contestation. The different interpretations of

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[36] Or, in a more poetic vein, that something as simple as a tree trunk is a "living landscape… comprised of an infinite series of intersecting micro-realms" (Gandy, 2019, p. 402).
[37] See Braun (2015) for links with an experimental approach to political ecology research.

flooding at Ibrahimpur, attributing responsibility to different groups, are one example of this potential. Interpreting differently often involves finding or developing different models. As another example, invoking the ‘project model’, as I have done in this chapter, serves to contest mainstream practices of development and their distributions of power and responsibility. Whether in dramatic or subtle ways, interpretation practices are part of how waterscapes are reproduced. Interpreting differently can aim to unknot relations of domination between people as well as over other-than-human life, and to make different ties. Such contestations and attempts to interpret differently are necessary for realising water justice.

7 Diversity and Habitability: Exploring multispecies histories

Diversity as an ethical orientation for multispecies habitability

Visiting the constructed wetlands at Ibrahimpur, Berambadi and Loch Leven, my attention was drawn to various beings within the wetland space: Grasshoppers flurrying away as I walked through the tall canna stems at Ibrahimpur; frogs sheltering under stones; tiny creatures zig-zagging through the water where I measured conductivity for a tracer experiment; bees and flies looping around the canna flowers while ants made their way up and down the fabric lining of the wetland edge at Berambadi; willow shoots and fungi poking up after coppicing at Loch Leven. Conversations with people living near the wetland deepened my sense of the constructed wetlands as spaces inhabited by a diversity of beings. Inspired by more-than-human geographies and other multispecies studies, this chapter begins from the premise that the habitability of constructed wetlands is a relevant concern for water justice. Constructed wetlands have the potential to be sites of multispecies flourishing (Haraway, 2008; Ginn, Beisel and Barua, 2014; Zenner, 2019; Tschakert *et al.*, 2021).

In one mode of accounting, the moments of encounter and wonder described above might aggregate to become 'constructed wetland biodiversity'. This is certainly how many previous studies that examine the habitability of constructed wetlands frame their findings. This can be seen through the common approaches to researching constructed wetland habitat; making a list of species, summing this up as species richness, or calculating other diversity indices[1] (Semeraro *et al.*, 2015; De Martis *et al.*, 2016; Fang *et al.*, 2020; Zhang *et al.*, 2020; Deacon *et al.*, 2021). These operations connect the habitability of constructed wetlands to a powerful normative discourse. Maintaining or increasing biodiversity is now a central normative goal of conservation and environmental policy (Escobar, 1998; Lowe, 2006; Lorimer, 2015a). David Takacs (1996) describes how the notion of biodiversity was invented by conservationists in the 1980s. Jamie Lorimer (2015a), drawing on Takacs, recounts that "biodiversity promised a new way of understanding and governing the environment; its advocates sought to rationalize existing conservation and galvanize future action" (p. 57)[2]. The

[1] Diversity indices use different mathematical transformations to convert the abundance of different species into a single metric. Various transformations weigh the importance of abundance differently. For example, if only one individual of a species is observed, does this have lower importance than more common species? This means that "the choice of index can profoundly alter the interpretation of results"! (Morris *et al.*, 2014, p. 2514)

[2] While I agree with the conclusion that biodiversity is a recent discursive construct, like any discourse, it has a longer genealogy. Escobar (1998) observes that there are precedents to biodiversity practices today in the networks of botanical collecting developed in the context of colonial-imperial exploration (p. 54). José Augusto

preservation of biodiversity becomes an urgent task in the context of mass extinction (Theriault *et al.*, 2020). Constructed wetlands, as biodiverse habitats, become part of this broader mission.

For those who have examined the operations of conservation biology, the world-making force of biodiversity discourses deserves critical reflection. Biodiversity is biopolitical, "a form of environmental governance actively shaping human and nonhuman subjects and the wider ecologies they inhabit'' (Lorimer, 2015 p. 59). Cecilia Lowe (2006) describes biodiversity as a "mode of biological and social organization" (p. 4). As Christine Biermann and Becky Mansfield (2014) argue "scientists become authorized not only to speak for nonhuman nature but also to identify and wage war against the actors and actions – both human and nonhuman – that threaten the future of life" (p. 263)[3]. Conservation is a biopolitical project whose human and other-than-human violences are given justification as efforts to preserve biodiversity. This project does not always sit comfortably with a concern for multispecies flourishing.

While these critiques are important, biodiversity is a discourse that maps – however imperfectly and unevenly – to the variety of life[4]. This variety deserves ethical consideration. Other scholars have highlighted how biodiversity is, in important ways, a polysemic concept (Escobar, 1998). Arturo Escobar (1998) describes how the biodiversity discourse has been torqued by nations in the Global South, as well as NGOs and social movements, in order to support their priorities. Lowe (2006) offers a detailed account of how this was done by conservation scientists in Indonesia. As Matthew Gandy notes (2013), biodiversity always works alongside other ways of valuing particular species, assemblages or landscapes. For a further example of this, we can turn to contrasting discourses of biodiversity developed in the context of forest regeneration in Europe. In European alpine regions, current multispecies assemblages are sustained through pastoralism. The abandonment of pastoralism and the self-introduction of wolves are both processes whose desirability has been debated through competing visions of biodiversity (Buller, 2008; Barnaud *et al.*, 2021). Though biodiversity operates in a similar scientific context to water quality – with pressures towards universalism and uniformity (Valera and Bertolaso, 2016) – there is still room for it to be enacted in different ways. These intricacies suggest that, when speaking of biodiversity, it is necessary to

Pádua (2012) suggests that a deeper genealogy of biodiversity might also connect with highly political 18th century arguments on "New World degeneracy", which included the claim that the Americas had a lower number of species than the 'Old World' (see Dugatkin, 2019).

[3] For more on the 'war' framing of biodiversity conservation see (Neumann, 2004).

[4] The choice, then, for those interested in this variety, is to use biodiversity or to find a different term for the "concrete biophysical referents" (Escobar, 1998, p. 53) that biodiversity is connected to. For example, Lowe (2006), aiming to work out from under the discursive power of 'biodiversity', uses the term 'nature's variety' (p. x). In this chapter I stay with biodiversity.

carefully articulate an ethical position, which may not straightforwardly align to mainstream biodiversity discourses. The connection between biodiversity and water justice must be carefully forged.

The emergence of biodiversity

How do constructed wetlands become sites of biological diversity? The interactions mentioned above might suggest that constructed wetlands are inherently supportive of diverse living beings. Is achieving multispecies habitability as simple as 'build it and they will come'? While all three wetlands supported other-than-human communities, there was a different *thickness* (Lulka 2009) of habitation across the three wetlands. This chapter explores some of the reasons for this difference by tracing the processes through which constructed wetlands become diverse habitats. I trace these processes because I believe they might help to understand how better multispecies habitability can be achieved, in locations where more-than-human communities and infrastructural function overlap.

Any project that aims to enable multispecies flourishing should consider how biodiversity emerges in different spaces. Jamie Lorimer (2008) develops a particular understanding of immanent biodiversity in the context of UK green roof conservation. I highlight this project here because, to interpret the grounded work of conservationists, he endeavours to build conceptual bridges between social and ecological theory. Lorimer suggests that biodiversity looks different in the context of non-equilibrium ecologies: the idea that a single stable end-state for a particular ecological patch is "illusory" and "rarely achieved for significant periods of time" (p. 2047). If ecologies can be characterised by a stable equilibrium state, then their ultimate biodiversity potential is also fixed. This perspective animates the policy of biodiversity offsets (zu Ermgassen *et al.*, 2021). But non-equilibrium ecologies must be approached in a different way. Lorimer brings non-equilibrium ecological theory into conversation with a Deleuzian theorisation of potentiality. Lorimer writes that "when 'biodiversity' is applied in contexts like urban brownfield conservation… it becomes the science of immanent differentiation concerned with future becomings rather than existing beings" (Lorimer, 2008, p. 2054). This points towards a difference between biodiversity as something a constructed wetland *has* and something that people and other wetland creatures are constantly working towards or away from.

But might we not still have some concern for existing beings? If so, then perhaps it is helpful to turn from futures and to consider histories of biodiversification and simplification. These histories can be examined through bridging ecological and geographical theory.

My starting point is to position biodiversity as a spatial property and to draw on geographical theorisations of space. At the heart of my approach is an attention to relations. In this way, I connect my explorations to relational theorisations of space within geography (Massey, 2005). I consider how biodiversity is dependent upon diverse relations that develop through both evolution and involution (Hustak and Myers, 2012). This relational approach requires an orientation towards process, to biodiversity as 'always becoming' (Tsing, 2012, p. 95)[5]. Thinking with relations also turns my attention to the relevance of working across scales and tracing motion and flows to understand biodiversity. Finally, I consider how the emergence of biodiversity is shaped by human and non-human cognition of space. Spatial representations, aesthetics, knowledge, and atmospheres are all part of the story of biodiversity in these constructed wetlands. Processes, relations, representations and atmospheres are the aggregations within which biodiversity emerges. These concepts frame the stories of biodiversity told in this chapter.

While the concept of non-equilibrium ecologies is central to Lorimer's exploration, I am interested in the specific ways that ecological theory explains the emergence of biodiversity. A growing interest in biodiversity prompted ecological scientists to pay greater attention to something that had previously been considered an 'epiphenomenon'; of minor interest relative to ecosystem functioning (Loreau, 2010)[6]. A longstanding theory links species diversity to the ecological concept of a 'niche'; the "habitat requirements for a particular species to survive and reproduce" (Moore, 2013, p. 649). Niche theory suggests that biodiversity is a subset of broader heterogeneity; varied niches allow for different species to coexist. Niches are shaped by both abiotic factors (such as rainfall or temperature) and biotic interactions (competition or predation) (Loreau, 2010). To speak of a niche bundles these factors into a multidimensional concept, one that Moore suggests can be imagined graphically as "an n-dimensional hypervolume" (Moore, 2013, p. 649). These 'dimensions' could also be considered as a set of relations that each organism develops. These relations, and the niches they create are not necessarily stable (Levins and Lewontin, 1985).

[5] Buller (2008) uses the term 'biodiversification' (p. 1594) to point to this.

[6] While biodiversity is now a strong normative goal of conservation and environmental policy, explorations of biodiversity within ecological science also have an instrumental dimension. Biodiversity is hypothesised to be a key part of ecosystem resilience (Smith and Dressler, 2019). The theory is that greater biodiversity leads to more stability and a stronger ecosystem equilibrium. However, this is an area of continuing debate as some low diversity ecologies can be very stable (Pennekamp *et al.*, 2018). This ecological resilience literature perhaps should be read alongside critical perspectives on resilience as a political concept (Evans and Reid, 2015; Ranganathan and Bratman, 2019; Taylor and Bhasme, 2021), as well as arguments from within ecology that 'stability' is not a helpful baseline (Rohwer and Marris, 2021).

However, some ecologists have challenged the niche model (beginning with Hubbell, 2001). Their argument was that it was possible for various organisms to fulfil the same ecological functions in a landscape. The existence of distinct niches was not a requirement for biodiversity. Diversity can instead come from the random distribution of species over time and space (Harpole, 2010; Faeth, Bang and Saari, 2011). This argument is referred to as a 'neutral theory of biodiversity'. Recent ecological research suggests that these two contrasting theories – niches and neutrality – represent "two ends of a continuum rather than mutually exclusive paradigms" (Furniss, Larson and Lutz, 2017, p. 1). Different ecosystems fall somewhere between these extremes. Conservation research has also emphasised the importance of connectivity. The diversity of any specific location depends on the ability of different creatures to move across broader landscapes (Amezaga, Santamaría and Green, 2002; Tickner *et al.*, 2020). In conclusion, while there are many mechanisms that can be invoked to explain patterns of species diversity, none of these mechanisms is adequate on its own (Begon, Townsend and Harper, 2005, p. 631).

We might also ask about the absence of explicit human actions in these models. Fortunately, accounts of biodiversity processes which bring social dynamics into the picture do exist. For instance, within conservation biology, Gardner et al. (2009) write that "a growing body of research demonstrates that spatial and temporal patterns of biodiversity are the dynamic product of interacting historical and contemporary human and ecological processes" (p. 561). Anna Tsing describes the multispecies relations that create diversity in the midst of human disturbance as 'slow disturbance': "slow disturbance landscapes are those that nurture interspecies collaborations" (p. 95). While not explicitly referenced, this strongly invokes the 'intermediate disturbance hypothesis' in ecology (Wilkinson, 1999; Moi *et al.*, 2020). Tsing argues that telling the histories of slow disturbance and the 'contaminated diversities' that it creates enables us to identify more-than-human "collaborative partners for a liveable earth" (p. 97). Framed this way, exploring the processes that allow biodiversity to emerge requires telling a more-than-human history, one that gives an adequate thickness to the world. Tracing processes of biodiversification produces a richer understanding of the other-than-human beings that find a home in these constructed wetlands, and shows the relations, scalar connections and representations that must be engaged with to enable multispecies habitability and flourishing at each site.

Plants: multifaceted histories of diversity

The vegetal diversity within these constructed wetlands illustrates the interplay of multi-scalar histories and representations of space. To start, Table 7.1 and Table 7.2 describe the plant species that I identified during surveys at Ibrahimpur (14 species) and Loch Leven (22 species)[7].

Table 7.1 - Ibrahimpur plant species identified: Planted species in blue, kitchen spillovers in orange, others/unknown introduction in green.

Common name	Binomial name or genus	Jun 19	Mar 20
Canna lily	*Canna indica*	x	x
Giant reed	*Arundo donax*	x	x
Rabbit-meat	*Alternanthera sessilis*	x	
False daisy/bhringraj	*Eclipta*	x	
Barnyard grass	*Echinochloa*	x	
Common purslane	*Portulaca oleracea*	x	
Hawksbeard	*Crepis*	x	
Physalis	*Physalis*	x	
Tomato	*Solanum lycopersicum*	x	
Bermuda grass/dūrvā	*Cynodon dactylon*		x
Celery buttercup	*Ranunculus sceleratus*		x
Water speedwell	*Veronica anagallis-aquatica*		x
Curly dock	*Rumex crispus*		x
Indian mustard	*Brassica juncea*		x

As a complement to these tables, Figure 7.1 and Figure 7.2 show a diversity of vegetal forms. This diversity is connected to the species diversity indicated in the tables, but it is not reducible to it. These images tell the story of plant diversity in a more immediate way: stems, buds and young leaves in a variety of shapes, flowers of different colours. These plants have developed their diversity of forms over evolutionary time. This makes evolutionary history a starting point for understanding plant diversity.

[7] For detailed descriptions of the survey method, refer to the methodology chapter.

Table 7.2 - Loch Leven plant species identified

Common name	Binomial name or genus	Apr 21	Jul 21	Sep 21	Nov 21
Reed sweet-grass	*Glyceria maxima*	x	x	x	x
Sedge	*Carex*	x	x	x	x
Common reed	*Phragmites australis*	x	x	x	x
Great Willowherb	*Epilobium Hirstutum*	x	x	x	x
Willowherb (small)	*Epilobium*	x		x	x
Dock	*Rumex*	x	x	x	x
Nettle	*Urtica dioica*	x	x	x	x
Marsh marigold	*Caltha palustris*	x	x	x	
Umbellifer	*f. Apiaceae*	x	x	x	
Purple loosestrife	*Lythrum salicaria*	x	x	x	
Fern	*c. Polypodiopsida*	x	x	x	
Ground elder	*Aegopodium podagraria*	x			
Cleavers	*Galium aparine*	x	x		
Herb-Robert	*Geranium robertianum*	x		x	
Buttercup	*Ranunculus*	x		x	
Iris	*Iris*		x	x	
Willow	*Salix*		x		x
Sow thistle	*Sonchus*		x		
Figwort	*Scrophularia*		x		
Thistle	*f. Asteraceae*			x	
Common nipplewort	*Lapsana communis*			x	
Water mint	*Mentha aquatica*			x	

Figure 7.1 - Ibrahimpur vegetation diversity. Photographs by the author, 2018-2020.

Figure 7.2 - Loch Leven vegetation diversity. Photographs by the author, 2020-21.

For these specific wetland spaces however, the story of diversification begins with a planting plan. These plans determined which species would be plan-ted in the wetland. At Berambadi and Ibrahimpur, the only species chosen was canna lily, *Canna indica*. The choice of canna alone was perhaps influenced by constructed wetland literature's hunt to find the most efficient plant for wastewater treatment (for example, Taylor *et al.*, 2011; Abbasi *et al.*, 2019; Maucieri, Salvato and Borin, 2020). In this way, mental models of the wetland focused on treatment efficiency supersede the possibility of diversity[8]. At Berambadi the final choice between several wetland plants was made by teachers at the school. Some project team members gave several additional reasons why having only a single species of plant was preferable, including that a monoculture is easier to maintain and makes water quality results easier to interpret. Others suggested that the idea of planting a mix of plant species was simply absent from planning discussions. Loch Leven had a different approach; the wetland designers selected around 14 different species to be planted within the two cells of the wetland, in different patches. Within the willow cell of the wetland approximately 10 different varieties of willow were planted. This design was motivated by a desire for diversity.

These human designs were quickly enveloped by a more complex story. Plants, working in tandem with other creatures and material flows, carried out their own forms of wetland plant-ing. At Ibrahimpur several plants grown and eaten as vegetables took root in the wetland, as wastewater flows to the wetland carried seeds discarded in kitchen waste. Other plants seen along stretches of the drain upstream were also found in the wetland. Plants have a variety of methods for harnessing the flows of water, wind, soil and animals in order to move. The nettle growing at Loch Leven is a good example of this. Seeds can be carried on the fur of animals, on the wind or with soil. Nettle seeds can remain in the soil for several years, ready to germinate at the right time (Taylor, 2009). The vegetal diversity at Ibrahimpur and Loch Leven is a culmination of diverse flows that bring plants to the wetland.

While some plants set about diversifying the wetland, these germinations were not always welcome. Weeding of the wetlands was carried out to remove some of the plants established in the wetland. In the case of Loch Leven, weeding also removed some plants that were initially planted in the wetland, but treated as weeds by gardeners. The maintenance guide for Ibrahimpur instructed local people to prune wetland plants annually. I don't have any evidence of local people taking up this guidance, but gardening staff from NIH worked on the wetland during one visit in June 2019, removing vegetable plants and other species. At Berambadi a maintenance worker was tasked with preventing weeds from moving into the wetland from the surrounding lawn. This was one of the reasons why I observed no other plants than canna in the Berambadi wetlands (and why this wetland

[8] This emphasis on using a single plant to produce the greatest efficiency is not entirely supported by evidence. Many studies of plant diversity have established that, in diverse conditions, a greater diversity of plants leads to higher biomass (Cardinale *et al.*, 2007). Given that a higher biomass would generally contain a greater amount of nutrients, it would seem logical that a mix of species would yield greater efficiency. However a meta-analysis of 28 studies found no evidence of this effect (Brisson *et al.*, 2020).

does not feature in the tables and figures above). Beyond the initial design decisions, mental representations of constructed wetland space continued to shape the diversity of wetland vegetation.

Another factor working against plant diversity at Berambadi is the abiotic environment. The water level in the wetland sat approximately 20cm below the surface of the gravel. In order to plant canna lily in the second wetland, Jagadeesh, Kumar and I dug through this gravel to place the roots of the canna in the water. A seed trying to establish in this wetland without human assistance would face a difficult task growing through this dry gravel layer, to reach both the necessary water and sunlight. Various relations between plants and abiotic conditions are central for understanding plant distributions, and commonly investigated by ecological science. Such factors include climate, sunlight, the texture and pH of the soil, as well as hydrology (Begon, Townsend and Harper, 2005). Many plants can't grow in waterlogged soil, while wetland plants are specifically adapted to do so (Taylor *et al.*, 2021). The niche concept is useful here to account for why certain plants grew in the wetland.

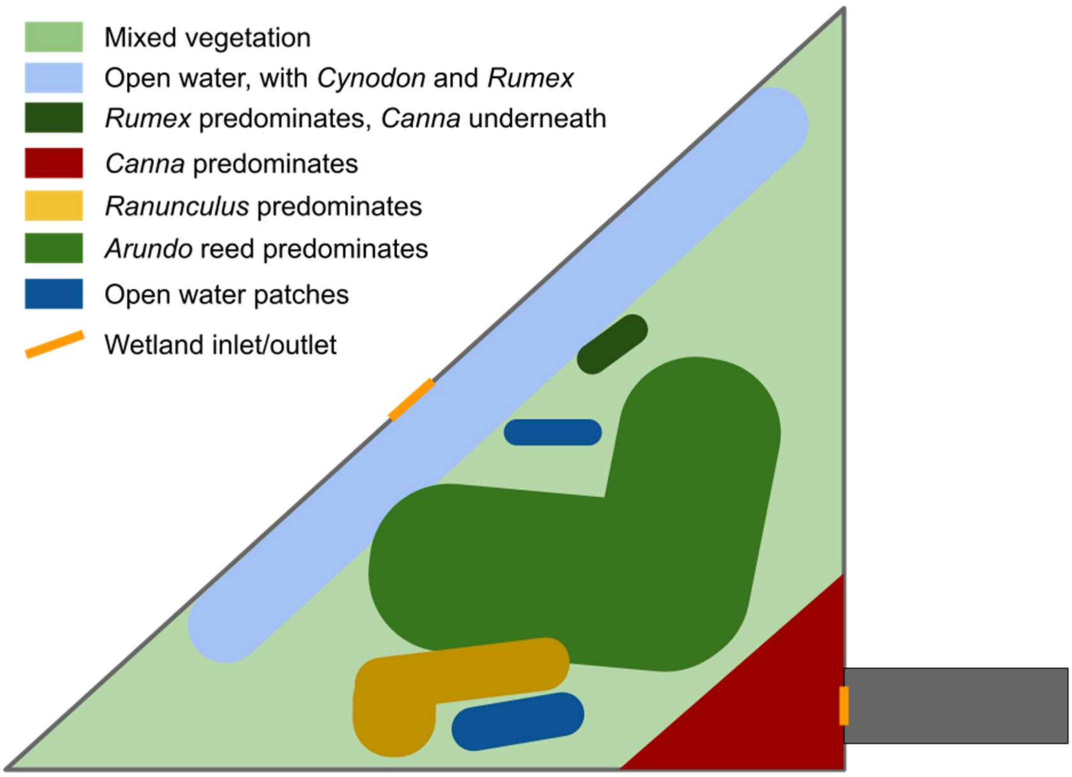

Figure 7.3 - Vegetation distribution at Ibrahimpur, March 2020. Diagram prepared by author.

I want to briefly consider here an element of spatial diversity that goes beyond species diversity aggregated over the entire wetland. Figure 7.3 shows the distribution of plants in Ibrahimpur wetland in March 2020. Much of the wetland was a mix of different vegetation, but canna lily was dominant near the entrance to the wetland. *Arundo* reed filled the centre, while near the outlet was mostly open water. Quadrat surveys provide a quantitative reading of this variation. Across fifteen quadrat locations, the number of plant species in each 1m2 area varied from one to six. The average vegetation height varied between 40 to 80 cm in most quadrats but was zero at three locations close to the pond side of the wetland (see Figure 7.5). Photos of Ibrahimpur wetland shortly after the canna was planted show small canna plants evenly distributed around the wetland. The variation in abiotic conditions within the wetland spurred a differentiation of growth patterns, and a structural diversity within the wetland.

Figure 7.4 - Another view of the patchy distribution of plant species within Ibrahimpur wetland. Photograph by the author, 2020.

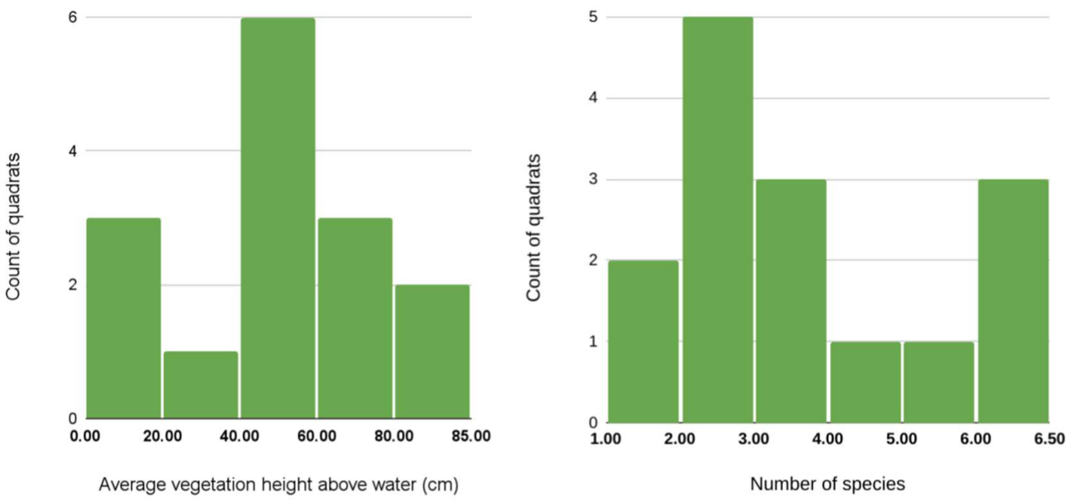

Figure 7.5 - Quadrat survey summaries showing the variability of plant height and species richness within Ibrahimpur wetland

The final set of relations that shaped the vegetal diversity in these constructed wetlands are those between plants. The species and spatial diversity of plants is not only structured by external influences but worked out by different plants as they interact. One of the dozen or more plant species planted at Loch Leven was sweet reed-grass, *Glyceria maxima*. In the few years after the planting of the wetland – but before my vegetation surveys – this reed became the dominant species in the wetland. Giant cane, *Arundo donax* was similarly dominant in some parts of the Ibrahimpur wetland. This is far from unusual, many wetland plants form dense stands of a single plant (Schooler, McEvoy and Coombs, 2006). Besides the influence of abiotic factors, and occasional weeding, the life histories of different plants suggest why some plants were better placed to become dominant. What appears particularly important are the different ways that plants grow and reproduce; how plant bodies are made. *Glyceria maxima*, *Arundo donax*, *Canna indica* and *Urtica dioica* (common nettle) are all able to propagate through rhizomes. Distinct from the non-hierarchical webs of philosophical rhizomes (Tuck, 2010), in plants, the rhizome is a means of vegetative propagation. Instead of growing from a seed, new stems of a plant grow from a rhizome that spreads horizontally beneath the soil (or gravel in the case of a constructed wetland). The rhizome is also a store of nutrients and starch, enabling rapid growth. At Loch Leven, the *Glyceria maxima* growing in the summer, once it had died in the autumn formed a thick mat over the wetland through until the following spring. Perennial plants with rhizomes or other below ground energy could grow through this layer, but any seeds within the wetland would be shaded out. In these cases, the action of plants was working *against* diversity.

The diversity of plants in each wetland is not determined by human decisions or environmental conditions. It unfolds shaped by both of these but also by the active work of plants themselves. It is only through the combination of these factors that certain plants flourish while others do not. Along the way, the embodied energies, materialities and structures produced by plants provide affordances for many other beings, which are the focus of the following sections.

Invertebrates and birds: diversity through involution and evolution

Figure 7.6 - QR code for wetland video

Alongside the text for this section, I also produced a summary video from the recordings I made at each wetland. To watch, scan the QR code above or follow this link: https://youtu.be/vD-gg12DRhc
If you would like to take a break from reading, now would be a good time to watch this video. You can also come back to it after reading this section.

Invertebrates were the most diverse and abundant animal life at each wetland. Terrestrial arthropods[9] represent the majority of wetland biodiversity globally (Batzer and Wu, 2020). At Ibrahimpur, walking through the wetland stirred the movements of grasshoppers, while small flies, butterflies and dragonflies were also seen around the wetland. At Berambadi, I found grasshoppers hiding inside the furled cones of canna leaves. Brightly coloured spiders and iridescent flies were also seen among the canna. A cloud of small bees and flies was usually present around the canna flowers, especially in the morning, while ants made a colony in one cell of the wetland, moving in and out up the wetland mesh. I also found a potter wasp nest built on one of the larger stones in the wetland (see Figure 7.7). The wetland was also a breeding site for mosquitoes, a habitation I will return to in

[9] Invertebrates with an exoskeleton and jointed legs – including insects, arachnids and crustacea.

the next chapter. Over the months I was visiting Loch Leven wetland, I saw a variety of flies, spiders, beetles, butterflies and moths. Figure 7.7 and Figure 7.8 show photos from Berambadi and Loch Leven that indicate the diverse invertebrate forms within the wetland.

Figure 7.7 - Invertebrates at Berambadi wetland. Photographs by the author, 2019-20.

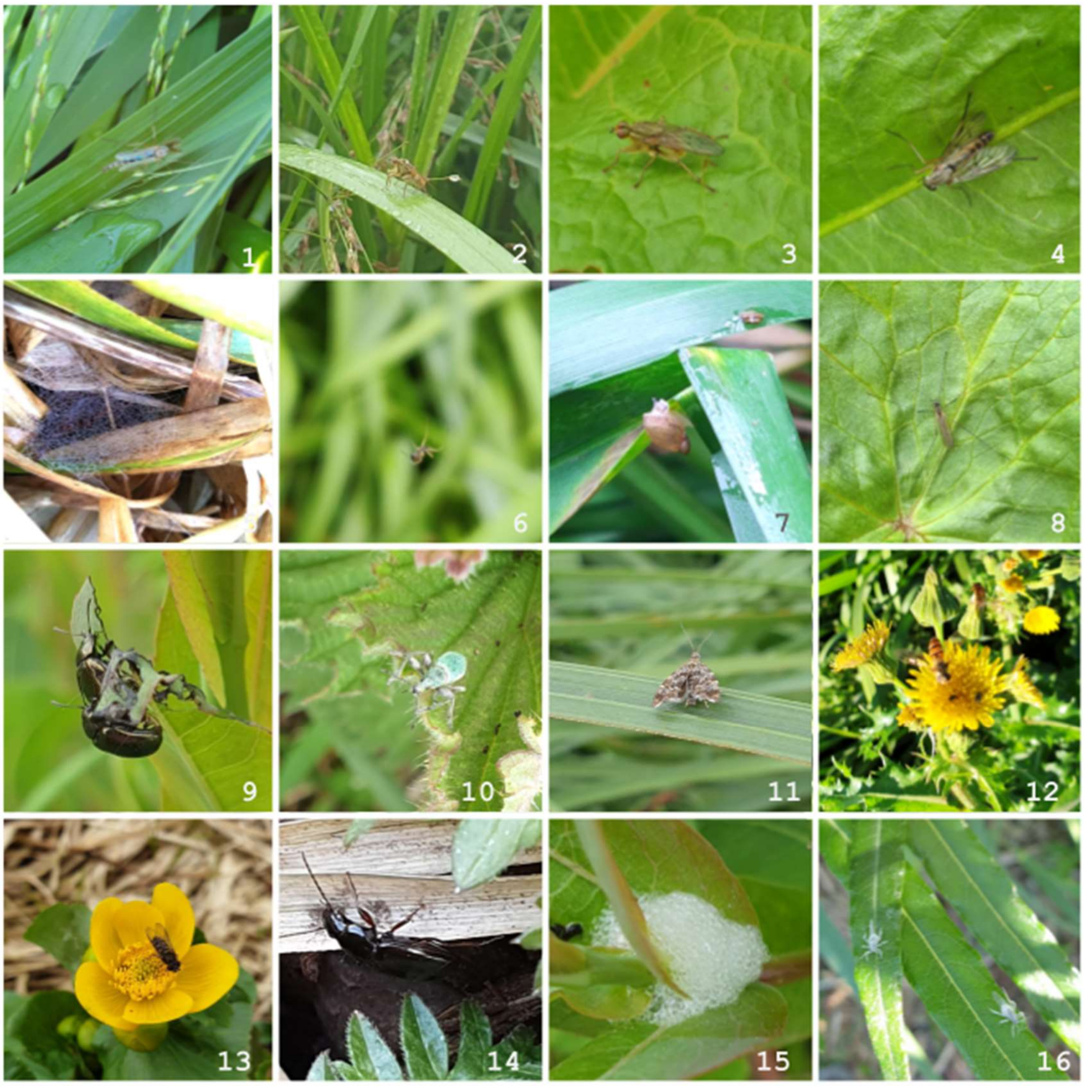

Figure 7.8 - Loch Leven invertebrates: 1-4: flies of different kinds, 5: spider web, 6: tiny spider, 7: amber snail, 8: cranefly, 9: beetles, 10: nettle weevil - Phyllobius pomaceus, 11: moth, 12: bee, 13: hoverfly?, 14: beetle, 15: 'cuckoo spit' from froghoppers 16: male scale insects? *(? indicates uncertain IDs).* Photographs by the author, 2020-21.

The taxonomic diversity of insects and other invertebrates rests on diverse relations. As an enormously divergent group of organisms, it is not surprising that invertebrates have many different modes of living, feeding, moving and reproducing. I observed a small group of nettle weevils (*Phyllobius pomaceus*) as part of my invertebrate survey at Loch Leven in June 2020 (image 10 in Figure 7.8 above). These beetles were part of the wetland fauna only because of the presence of nettle plants, with adult insects feeding on leaves, while larvae eat the plant roots (*Phyllobius pomaceus*, no date). This kind of specific plant-herbivore relation is common in many wetlands (Batzer and Wu, 2020). For spiders and other carnivorous insects, it is the abundance of other insects in the wetland that supports their habitation (ibid.). Many of the bees and butterflies observed in the second cell of the Loch Leven wetland were visiting the wetland because of flowering plants. Marsh marigold, purple loosestrife and great willowherb all had flowers that attracted insects (see Figure 7.9). Shifting to thinking with evolutionary time, these relations connect back to the story of plant diversification. Attention to a wide range of relations is necessary to understand the diversity of insects in these wetlands.

Figure 7.9 - Purple loosestrife, a food source for many insects. Photograph by the author, 2020.

Turning to birds, Figure 7.10-12 show the bird species that I observed at each constructed wetland. As with plants and invertebrates, a variety of forms is apparent. The diversity of bird species at Berambadi and Ibrahimpur includes wetland birds – waterhens at both sites, plus moorhens and sandpipers at Ibrahimpur – as well as what could be described as 'generalist' species. At Loch Leven, most of the birds observed are passerines, belonging to the order Passeriformes, a word whose Latin roots describe these birds as sparrow-formed[10]. These are not wetland birds, but birds that live along a terrestrial continuum between open meadows, fields, lawns, car parks, and the sheltered spaces of forests, hedgerows and gardens. Unlike the plants rooted in the wetland, these birds moved in and out of each wetland. Some of them were only very occasional visitors. All the same, these diverse birds find something about the wetland space worth including into their habitat.

[10] Some of the small birds that I saw visiting the wetland I was not able to definitively identify. As a result, some warblers or buntings may have been missed from this visual summary. There is a bias in my results towards the more numerous species that I was able to see regularly and identify more easily.

Photos from Wikimedia Commons (*Bird*, Photographer, Licence)
Waterhen, Hari K Patibanda, CC BY 2.0; *Drongo*, 25 Cents FC, CC BY-SA 3.0; *Fantail*, Koshy Koshy, CC BY 2.0.

Figure 7.10 - Birds observed at Berambadi wetland.

Photos from Wikimedia Commons (*Bird*, Photographer, Licence)
Moorhen: J.M.Garg, CC BY 3.0; *Sunbird*: J.M.Garg, CC BY-SA 3.0; *Sandpiper*: Afsarnayakkan, CC BY-SA 4.0; *Waterhen*: J.M.Garg, CC BY-SA 3.0, via Wikimedia Commons; *Sunbird*: J.M.Garg, CC BY-SA 3.0, via Wikimedia Commons; *Tailorbird*: Akshay Charegaonkar, CC BY-SA 3.0; *Wagtail*: Mike Prince, CC BY 2.0; *Kingfisher*: Arindam Aditya, CC BY-SA 4.0; *House crow*: Muhammad Mahdi Karim, GFDL 1.2.

Figure 7.11 - Birds observed at Ibrahimpur wetland.

Habitat quality for a bird is also the sum of many different relations. The book *Bird Ecology and Conservation: a handbook of techniques* (Sutherland *et al.*, 2004) was my starting point for understanding these relations. In the habitat chapter there are sections on food abundance, predator abundance, vegetation – including broad type, specific species, and structure; each important in different ways – as well as abiotic environment: temperature, rain, soils and water chemistry (for water birds). Digging into further detail, food abundance for a particular bird, depends not only on the raw abundance, but also on food availability, which is "affected by prey activity, protective attributes (such as thorns, camouflage or poisonous compounds), depth in the substrate or height above ground in vegetation." (ibid., p. 263). If evaluating habitat quality for a particular bird is complex, then making good habitat for a wide variety of birds is an even more difficult task[11]. Without

[11] This observation is supported by the approach to habitat making in the nature reserve adjacent to Loch Leven, as described to me by one of the staff there. Habitat management focuses on a particular group of water birds.

open water or tall vegetation, Berambadi has less to offer a bird. The three birds seen at this wetland were only short-term visitors. But, to some extent, each of these three wetland sites were evidently worth being in relation with. Through observations, both directly and through camera trap recordings, I was able to see some of these relations in action. Thinking through these relations is a way to tell the story of avian diversity in these wetlands.

Photos from Wikimedia Commons (*Bird,* Photographer, Licence)
Blackbird: Mashpb, CC BY-SA 3.0; *Blue Tit & Yellowhammer*: Andreas Trepte, www.avi-fauna.info, CC BY-SA 2.5; *Sparrow*: Polina Pasechnyk, CC BY 4.0; *Meadow Pipit*: Tina Ellegaard Poulsen, CC BY 4.0; *Chiffchaff*: Charles J. Sharp, CC BY-SA 4.0; *Great Tit*: Frank Vassen, CC BY 2.0; *Robin*: Alexis Lours, CC BY 4.0; *Magpie*: Pierre-Selim, CC BY-SA 2.0; *Wren*: Ron Knight, CC BY 2.0; *Starling*: Zeynel Cebeci, CC BY-SA 4.0.

Figure 7.12 - Birds observed at Loch Leven wetland

Evolutionary histories are a starting point for this approach. The variety of sizes and body shapes shown in the figures above reflect evolutionary histories of relational attunement. According to the evolutionary science legend Charles Darwin developed his evolutionary theories through thinking about bird's beaks in the Galapagos Islands (Sulloway, 1983)[12]. In the photos above, we see the blunt beaks of waterhens and sparrows and the thin curved beaks of tailorbirds and sunbirds. For moorhens their webbed toes enable them to swim through the flooded parts of Ibrahimpur wetland. The legs of waterhens allowed them to move quickly through the Ibrahimpur wetland, either slipping between the reeds, or striding on top of them, grabbing and bunching enough stems

[12] Though Darwin wasn't actually so observant, these finches do offer a case study of evolutionary radiation.

beneath their toes to support themselves. They could also run towards and chase away other waterhens. Passerines have feet that are adapted to grip onto plant stems, even if the bird is sleeping (Gill, 2007, p. 8). This gripping ability is put to use by a fantail hopping between canna stems in Berambadi, or sparrows at Loch Leven holding tightly to the willow trees as they whipped back and forth in the wind. The vertical stems of willow, canna flowers or *Glyceria* and other wetland grasses allowed smaller birds to move freely through the three-dimensional space of the wetland, often moving in short hops between different stems. Finally, if they felt they were in danger, from another bird, or a PhD researcher getting too close, all these birds had the option to spread their wings and move quickly to somewhere safer. While Richard Levins and Richard Lewontin (1985) caution against reading evolution as a teleology of diversification, these evolutionary histories are part of the biogeography of these wetlands; they help to understand potentials for biodiversity.

At the same time, there are other histories that are relevant for understanding processes of biodiversification. Carla Hustak and Natasha Myers (2012) engage with Darwin's writings on orchids in order to highlight a blind spot in evolutionary biogeographies. Evolutionary accounts can only tell part of the story of how organisms relate:

> "Practices that fall outside the domain of reproduction or survival, including organisms' improvisations and playful experiments, do not record themselves in evolutionary memory; deemed irrelevant, they are rendered invisible in these broad sweeps of time." (p. 95)

In response, Hustak and Myers offer the complementary notion of *involution*, "the 'rolling, curling, turning inwards' that brings distinct species together to invent new ways of life" (p. 96). Involution speaks to the affective and relational nature of habitation.

> "Involutionary momentum helps us to get a feel for affective push and pull among bodies, including the affinities, ruptures, enmeshments, and repulsions among organisms." (p. 97)

Watching the birds at each wetland offers examples of exactly this inventive and affective cohabitation, outside of evolutionary stories.

In June 2019 at Ibrahimpur, iridescent black-purple (male) and pale olive-white (female) sunbirds flew in and out of the wetland, perching at the base of the orange and pink crowns of canna flowers. Watching their movements carefully, it was apparent that these birds were 'robbing' nectar from the base of the flowers (Irwin *et al.*, 2010), using their sharp beaks to access nectar by poking through the base of the flower. This was not a symbiotic relationship that enabled pollination for the canna. Rather than a mutual alignment of plants and pollinators built up over evolutionary time, it is a relation that has existed only since canna was introduced to India by colonial horticulturalists (Food and Agriculture Organisation, no date). Similarly, as tailorbirds stitched their nests out of canna leaves at Ibrahimpur, they were making use of a novel material, by evolutionary timescales. For the sparrows, chiff-chaffs and wrens who explored Loch Leven wetland, the thin wire of the surrounding fence was perfect for gripping on to; a perch from which to examine the surroundings before flying into the wetland. These examples point to a biogeography, a story of species presence, that is messier and more contingent than one built on evolutionary relations. Wetland affordances exceed evolutionary histories. These are relations that can't be explained by evolutionary adaptations, but they are no less important for telling the story of biodiversity in these wetlands.

To focus on involution is to emphasise "an affective ecology in which *creativity* and *curiosity* characterize the experimental forms of life of all kinds of practitioners, not only the human ones" (Hustak and Myers, 2012, p. 106). As I watched birds move around each constructed wetland what I interpreted from their actions was a process of exploration driven by such curiosity. The affordances of these wetland spaces weren't known in advance but instead had to be investigated. Birds moved around in short hops and flutters, checking each stem or patch of ground. This curiosity is a noted feature of UK robins, while robins elsewhere are more cautious due to less positive interaction with people (British Trust for Ornithology (BTO), no date). Camera trap footage from Loch Leven confirmed that robins were most often seen when people or tractors were passing the wetland. Curiosity also seems relevant in understanding the diet of the moorhens and waterhens at Ibrahimpur. Reference texts describe a varied diet for moorhens: pond weeds, seeds and berries as well as "worms, snails, spiders, insects, small fish and eggs of other birds" (Holden and Gregory, 2021, p. 104). According to bird watchers in Singapore and Malaysia the diet of white-breasted waterhens is also "large and varied, comprising many insects, earthworms, some molluscs, grass seeds [and the] roots/shoots of some plants" (BESG, 2016). Rather than relational specificity, these behaviours and feeding patterns suggest to me a creative openness to feeding. Birds perhaps weren't sure if the wetland offered what they needed, but it was worth investigating.

I read the lines of movement of insects as evidence of their own curious explorations, which generated for me a combination of wonder and confusion[13]. On one visit I watched a fly examine each of the 5 branches of a willow stem, walking to the end of each, before turning around, going back and then doing the same on the next branch, occasionally stopping to sense something on the willow

[13] Similar affects of insect watching are explored in Hugh Raffles' *Insectopedia* (Raffles, 2011)

surface. Flies, beetles and snails navigated along the tangled lines of plant stems and leaves. Spiders also traversed the architecture of plants, adding to this the lines of their webs, which create other paths through the wetland vegetation and extend their ability to sense the vibrations of the wetland and its inhabitants. For insects in flight, lines of motion across the wetland were also common. Butterflies filmed in wildlife camera recordings at Ibrahimpur and Loch Leven often didn't stop within the wetland, making a looping path over the plants before heading off again.

Involution highlights more-than-human creativity as part of an affective reading of ecology. Combining evolutionary and involutionary accounts – both deep histories and creative improvisations – provides a richer understanding of constructed wetland biodiversity. Linking biodiversity to more-than-human affects also suggests that the story of biodiversity shouldn't be told separately from how birds, and other creatures, understand wetland spaces cognitively or socially.

Thinking with affective 'animal atmospheres' (Lorimer, Hodgetts and Barua, 2019) emphasises that part of any 'niche' is the perception of safety it affords. In each of these wetlands, dense vegetation was a place of shelter. For wrens in the Loch Leven wetland, the grasses growing at the edge of the willow were a sheltering place, as were the piles of willow stems that were cut but not collected over winter. The significance of willow as a place of safety at Loch Leven is suggested by the findings from monthly bird surveys. When I began the surveys in April, a few months after the willow had all been cut, thirty minutes of early-morning observation passed without a single bird visiting the wetland. By September and November, sparrows, tits, wrens, chiffchaffs and robins were all seen moving back and forward between the willow section of the wetland and nearby hedgerows and trees. While I can't confidently attribute this increase in bird numbers to the growth of the willow alone, this seems very likely to be a factor. Wetland plants also afforded opportunities to shelter for several insects. Grasshoppers sheltered within the furled cones of canna leaves in the Berambadi wetlands. At Loch Leven one fascinating approach to shelter is shown in image 15 in Figure 7.8, which shows a clump of bubbles surrounding a plant stem. In June 2021 I found these bubble nests on many willow plants, as well as some willowherb and some grass stems. Inside of each was a froghopper larvae (superfamily *Cercopoidea*), who use the liquid of the plant sap to blow these bubbles in order to shelter inside (Ankrah *et al.*, 2020). These wetlands become biodiverse habitats by offering affective and material safety from vulnerability, a theme I will return to in the next chapter.

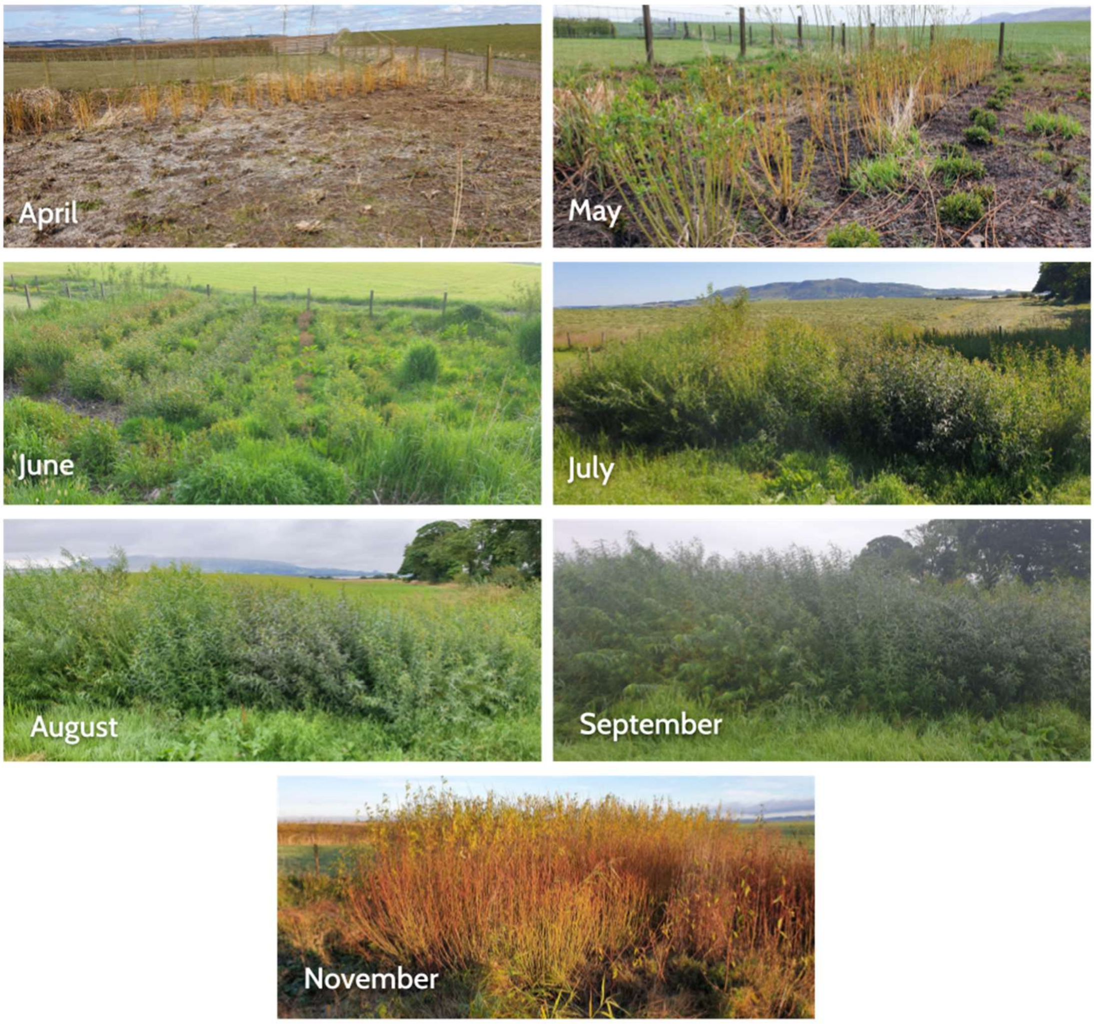

Figure 7.13 - Growth of willow in 2021 at Loch Leven. Photograph by the author, 2021.

For several of the birds at Ibrahimpur and Loch Leven wetlands, the wetland is more than a safe space, it is a social space. This can be heard in wetland soundscapes, especially in the morning, where a near constant symphony of songs, alarm calls, 'advertising' or 'aggressive' calls (Chen, Lin and Yang, 2019) overlays the sound of tractors, planes, cars, cows, and human voices. Waterhen calls intruded into social research, as a background noise in interview recordings at Ibrahimpur. A particular form of sociality shared by several of the observed bird species is the creation of territory. Singing is an important part of this enactment of territory, as well as physically chasing other birds away. Ibrahimpur videos showed examples of this behaviour from waterhens, while at Loch Leven, robins also chased other birds away from the wetland. Through such behaviour the wetland becomes a particular kind of affective space for the birds caught up in these interactions. Through making the wetland unwelcome to other birds, these enactments of territory could be framed as birds acting against diversity. For instance, research in the tropical forests of South-eastern Peru has indicated that territoriality leads to reduced species diversity on a local scale (Freeman, Tobias and Schluter, 2019)[14]. But in the case of these constructed wetlands, I want to frame these territorial practices differently. I describe these territorial practices as a form of sociality, inspired by Vincienne Despret's work. Rather than zones of exclusion, Despret (2021) suggests an alternative reading of territories, focused on the activity and social stimulation occurring at their peripheries. Any reading of avian territory needs to be done carefully, with attentiveness to the ideologies that influence how people read competition or other dynamics into the living world[15].

Thinking with Scottish Ospreys, Ben Garlick (2019) argues that birds' spatial practices and attachments constitute a non-human cultural geography. As Garlick's work highlights, these geographies do not map neatly to species divisions, but instead can be specific to smaller groups of birds. This offers another way of approaching wetland biodiversity. While I can't know exactly how different birds interpreted the wetland space, it seems justified to argue that birds have their own rich and diverse spatial understandings. Alongside diverse species, we have diverse knowledges and practices – including those of territory making – as a social (bio)diversity.

Other beings: the openness of biodiversity

The creatures introduced in the previous sections were those whose presence I investigated systematically, but these were far from the only living beings to make these constructed wetlands a part of their habitat. School teachers described how monkeys visited to eat the canna flowers at Berambadi wetland. Camera trap footage also recorded a few dogs visiting the wetland. Frogs were another inhabitant of, or visitor to, all three constructed wetland sites. Though there was no space for sustained frog habitation in the Berambadi wetland, at least one frog found the wetland worth visiting, as revealed once again by the camera trap footage. At Loch Leven the sound of frogs was one of the signs of inhabitation reported by residents, and some of these frogs were seen among the reeds in the first wetland cell during one visit. When staying beyond daylight hours at Ibrahimpur, frogs were easily visible as they ventured from the wetland and pond onto the roads. Ibrahimpur residents suggested that turtles made their home in the pond, while the snakes that occasionally ventured into peoples' homes were also linked to the pond and wetland[16].

[14] This research aligns with a broader recognition of the importance of animal behaviour for conservation biology work aiming to protect threatened species (Tobias and Pigot, 2019).
[15] Kamath and Wesner (2020) have scrutinised the concept of animal territory more broadly, suggesting that animal behaviour research often "implicitly embedded[s] notions of property and ownership" (p. 233) with the result that it can focus on "how animals are expected to behave rather than how they actually behave" (p. 233).
[16] More on snakes in the next chapter.

Figure 7.14 - Frogs at two of the wetland sites. Photographs by author, 2019-2021.

There is also a huge diversity of small beings. During the flooding of Ibrahimpur wetland, tiny invertebrates could be seen swimming in the water, between the rocks. Without a microscope these creatures could not be identified. Within the constructed wetland literature, this microbial diversity is attested by a study that identified “more than 70 species of bacteria, amoebae, ciliates, rotifers, colourless flagellates, cyanobacteria and algae” in three small subsurface wetlands (Vymazal, Sládedek and Stach, 2001, p. 211). All of the constructed wetlands were likely also habitat for different fungi (Gandhi, Tatu and Kamboj, 2018; Calheiros *et al.*, 2019), with one type observed growing from the cut willow stems at Loch Leven (see Figure 7.15). Finally, there are realms of biodiversity within the bodies of wetland creatures. For instance, many insects, including the froghoppers busy making bubble nests in Loch Leven wetland, rely on symbiotic relationships with bacteria to receive adequate nutrition (Ankrah *et al.*, 2020)[17]. To verify the presence of any of these beings would have required different specialised methods. While the aim of my methods was to indicate the biological diversity of these constructed wetlands, they have a narrow taxonomic range. Because of this they can elucidate only a fraction of wetland inhabitants[18].

[17] I was attuned to uncover these relations by Donna Haraway’s fascination with symbiosis and other forms of multispecies companionship (Haraway, 2008, 2016).

[18] The same is true of other papers, such as those mentioned in the introduction section, that record wetland biodiversity with a focus on birds and invertebrates.

Figure 7.15 - *Xylaria longipes* fungus growing on cut willow stems at Loch Leven. Photograph by author, 2021.

Conclusion: biodiversity histories across time and space

While my ecological methods focused on a particular bounded space, the relational histories that are required to understand biodiversity extend across scales. This is clear first when considering the lifeways of beings seen within the wetland. None of the insects observed in the wetland would be present if they – or their ancestors – couldn't first find somewhere else habitable, from where they could move to the constructed wetland. This is true whether that movement was a few hundred metres, or – as for a surprising number of insects – hundreds of kilometres (Raffles, 2011; Hu *et al.*, 2016). Birds also move through the wetland as part of wider lifeways. For chiffchaffs in Scotland, these migratory paths likely extend to West Africa (Holden and Gregory, 2021). Purple sunbirds migrate within the Indian subcontinent (Sharma and Kashyap, 1999). For other birds, these movements are more local. Nevertheless, they tie biodiversity in these wetlands to other landscape patches, across various scales. Similarly, while planting decisions demonstrate how imaginaries of constructed wetlands determine plant diversity, the enactment of these decisions constitutes a flow of plants to the wetland from different locations. For example, the Berambadi canna lily was sourced from a nursery in Bengaluru. The ancestors of these canna plants were transported to India from South America, most likely via Europe. The diversity of willow plants at Loch Leven represents cuttings taken from different locations around the UK; collected and cultivated by the person hired to plant this section of the wetland. Alongside initial planting choices, the plants in each wetland were shaped by the vegetative diversity of their surroundings, for example, the contingencies of upstream kitchens or pre-existing soil seed banks. Biodiversity is generated as these diverse lines of movement are tangled together (Ingold, 2011).

One consequence of this connection across scales is that the possibilities for biodiversity in these wetlands, or any other small patch, are always linked to broader landscape histories. For all three wetlands, located in rural landscapes, agricultural practices are crucially important for both bird and insect abundance. Artificial lighting is also significant for shaping insect abundance and diversity across broader landscapes (Gandy, 2022b). To track these larger-scale landscape histories, the observational methods used in this chapter need to be supplemented by other approaches. Understanding constructed wetland biodiversity as shaped by relations both within the wetland and at a multitude of larger scales is necessary to tell biodiversity stories well.

Because of how these infrastructures are assembled, the biodiversity of constructed wetlands doesn't have the same relationship to scale as the landscapes typically studied by conservation biologists. My observations showed how it was also marked by different temporalities. Biodiversity discourses connect to diverse temporalities: the time of biodiversity is static (Bowker, 2008); teleological (towards ongoing diversification (Levins and Lewontin, 1985)); catastrophic (biodiversity crisis) or slippery (as with biodiversity offsets (Bowsher and Reeves-Evison, 2019; zu Ermgassen *et al.*, 2021)). In contrast to these big narratives, I want to describe here how small shifts in the affordances of these constructed wetlands were reflected in my observations of different taxonomic groups. Variations were sometimes the result of seasonal patterns. Spiders were early to arrive at Loch Leven wetland in the spring. Larger flies, bees and butterflies came later in summer in sync with the growth of flowering annual plants. Some shifts are more random. When I began the camera trap recording at Ibrahimpur in March 2020, the water level was a few centimetres below the wall. Crows visited the wall to drink from the water; moorhens, wagtails and sandpipers walked back and forward along its length, occasionally pecking at the water. When rain caused the water level to rise, the wall was submerged. Even though it was still only a few centimetres below the water's surface, it no longer attracted so many birds. As the Ibrahimpur wetland began flooding more regularly, there was also a shift in the plants observed. As the outcome of myriad processes of diversification and simplification, biodiversity in these wetlands does not have a fixed direction.

Massey (2005) argues that openness and multiplicity are intrinsic to relational understandings of space. I have described biodiversity as unfolding through the combination of both evolutionary history and involutionary momentum (Hustak and Myers, 2012). Biodiversity, as a spatial property, is “a simultaneity of stories-so-far” (Massey, 2005, p. 9). For Hustak and Myers (2012), involution entails “constantly inventing new ways to live with and alongside one another” (p. 97). The overlapping scales and temporalities of constructed wetland biodiversity contribute to this openness. Can openness be a part of how biodiversity is measured and described? Jamie Lorimer (2015b) argues that biodiversity conservation is informed by a desire for panoptic knowledge. However, Steve Hinchliffe and Sarah Whatmore argue a convivial politics requires, in contrast, “relaxing the co-ordinates of presence and absence” (Hinchliffe and Whatmore, 2006, p. 137). Is there a way to engage with biodiversity that leaves room for what can’t be known concretely? what is yet to come? what can only be speculated about? As an relevant example of the ‘future becoming’ that Lorimer highlights (2008), in the UK there are several species of amphibian that are currently extinct or rare (Wildfowl & Wetlands Trust, 2022). If these amphibians were reintroduced into the UK from elsewhere, and supported to thrive, then they might find the Loch Leven wetland habitable. These frogs are a sign of the potentials of habitat that are not currently realised. Perhaps this potential habitability might extend to birds whose flourishing requires changes in agricultural practices. It seems important to also consider the frogs, insects, birds, other animals and plants who might find these constructed wetlands to be important habitats in future amid ongoing climatic disruptions.

Figure 7.16 - Track and burrow of an unknown creature at the side of Loch Leven wetland. Photograph by author, 2021.

What practices and principles are required to support biodiverse infrastructural habitats? Multispecies scholars have argued that there is a need to develop new concepts to support multispecies cohabitation (Houston *et al.*, 2018; Srinivasan, 2019b)[19]. In an era of nature-based solutions, infrastructures and environments are being melded (Hetherington, 2019). Multispecies justice requires not losing sight of how as natures are converted into infrastructure, they remain habitat for numerous creatures. In these contexts, the variety of life indexed by biodiversity deserves ethical consideration, even if this is 'contaminated biodiversity': "collaborative adaptation to human-disturbed ecosystems" (Tsing, 2012, p. 95). The biodiversity of constructed wetlands is contingent on more-than-human practices. It is constantly being rewritten. A focus on relations, histories and motion is helpful for recognising multispecies curiosity, creativity and potentiality, and identifying potentials for multispecies flourishing.

[19] While these arguments are oriented towards urban cohabitation, I believe they are also relevant to rural areas.

8 Ethical Exclusions: Tracing vulnerability in constructed wetlands

Introduction

A biodiverse constructed wetland implies multispecies cohabitation. This cohabitation extends to the residents of houses around the Ibrahimpur and Loch Leven wetlands; to the students and teachers at Berambadi school; and the project teams as they visited the wetland. In interviews and other conversations, talking about wetland inhabitants often highlighted the difficulties of living with wetland life, in particular animals such as snakes or mosquitoes. For people, unwelcome snakes and mosquitoes are *vulnerabilities* inherent to a lively waterscape. Significantly, in this context vulnerability is not a passive condition. Residents and project staff recognised and responded to vulnerabilities, in different ways, with varying degrees of success. These responses were often attempts at *exclusion*; spatial orderings to manage vulnerability through avoiding relations. At the same time, due to a combination of exclusions and infrastructural design, other-than-human beings also experienced forms of vulnerability. The distribution of vulnerability over space and across bodies is hence a question of multispecies justice.

This chapter foregrounds vulnerability and exclusions as part of the politics of lively waterscapes. The related concepts of vulnerability and precarity have a complex history in social theory (Gibb, 2018; Joronen and Rose, 2021, pp. 1406–9). Often, the focus of these accounts has been to position vulnerability as generated by the destabilising dynamics of capitalist modernity or other uneven power relations (Hanson and Buechler, 2015; Millar, 2017; Gibb, 2018; Smith and Dressler, 2019; Barnett, 2020). Such accounts attempt to counteract the use of vulnerability as a depoliticised concept tied to discourses and projects of resilience and capacity building (Gibb, 2018; Smith and Dressler, 2019). What connects much of this critical scholarship is a positioning of vulnerability as the *product* of power. In contrast, Mikko Joronen and Mitch Rose (2021) draw upon the work of Judith Butler (e.g. Butler, 2012) to argue that vulnerability is *existential*. It reflects the fragility of being alive, and hence "a constitutional feature of all bodily beings" (p.1410). On this basis, Joronen and Rose argue that power and politics are driven by vulnerability, but also ultimately limited by it: “we cannot not respond to vulnerability. But on the other [hand], no response will ever be sufficient” (p. 1414). This existential notion of vulnerability aligns with explorations of vulnerability in more-than-human geographies. Introducing a special issue *Flourishing with Awkward Creatures*, Franklin Ginn, Uli Beisel and Maan Barua describe vulnerability as "key to understanding everyday relations with nonhumans" (Ginn, Beisel and Barua, 2014, p. 118). "Vulnerability, violence, and death are part of on-going, generative engagements with nonhuman others, rather than simply being negative elements that can be repressed, ignored, or solved" (ibid., p. 121). The fact that vulnerability, human or otherwise, cannot be solved in any straightforward way brings to the fore questions of more-than-human ethics. For Krithika Srinivasan and Alasdair Cochrane (Celermajer *et al.*, 2020), acknowledging a 'shared vulnerability' is the starting point for non-anthropocentric mapping of harms. The ethically saturated responses that vulnerability imposes upon us are central to multispecies justice.

By foregrounding exclusions, this chapter develops an important line of enquiry within more-than-human geographies. Eve Giraud (2019) argues that an emphasis on entanglement, as is common in more-than-human studies, does not automatically lead to more ethical relations or a better, less anthropocentric politics. For Giraud, exclusions – the foreclosing of particular relations – are inevitable in any situation or environment. If this is the case then exclusions are "neither something that can be avoided nor something that is intrinsically negative" (ibid., p. 4); "the act of excluding certain relations is precisely what creates room for others to emerge, or for existing forms of life to be sustained" (p. 11). Exclusions are what allow desirable forms of more-than-human flourishing to emerge. For Giraud, what is important is to make exclusions visible. This visibility is the prerequisite for fostering responsibility and obligations for exclusions. It also opens exclusions to "future contestation and the possibility of alternatives" that would more justly distribute the vulnerabilities and responsibilities of living in relation (ibid., p.4). A grounded example of this argument is found in Franklin Ginn's account of the relations between gardeners, slugs and plants in UK gardens (Ginn, 2014). The gardeners that he encounters try to exclude slugs, to enact a "hoped-for absence" (ibid., p. 540). Ginn frames these attempts as forms of detachment; "a range of dispositions in which life is not drawn together, but pulled apart" (p. 534). Detachment refers to processes of pulling apart, which aim to enact exclusions but might not (fully) succeed. Ginn's argument is that detachment is an "enabling constituent of more-than-human ethics" (p. 532). Multispecies habitability relies on conscious acts of exclusion. This chapter asks what practices of exclusion are enacted around these constructed wetlands? and who do they protect?

In the following analysis, I approach waterscape vulnerabilities and exclusions with a sensitivity to social and ecological histories and concepts. I explore how ecological science can assist with theorising more-than-human vulnerability. I also place the contemporary politics of vulnerable multispecies habitability alongside colonial histories of extermination in the Indian context.

Constructed wetlands in India are part of a history of different techniques that have reshaped vulnerabilities in more-than-human waterscapes. This historical perspective contributes towards politicising current practices.

To add empirical depth in this chapter, I incorporate findings from a second wetland location at Berambadi. This is a *non*-constructed wetland. It was formed, I was told, due to a land dispute involving the reallocation of land by the Panchayat. Sitting at the confluence of two storm drains, this low-lying area filled with water due to human abandonment. It became a densely vegetated wetland through the quick spreading of bullrush seeds on the wind. During field visits to Berambadi I interviewed several people living around this wetland. Their experience speaks to the concerns of this chapter. Various exclusions were attempted in response to the vulnerabilities that this wetland accentuated.

Figure 8.1 - Non-constructed wetland at Berambadi. Photograph by author, 2018.

I explore waterscape vulnerability through several complementary examples. The next section describes how constructed wetlands at Ibrahimpur and Berambadi supported mosquito populations, which raised the vulnerability of people living or spending time near the wetlands. Responses aimed to exclude mosquitoes from the wetland or from household or personal spaces. I locate these responses within a complex history of human-mosquito-disease relations. I then turn to the exclusions built into the design of the constructed wetlands. Fences around each wetland enact a desired form of habitat. In contrast, the lack of a fence at the non-constructed wetland distributes vulnerability unevenly. My third example takes up the relation between people and snakes around Ibrahimpur wetland. I describe a potential ecological trap for snakes, and a physical and affective vulnerability for people. I consider this case in relation to broader histories of snake-human relations in India. Finally, I explore how wastewater toxicity creates a distribution of vulnerability, as constructed wetlands serve as a tool for excluding pollution from broader waterscapes. I consider the vulnerabilities this creates for wetland creatures. Taken together, these examples show that each of these constructed wetlands were sites where vulnerability was actively negotiated. Responses to vulnerability are always limited. Rather than straightforwardly resolving waterscape vulnerabilities constructed wetlands redistribute vulnerabilities, among human and non-human beings. If constructed wetland habitat-making is a negotiation of relations and detachments, I argue that ethical exclusions require ecological knowledge. Attention to how exclusions are scaled, and who is responsible for them allows a (re)politicisation of vulnerabilities.

Mosquitoes and modes of exclusion

Robert Knight and co-authors write "all wetlands produce mosquitoes" (Knight *et al.*, 2003, p. 212). Perhaps more specifically, mosquitoes create mosquitoes, using the affordances of constructed wetlands. A short introduction to mosquito biology explains this connection. The life of a mosquito starts with an egg, laid on the water surface or on wetland vegetation, depending on the species (Hawkes and Hopkins, 2022). This egg soon hatches into a mosquito larva. Larvae live in the water, feeding on bacteria, algae and organic matter, while breathing air from the water surface. This means that mosquito larvae are well adapted to thrive in waters with high dissolved organic matter concentrations, such as constructed wetlands (Knight *et al.*, 2003). After four moults, mosquito larvae transition to a pupa. These float at the surface of the water, developing into adult mosquitoes. During their aquatic life stages, mosquitoes are vulnerable to predation by fish, dragonflies and other animals. By laying eggs in wetlands, or other small water bodies – used tires, buckets, puddles, tree hollows etc. – female mosquitoes reduce the vulnerability of their offspring.

While mosquito bites are annoying, what multiplies the human vulnerabilities of human-mosquito cohabitation are the diseases that female mosquitoes may transmit as they drink the blood required to produce their eggs. In India, both dengue fever and malaria – generally carried by mosquitoes in the genera of *Aedes* and *Anopheles* respectively – are serious public health concerns (Singh and Taylor-Robinson, 2017; Ghosh and Rahi, 2019). The Government of India, supported by the World Health Organisation, has an ambition to eliminate malaria by 2030 (National Vector Borne Disease Control Program, 2017). Meanwhile, dengue outbreaks in several states have been attributed to a limited program of mosquito control, and increasing unplanned urbanisation (Barnagarwala, no date). Living with mosquitoes has harmful and potentially fatal consequences.

The connection between wetlands, mosquitoes and disease was acknowledged by the Berambadi team during the planning stage of the project. Mosquitoes forced further discussion when they began biting members of the project team who were visiting to collect water samples for testing. "The density [of mosquitoes] was so high" that collecting water samples wasn't possible without repellent[1]. Mosquitoes were also acknowledged as a problem by those working around the wetland. Teachers at the school recounted in our interview that large mosquitoes were present around the constructed wetland and were biting the school students. The person paid to maintain the wetland agreed that mosquitoes were an issue for the wetland, especially at certain times of day, suggesting that "if we go there in the morning, we cannot even stand there". Within the project team there were different assumptions about how mosquitoes were interacting with the wetland – and how they could be excluded. One project member attributed "really high numbers"[2] of mosquitoes to a higher water level in the wetland during rainfall. Another person involved in designing the wetland explained that, if water is kept below the surface of the wetland, "we are not supposed to have that kind of problem [with mosquitoes]"[3]. They also recommended putting a lid on top of the tubes used to collect water samples, as these tubes offer a route to the water below. This matches with my observations during wetland visits. In February 2020, placing a measuring probe into any of these sampling tubes stirred up a small cloud of adult mosquitoes. A sample of water taken from the tube contained several mosquito larvae and pupae, spinning through the water with their characteristic jerking motion when disturbed. While planting canna lily in the wetland I also observed that, in the parts of the wetland with larger stones, there was enough space between the stones for mosquitoes to fly down to the water. Assumptions about how to exclude mosquitoes that emerged in project interviews had not been ground truthed by visits to the wetland.

The constructed wetland literature offers a wealth of ideas about managing mosquitoes. These methods span chemical, ecological, hydrological and spatial relations. Both the design and ongoing operation of wetlands are important. Amelia Kivaisi's review on constructed wetland potential in developing countries notes that "in order to avoid wetlands becoming public health risks by aggravating the existing condition with malaria, mosquito control must be integrated in the design as well as the operation of a wetland" (Kivaisi, 2001, p. 556). Kivaisi goes on to suggest a combination of ecological and biological control measures – pesticides derived from bacteria, fish predators, vegetation management – that might be used for such control. Richard Russell writes from an

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[1] Project team interview 1. To preserve interview respondents' anonymity, I will only provide interview numbers here.
[2] Project team interview 2
[3] Project team interview 3

‘Australian perspective’ where Ross River virus is a serious health concern (Russell, 1999). His article lays out the wide variety of ways that mosquitoes can be tackled:

> “Mosquito control should not rely solely on chemical and biological agents. Design of wetlands is important: shallow water and dense vegetation promote mosquito production. Deeper habitats with cleaner steeper margins, and more open water, produce fewer mosquitoes. Water and vegetation management can reduce mosquitoes: aeration and sprinkler systems, and flooding and drainage regimes, can reduce larval densities; vegetation thinning can assist mosquito predators. Such measures may appear incompatible with objectives and operations of wetlands, but mosquito management must be an integral objective of modern wetland design and maintenance in order to minimise health hazards.” (Russell, 1999, p. 107)

There are a wide variety of mosquito control strategies that might be applicable in different circumstances (Rey *et al.*, 2012). Vegetation management and other ecologically focused techniques are often oriented towards wetlands which have some percentage of open water (Greenway, Dale and Chapman, 2003; for example, Dale and Knight, 2008). In contrast, both Ibrahimpur and Berambadi wetland were designed as subsurface flow wetlands. In this context, the *Saph Pani* report on constructed wetlands and similar technologies in India argues that:

> "communities seem to prefer [horizontal sub-surface flow wetlands] even more in the recent time owing to the innate advantage offered by [these wetlands] in the context of minimizing mosquito breeding" (Wintgens *et al.*, 2016, p. 133).

The mosquitoes at Berambadi wetland urge against such generalisations. The overall framing of mosquito-human relations in this literature is one of *control*. Mosquitoes are, it would seem, more or less unavoidable, so the key task is to devise appropriate control measures. Some papers take this further by identifying a trade-off that mosquito control measures should try to balance. Schäfer et al. (2004) frame their research on mosquito species in natural and constructed wetlands in Sweden as an accounting of ‘biological diversity versus risk’. Knight et al. (2003) situate mosquito control within an econometric ‘net benefits’ framing: ecological risks associated with the use of mosquito control chemicals must be weighed against the habitat benefits provided by these constructed wetlands. The right balance between these competing goals can be recognised by the design that provides the greatest net environmental and societal benefit. This trade-off is grounded in the idea that human actions can accurately control how many and which mosquitoes are present. It's a precisely balanced vulnerability that was not possible at my study sites, and perhaps not anywhere.

The design of the Berambadi wetland aimed to exclude mosquitoes from this wetland ecology. As one project team member put it, "we didn't want people developing malaria or dengue or something"[4]. However, the precise ethical responsibility that the project team had in regard to human-mosquito interactions did not emerge from my interviews with any clarity. Due to the issues with mosquitoes described above, the project team conducted "risk assessment interviews". The aim was to get a sense of whether mosquitoes were "an overwhelming problem". The survey established that they were not[5]. But this framing – "is the problem overwhelming?" – is just one way to think through the impact of the constructed wetland. Another project member suggested that evaluating the presence of mosquitoes in the constructed wetland should consider other potential mosquito breeding locations nearby, and the fact that the timing of peak mosquito activity falls outside school hours[6] (though this isn't true of *Aedes* mosquitoes that carry dengue). Rather than a strict exclusion of mosquitoes from this wetland, some level of mosquito presence was accepted.

This situation is mirrored at the other wetland area within Berambadi village. Here, open water and dense vegetation also supported the (re)production of mosquitoes. Those interviewed around the wetland spoke of lots of large mosquitoes which gave children fevers[7]. I was told that when mosquito numbers were too high, the wetland area was sprayed with the insecticide normally used on crops[8]. Ideally, those living nearby wanted the wetland to be filled in or built upon, removing the mosquitoes entirely[9]. But until that happened, a judgement was being made about when the problem became overwhelming.

At Ibrahimpur, mosquitoes were also raised as a concern by those living around the pond and wetland. What was less clear was whether the wetland had exacerbated the problem, as there was already a pond in this location before the constructed wetland project. Different group interviews gave different accounts about trends in mosquito numbers. Similarly, several households discussed past issues with mosquito-borne diseases, including malaria and dengue, while others indicated there hadn't been any issues. At many households there was laughter when we asked about how

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[4] Project team interview 4
[5] Project team interview 4
[6] Project team interview 5
[7] BER GI4
[8] BER GI5
[9] BER GI5

they deal with mosquitoes, colliding with my own mosquito anxieties coming from a place without severe mosquito-borne diseases. A range of responses were used to deal with mosquitoes including fans, moving to upper levels of the house or, most commonly, either mosquito nets or coils. Here, the effort to exclude mosquitoes shifts. Rather than working to remove mosquitoes from the waterscape entirely, the objective is only to exclude them from the space around humans.

A different view of mosquito politics emerges if we consider colonial attempts to control or eradicate mosquitoes in India and elsewhere. While there are deep histories of figuring out how to live with (or to exclude) mosquitoes all around the world (Hall and Tamïr, 2022), many 19th and 20th century mosquito control efforts were shaped through the guiding influences of imperialism and war (Mitchell, 2002; Deb Roy, 2017). Rohan Deb Roy (2017) writes about the significance of mosquitoes in the continual reworking of empire in India in the early 20th century:

> "Mosquitoes commanded continued attention as an object of imagination, an excuse for intervention and commerce and a mirror against which humanity could be defined. Thus, mosquitoes appeared not only to justify imperial rule, but also figured as its subjects." (p. 271.)

Timothy Mitchell, reflecting on mosquitoes in 20th century Egypt, explains how techniques of mosquito control were developed based on modern warfare; "disease was to be defeated not by improved social conditions or medical intervention but by the physical elimination of the enemy species" (2002, p. 26). From the 1930s onwards, mosquito elimination campaigns supported by the Rockefeller Foundation took an approach to mosquito control characterised by a heavy use of chemical insecticides delivered by aerial spraying (Mitchell, 2002; Rehman, 2020). These histories emphasise that efforts at mosquito control are not only calibrations of vulnerability, they have often served larger political purposes (Mitchell, 2002; Deb Roy, 2017; Rehman, 2020).

Contemporary efforts to control mosquitoes in areas where vector-borne diseases are prevalent demonstrate a more fine-grained approach to managing the vulnerabilities created by mosquitoes. Drawing on research in Ghana, Uli Beisel (2015) writes that "malaria management involves the continuous calibration of micro-environments, namely of the entangled habitats of mosquitoes, parasites and humans" (p. 146). Alex Nading (2022) describes an ambivalence at the heart of this enterprise. Even as community health workers in Nicaragua aim to remove mosquitoes and eggs from people's dwellings, they develop a "thoughtful appreciation of the complexity of the worlds shared and shaped by people, insects and microbes" (ibid., p. 187). Both precise control – as per the constructed wetland literature – and elimination of mosquitoes are shown to be unworkable strategies. Nida Rehman (2020) describes how responsibility for mosquito control is individualised in Lahore, Pakistan, due to the inequitable provision of water infrastructure. These mosquito control measures rework the distribution of vulnerability but also the responsibility for managing vulnerability.

While predominantly understood as a health measure, excluding mosquitoes from wetlands or other spaces has ecological effects. While female mosquitoes rely on blood to produce eggs, male mosquitoes feed on nectar, forming a symbiotic relationship with plants. In turn, mosquitoes are a significant food source for birds and other animals (Hawkes and Hopkins, 2022). These are just a few examples of the web of ecological relations that mosquitoes are part of (Schäfer *et al.*, 2004; Hawkes and Hopkins, 2022). The specific methods used to exclude mosquitoes may also be ecologically harmful. The impact of DDT on birds serves as an iconic example of this (Carson, 1962). Meanwhile, for people, the use of mosquito coils to exclude mosquitoes from indoor spaces has a negative impact on air quality, potentially contributing to respiratory issues (Rao *et al.*, 2022). Excluding mosquitoes produces a rippling outward of vulnerability across webs of living relations.

Exclusions by design

Constructed wetland with water kept below the surface, aim to design mosquitoes out of these spaces. These were not the only exclusions that were enacted as these constructed wetlands were planned, built and maintained. For example, we can firstly consider the exclusion of undesirable plants from each wetland. At Loch Leven, herbicide spraying to kill *Glyceria maxima* was used to ensure that the willows had enough sunlight during the first stages of their regrowth after coppicing. The logic for weeding the constructed wetlands may have been partly aesthetic. But it also was a response to the vulnerability that some of the desired wetland plants faced: being smothered or outcompeted by weed species.

Figure 8.2 - Fences at Loch Leven and Ibrahimpur wetlands. Photographs by author, 2020-21.

Despite their varied sizes and locations, all three constructed wetland sites shared one key design feature: they were all surrounded by some kind of fence. At Berambadi the school-facing side of the wetland had a high steel and mesh fence, with concrete walls on the other sides. At Ibrahimpur the fence surrounding the wetland was made of three strands of barbed wire. This fence did an adequate job of keeping livestock out of the wetland, though some of the reeds and canna at the edge of the wetland showed the effect of grazing from buffalo who were sometimes tied up just beside the fence. At Loch Leven, the constructed wetland was surrounded by a post and wire fence that was fitted with a fine mesh, which the design drawings specify as 'rabbit-proof' fencing. The designer of the wetland explained that rabbits are largely a concern during the early stages of the wetland, when they may eat the new vegetation. Deer are another concern, especially as the new willow shoots of the wetland are a preferred food. Hence fences served at all sites to keep out animals that would damage wetland plants. This had the additional benefit of protecting wetland nesting birds at Ibrahimpur and ground-nesting birds in the Loch Leven wetland from disturbances. But at Berambadi the fence was doing more than keeping out livestock. In interviews with the project team, different logics were discussed. Primarily the fence was intended was to keep school children away from the wetland area and its sewage water[10]. However, this was a vulnerability in both directions. While children picking up pathogens from water was a primary focus, interviewees also noted the

[10] Similar ideas of excluding children might have also been relevant at the other sites, this wasn't something I managed to confirm with my research.

potential for littering to interfere with the constructed wetland. These fences were a response to multiple vulnerabilities. While fencing on a larger scale often brings significant complexities for multispecies flourishing (Hayward and Kerley, 2009), around these constructed wetlands fencing enabled both infrastructural stability and desired forms of wetland habitat.

The other wetland area in Berambadi was not the result of any process of (human) design. Unlike the constructed wetlands, no fence was placed around it. This was a benefit to cows passing by (see Figure 8.3), but it also played a significant role in shaping vulnerability around this wetland. Conversations with those living around this wetland were quick to highlight that the wetland would attract wild boar in the evenings during hot summer months. While this small patch of bullrush offered these boar a place of shelter, this was an unwelcome and risky cohabitation for the people living next to this plot of land. As a result, I was told that when wild boar arrived, people would attempt to drive them away by throwing stones at them, though this was not always successful. An important characteristic of this arrangement of vulnerability is that there is a clear contrast between the two houses that are located immediately adjacent to the wetland. On one side, the house was enclosed by a concrete brick wall, with an iron gate at the entrance. The other house was a more modest dwelling. Like many other households at Berambadi, water was available only at a roadside tap. No fence separated this outdoor space from the wetland just a few steps away. I describe these details to emphasise how the possibility of an infrastructural fix to vulnerability was not available to all. This is just one of the mechanisms through which a lack of economic power translates to corporeal vulnerability.

Figure 8.3 - Cow grazing at Berambadi non-constructed wetland site. Photograph by author, 2019.

Snakes and waterscapes of layered vulnerabilities

During initial surveys at Ibrahimpur I was surprised by respondents who mentioned snakes as an issue. Snakes, at the time, weren't part of my conception of wastewater issues. The households bringing up snakes were – with one exception – those living closest to the pond. The connection between snakes and wastewater was confirmed in focus group discussions in May 2020; asking what animals could be seen around the pond almost always brought snakes into the discussion. Snakes were also raised as an issue by those living around the 'non-constructed' wetland at Berambadi, while teachers at Berambadi school mentioned snakes when asked about the animals seen near the constructed wetland. It would seem that snakes are a common component of constructed wetland assemblages in rural India.

Though Ibrahimpur residents mentioned varied species, a good proportion of snakes that were seen around the pond are likely to be Checkered Keelback water snakes, *Xenochropis piscator*. Romulus Whitaker (1992) suggests this is the most common of water snakes, and indeed 'probably the most common and abundant' of all snakes in India: 'prolific, adaptable and found almost everywhere' (pp. 22–24). This snake is non-venomous and harmless to humans. However, the Checkered Keelback's response when excited is commonly mistaken for a cobra (ibid.). Water snakes feed on frogs – plentiful in the pond and wetland – and other small animals. One woman living in a house adjacent to the wetland pointed out that snakes could be heard by the sound a frog makes when seized in a snake's jaws. The fact that the wetland is a good habitat for snakes raises vulnerability not only for human beings.

The unwelcome – to humans and frogs at least – presence of snakes around these waterscapes speaks to a complex and troubled cohabitation of people and snakes in India more broadly. In India, snakes live in proximity to people, threading lifeways through both rural and urban spaces. India has somewhere around 280 species of snakes (Whitaker, 1992). Around 60 of these species are venomous (Price, 2017). One consequence is that an estimated one million people suffer snake bites annually in India. When combined with a healthcare system often poorly equipped to respond, venomous snakes cause close to 50,000 deaths annually (Mohapatra *et al.*, 2011). The vast majority of snake bite morbidity and mortality comes from four species of snakes, including the cobra (Narayanan, 2016). At the same time, snakes have a strong cultural and religious significance in many parts of India (Whitaker and Whitaker, 1992).

A brief history of snake control since the 19th century in India adds some perspective to contemporary tensions. In British India practices of living alongside or venerating snakes represented, to colonial officers, a "subservience to the natural world" (Price, 2017, p. 207). In this context, a bounty scheme, beginning in 1871, that offered money for each dead snake aimed to do more than reducing mortality by eliminating snake populations. The scheme also "serve[d] as a pedagogic process, encouraging the people of India to act using reason instead of superstition" (ibid., p. 207). As Lloyd Price (2017) explains, during a period of several decades, this policy failed to reduce the number of snake bites. Instead, several colonial officials challenged the initial idea that Indian culture had exacerbated the problem of snake bites. As a result, snake control shifted to a 'sanitation' approach. Officials aimed to control snake populations around villages by dealing with the "rubble, plants and waste" that were argued to allow snake movement (ibid., p. 211). After first aiming to eradicate snakes, the response shifted towards aiming to exclude snakes from villages.

At Ibrahimpur, I asked about how people reacted to snakes. The answer, more often than not, was laughter and a simple reply. As one man put it, "we don't need to relate to them, we just kill them". The 'we' doing the killing is a gendered subject, women spoke more of feeling afraid. The danger of snakes was not provided as a justification for this killing. One person mentioned a fatal bite that had occurred 'long ago'[11]. But it was also explained that snakes were "treated the same if dangerous or not"[12]. With further discussion, this killing of snakes was delineated; snakes are dealt with based on a spatial ordering of household spaces and 'here and there' (generally in or around waterbodies). Women cheerfully recounted seeing the snakes 'sunbathing' on the banks of the pond[13]. It was also clarified that snakes were left alone when they were seen 'just passing by' or going 'here or there' [14]. Killing of snakes takes place when they come into or near houses. Given the lack of other justifications, this spatial logic appears to be all the reason necessary for killing snakes. These interviews gave no sense that snakes are hated in general; there are areas where snakes are tolerated, and others where they are not. These encounters are stressful for both people and snakes. But, in the vast majority of cases, they were worse for the snake, whose curiosity, desire for food or a cool place, and inability to read human territorial divisions has deadly consequences.

Because of the guiding of wastewater into wetlands and ponds, water-snakes and wastewaters are tied together. When these wetlands and ponds are located near to houses, as at Ibrahimpur, encounters between snakes and people take place. But there remain other ways that this

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[11] IBM GI1- Male respondent
[12] IBM GI7
[13] IBM GI1 -Female respondent
[14] IBM GIs 1,4 10 - Female respondents

cohabitation could be dealt with. This is not to say that such a change would be straightforward. Speaking of the situation in Bengaluru, Yamini Narayan and Sumanth Bindumadhav (2019) emphasise that “there is no simple way to resolve this complex issue of coexistence” (p. 6). At the same time, their research offers several examples of sites and communities in Bengaluru where learning ‘tools of coexistence’ (p. 6) allowed for more harmonious relations. Excluding snakes from houses through violence is not the only option.

Distributing the vulnerabilities of wastewater toxicity

Thinking through a framework of vulnerabilities and exclusions, constructed wetlands aim to detach polluted water from the rest of the waterscape. Such an exclusion is characteristic of most wastewater treatment infrastructures. In the case of constructed wetlands, this process creates wetland habitat as a ‘sacrifice zone’ for toxicity (Liboiron, 2021). As water seeps, trickles and swirls through the constructed wetlands, it contains within it a complex mixture of chemical compounds, many of which are recent inventions (Liboiron, Tironi and Calvillo, 2018). Within a typical wastewater stream these might include caffeine, artificial sweeteners, paracetamol and other pharmaceuticals, beauty products or residues from plastics and non-stick cookware (Wilkinson *et al.*, 2022). On top of this, some chemicals are conscious additions to the wetland, such as the herbicides and fungicides used to control the growth of reeds or to treat canna rust. These chemicals are harmful to different bodies, depending not only on their concentration but also interactions with other chemicals, or physical-chemical conditions such as pH and temperature (van der Eerden, 1982). Different chemicals, ranging from metal ions to complex and novel organic compounds, interact with bodies in very different ways. They also exhibit different physio-chemical affinities for other materials. This all impacts on how they move and persist. While toxicology research has historically focused on determining concentrations that cause acute harm, there are slower and subtler ways that chemicals may create vulnerabilities for living beings; many of the chemicals of significant concern in environmental toxicology are those that are highly persistent, such as plastics or PCBs (Murphy, 2017). Through processes of bioaccumulation even very low concentrations can become damaging for a body over time. In constructed wetlands this bioaccumulation is often the point; heavy metals are intended to accumulate in plant bodies.

To be more specific about toxicity and vulnerability, we can take ammonia as an example. Ammonia is a key inorganic form of nitrogen, and hence inseparable from life processes. Ammonia forms part of the circuits through which nitrogen passes between bodies and through waterscapes. It is excreted in urine, and produced by microbial life as they break down organic matter. Hence, ammonia is not just a troublesome addition to water, one that could be dealt with by preventing its use and discharge. Figure 8.4 shows that concentrations of ammonia at all sites varied significantly. Concentrations at Berambadi wetland were the highest. This reflects a wastewater inflow that has been treated through un-aerated septic tanks and contains a higher proportion of sewage compared to the other wetlands. However, reading these results as indicative of vulnerability is difficult. The toxicity of ammonia is complex, varying depending on pH, temperature and the presence of other salts, which alter the form in which ammonia is present in solution (Constable *et al.*, 2003). Furthermore, different species have developed widely diverse physical and metabolic structures to manage and excrete ammonia (Weihrauch, Donini and O'Donnell, 2012). There is some research on the ammonia tolerance of wetland plants in constructed wetlands (Clarke and Baldwin, 2002; Wang *et al.*, 2016), as well as research that emphasises that insects have a higher ammonia tolerance than many other animals. Yet these results are far from a complete picture of how ammonia affects the diversity of beings in each wetland: plants, insects, snails, spiders, birds, frogs, fungi and countless micro-organisms. For example, water high in ammonia may create a good niche for those species who can tolerate it, and face less vulnerability from predation or competition as a result (Durant and Donini, 2019). Thinking with ammonia emphasises the complex remaking of vulnerabilities that arise as the flow of water distributes toxicity through constructed wetlands.

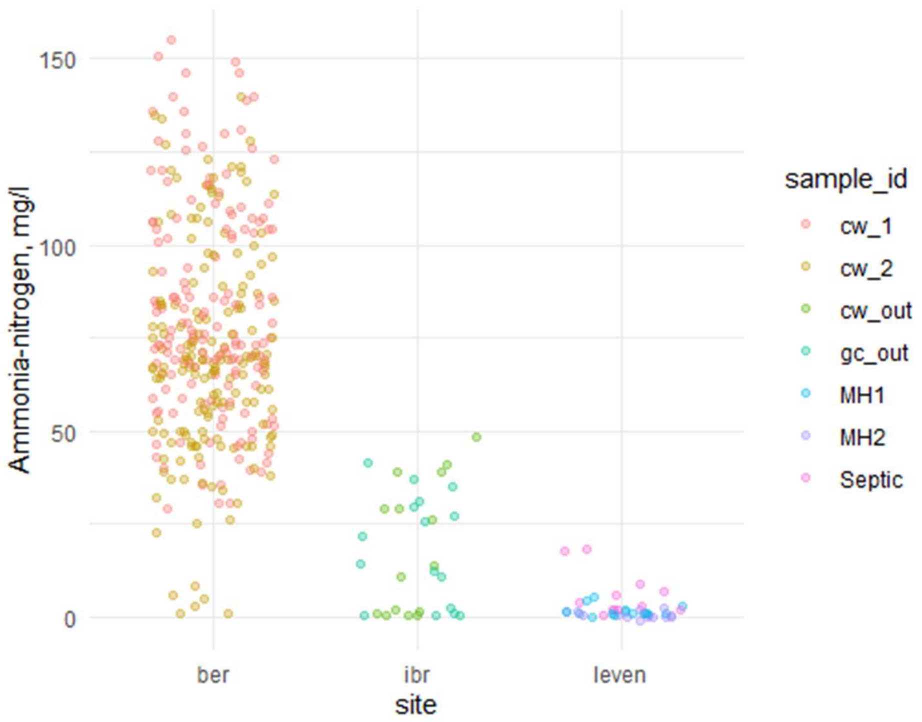

Figure 8.4 - Ammonia-nitrogen concentrations within the three constructed wetlands

To think through this situation, a concept from ecological sciences is helpful. The idea of an 'ecological trap' has been used to name the vulnerabilities produced by spaces that are largely human created. This concept is built on the notion that animals (and other beings) are not always able to judge which habitats offer the best prospects for flourishing. They might instead choose habitats that appear to be good, but actually expose them to significant vulnerabilities (Battin, 2004). As an example, William Keilsohn, Desireé Narango, and Douglas Tallamy (2018) suggest that planting vegetated medians along roads is a potential ecological trap, as insect mortality is increased due to vehicle collisions. Insects judge these areas of vegetation to be good habitat, as they don't consider the risk from vehicles in their processes of habitat selection. The concept of an ecological trap cautions that actions taken with the intention to provide habitat may have negative consequences for non-human well-being. Christopher Murray and Andrew Hamilton (2010) follow a similar line of thought in examining the risks that contaminants and pathogens in wastewater treatment wetlands pose to wetland birds. These constructed wetlands may appear to be good habitat from a wetland bird's perspective, while containing hidden risks. We could also consider the snakes above, who inhabited the wetland but would be killed if they ventured into homes. Continuing the focus on wetland ecologies, Sievers et al. (2018) conduct a meta-review comparing 'human-altered' and 'reference' wetlands. They find that organisms in 'altered wetlands' have a reduced fitness. However, there was not enough data available on habitat preferences to determine if these altered wetlands were acting as ecological traps. Different methods of research would be required to determine if the constructed wetlands at Ibrahimpur, Loch Leven and Berambadi fit the concept of an ecological trap. Such determinations are usually made by examining the reproductive success of wetland inhabitants, compared with those in non-polluted wetlands. All the same, the possibility of creating such ecological traps should be a consideration of constructed wetland habitat making.

If ammonia toxicity and the attendant risk of ecological traps can only be speculated about, what is certain is that high ammonia is not a coincidental feature of constructed wetlands. Wastewater wetlands are a point of convergence for nitrogen-rich waters. Constructed wetlands could be considered as a sacrifice zone. They are a space that reduces vulnerability for (aquatic) creatures and plants downstream, a spatial method of detachment. If wastewater treatment is effective, then vulnerability to ammonia and other pollutants is redistributed. Thinking of constructed wetlands as habitat rather than infrastructure highlights a disjuncture between wastewater treatment processes and care for wetland-inhabiting creatures and magnifies ethico-political questions related to how vulnerability is distributed.

Conclusion: responsible exclusions

Constructed wetlands work at the nexus of several vulnerabilities. First, they are a response to the ecological vulnerabilities intensified by water pollution. Guiding wastewater flows to a constructed wetland aims to focus pollution on plant and microbial bodies that are hoped to be less vulnerable. Second, in the Indian context, these wetlands also function, alongside other water infrastructures, as a response to water scarcity (Mehta, 2003; Goyal *et al.*, 2020; Jamwal *et al.*, 2021). Similarly, at Loch Leven, the wetland was part of a response to eutrophication in Loch Leven, and the vulnerabilities that this produces. Finally, whether or not they are recognised as habitat, constructed wetlands offer affordances to birds, frogs, snakes, insects, plants and other beings as they respond in their own ways to the existential vulnerability of being alive. Yet, as the previous sections have shown, in responding to some vulnerabilities, others are exacerbated.

My central argument isn't that the impact of water infrastructures on more-than-human vulnerabilities needs to be recognised. This recognition already exists. It is evident in the various exclusions explored above. Instead, what requires greater emphasis are the ethical choices that are implicit when exclusions are enacted and vulnerabilities are redistributed.

One way to do this is through paying attention to the spatiality of exclusions. Franklin Ginn (2014) notes that exclusions are a way of making spaces (p. 540), they also work on particular scales. This is visible in Ginn's empirical account. It is the difference between placing a ring of slug pellets around a particular garden bed, throwing slugs over the fence or flushing them down the toilet. The spatial logic described by Ibrahimpur interviewees, of killing snakes when they come into homes and otherwise letting them be is an exclusion at a particular scale. It represents a down-scaling compared to efforts in the late 19th century to exclude snakes from entire villages (Price, 2017). The possibility for multiple scales of exclusion is also evident when considering mosquitoes. Historic practices of mosquito exclusion in colonial contexts served as a driver or justification for segregation (Rehman, 2020; Beisel and Wergin, 2022). Later eradication campaigns using DDT and other insecticides aimed to exclude mosquitoes across wide areas. In contrast, the mosquito coils used at Ibrahimpur work in single rooms, and mosquito nets define an even smaller volume of exclusion. Another measure for controlling mosquitoes in the context of constructed wetlands is to site the wetlands away from any houses (Knight *et al.*, 2003); mosquitoes aren't excluded from the wetland, but from people, due to the distance between them. Taking the rescaling of exclusion one step further, Wolbachia-infected mosquitoes – released as part of disease prevention efforts in Medellin, Colombia – prevent mosquitoes from passing on viruses, enacting an exclusion within mosquito bodies (Sims, 2021). A focus on scale emphasises the ethical judgements entailed in making exclusions, beyond an inclusion/exclusion binary.

Looking to a different domain of hydrosocial relations, flood control measures also rework the spatiality of vulnerability within waterscapes (Parsons *et al.*, 2019). But rivers controlled by dams, constrained within stop banks and floodwalls, and disconnected from floodplains are ecologically impoverished (Kingsford, 2000). I raise this example to suggest the need for a less anthropocentric ethics of exclusion. The examples of mosquito control and wetland toxicity move in this direction. This consideration of a broader ecology is a necessary component of a multispecies water justice.

The stories of vulnerability and exclusion developed in this chapter also suggest to me that a more just waterscape in this context might require a specificity developed through ecological knowledge. For example, while I saw mosquitoes and their larvae at Berambadi, I did not know which species of mosquito they were, and hence the likelihood that they might act as disease vectors. Similarly, if attempts are made to exclude mosquitoes through placing constructed wetlands further from people, it matters that some species and genera of mosquitoes are poor fliers, who will not travel more than 100 metres on average, while other mosquitoes are capable of flying distances of up to five kilometres (Verdonschot and Besse-Lototskaya, 2014; Hawkes and Hopkins, 2022). In my explorations of toxicity, understanding how concentrating wastewater in these wetlands distributes vulnerability was difficult without a more specific understanding of tolerances across different organisms. Research into ecological traps develops this kind of understanding (Sievers *et al.*, 2018), the results may be surprising (Kirksey, 2020). Finally, a greater ability to discern venomous and nonvenomous snakes – and an appreciation of snake's ecological role – might allow a less deadly sharing of space at Ibrahimpur, though making this shift requires more than just knowledge (Narayanan and Bindumadhav, 2019). Such specificity is not always easy, but it enables a better understanding of waterscape vulnerabilities, and hence different practices of exclusion.

Eve Giraud (2019) suggests that the importance of making exclusions visible is to both foster responsibility and to make other possibilities visible. This is particularly significant in a wider context where the concept of vulnerability is so often depoliticised (Smith and Dressler, 2019). Layering a broader historical perspective onto stories of snakes and mosquitoes at these wetlands highlights various ways of redistributing the vulnerabilities of cohabitation. It is important to note that distributions of vulnerability also entail distributions of responsibility. Considerations in the Berambadi project team about the risk of mosquitoes were attempts to establish where responsibility for mosquitoes might lie. On one level it seems reasonable to argue that the responsibility for vulnerabilities exacerbated by these constructed wetlands should be taken by those who designed and built them. At the same time, colonial histories show that taking on the responsibility for exclusions is not politically benign; vulnerabilities are often mobilised in the interest of power (Joronen and Rose, 2021). This chapter has developed a framework of vulnerability and exclusion in order to examine the frictions that arise in lively waterscapes. This analysis is motivated by a conviction that more ethical modes of cohabitation are possible. If vulnerability is understood as a shared existential condition – and ecological knowledge and environmental histories are brought to bear in examining exclusions – it becomes clear that responding to waterscape vulnerabilities is a form of more-than-human politics. Water justice is most likely to flow from a situated politicisation of these vulnerabilities.

9 Conclusion

Synopsis: constructed wetlands and water justice

Across the empirical chapters of this thesis, I have shown how thinking with constructed wetlands contributes to a richer understanding of water justice in more-than-human waterscapes.

The first empirical chapter, Chapter 4, reviews constructed wetland literature to highlight the social, economic and environmental normativities implicit in constructed wetland projects. I read the rationale statements used to advocate for constructed wetlands as indicative of diverse and not necessarily coherent socio-technical imaginaries. Within five thematic areas, I describe how these imaginaries indicate desired futures in which people, water, infrastructures and nature relate in particular ways. By connecting rationale statements to socio-technical imaginaries this analysis brings to light the visions of water justice that are implicit in constructed wetland discourses.

Chapter 5 concerns judgements of adequate water quality, and the knowledge politics that underlie these judgements. The scientific teams involved in building the wetlands and local people who live in these waterscapes judge adequate water quality differently. Local peoples' judgements are derived from the relations inherent to their everyday use of water. In contrast, the methods and broader tools of evaluation through which scientific teams judge water quality, while treated as universal, were developed through specific more-than-human water relations in different times and places. For example, while E. coli indicates faecal contamination in temperate regions, in India this connection does not hold. Attention to more-than-human relations demonstrates that assessments of good water quality cannot be universal. Attention to ecological and historical context and careful generalisation are the necessary conditions for just ways of knowing water quality.

Chapter 6 examines how changes in water quality are interpreted. This chapter offers contrasting examples in order to demonstrate the partial and political nature of all socio-ecological interpretation. A key argument here is that simplified explanations, such as those found in the constructed wetland literature, sustain relations of domination in waterscapes. First, they support the social power of expertise: an unevenly distributed and non-democratic ability to shape waterscapes. Second, these interpretations deny more-than-human capacities, rendering other-than-human life as no more than a functional component of waterscapes. The interpretations that I develop in this chapter aim to highlight the responsiveness of plants and microbes, and to question functional explanations of ecological processes within constructed wetland science. I emphasise the thickness of more-than-human relations by positioning the actions of humans and other-than-human beings as creative responses to their conditions. A more experimental and responsive approach generates the counter-interpretations that are required for multispecies water justice.

These water quality analyses challenge instances of human exceptionalism embedded in water quality politics. Changing how water quality is conceptualised works in tandem with changing water infrastructures to enable both human and other-than-human flourishing. The following chapters continue to advance a multispecies scaffolding for water justice by examining how constructed wetlands are sites of multispecies habitability.

Chapter 7 foregrounds the other-than-human communities that inhabit these constructed wetlands. I combine geographical and ecological theorising in order to attend to processes of biodiversification. I explore these processes in relation to the plants, invertebrates and birds that I observed at each site. Tracing processes of biodiversification produces a richer understanding of the variety of life within wetlands and other water infrastructure. It shows the relations, scalar connections and representations that must be engaged with to enable multispecies flourishing in each waterscape. I also argue that the biodiversity of constructed wetlands is open and multiple: containing unknown beings and with no fixed direction of development.

Chapter 8 looks at how the vulnerabilities generated by these constructed wetlands are recognised, responded to and redistributed. I suggest that exclusions – made in response to vulnerability – are a focal point for more-than-human ethics and obligations. Examining the responses to snakes and mosquitoes at the two Indian wetland sites demonstrates varied responses to the vulnerabilities of multispecies coexistence. I then turn to the exclusions and distributions of vulnerability that are embedded in constructed wetland design through the fencing wetlands and directing wastewater. Considering these cases, I suggest that judging the ethics and effects of particular exclusions requires ecological knowledge. Attention to the scale of exclusions and to who is responsible for deciding and enacting them is central to achieving water justice in the context of existential vulnerabilities.

Waterscape concerns

This thesis offers a perspective on waterscape processes that is centred at the intersection of wastewater and wetlands, both marginal concerns in most waterscape research. Through focusing on constructed wetlands, water quality and multispecies habitability emerge as the key concerns of this thesis. Working across three constructed wetland projects has allowed me to see how these two concerns resonate within different socio-ecological assemblages. While these concerns have particular resonance for constructed wetlands, my arguments throughout the thesis are significant for water infrastructures and waterscapes more generally. It is not only in relation to constructed wetlands that more adequate understandings of water quality are necessary. Constructed wetlands are not the only water infrastructures that serve as multispecies habitat. Attending to water quality and multispecies habitability generates insights on two cross-cutting themes: vulnerability and knowledge politics.

The distribution of vulnerability is perhaps the key material concern of this thesis. While I address the vulnerabilities of constructed wetland ecologies in Chapter 8, vulnerability is also a latent component of water quality analysis. Water pollution generates an unequal distribution of vulnerability. This bodily vulnerability is foundational to most notions of water quality. Yet the anthropocentric ways that water quality is governed in many places treat only the vulnerability of people – or economic activities – as significant. Water quality standards hence reflect a political settlement regarding the distribution of vulnerability and responsibility, one that this thesis has aimed to unsettle. I argue that more situated ways of understanding water quality are needed to better respond to the harms of water pollution. In chapter 8 I argue that vulnerability can also be examined by exploring different practices of exclusion. Mapping how vulnerability is recognised and validated, and the fragile ways that vulnerabilities are responded to, constitutes a fruitful analytical approach to a more-than-human waterscapes. While vulnerability has been a significant theme in previous waterscape analyses (Hanson and Buechler, 2015; Correia, 2022), the conceptualisation of vulnerability offered by this thesis is novel. The vulnerabilities that I trace in this thesis do not point towards processes of marginalisation, but instead to vulnerability as a shared condition of more-than-human life.

Fundamental to my analysis across the thesis is an awareness of how environmental knowledge and interpretation is marked by historical contingencies and relations of power. The politics of knowledge is a crucial component of critical environmental research. My goal in engaging concepts such as vulnerability, biodiversity or biosensing is to examine the role they play in these waterscapes, and to ask how they might be imagined and used differently. These ideas have the ability to shape how waterscapes unfold. Asking about concepts raises the questions of who develops these concepts? how do these concepts travel? and what ethical visions are they underpinned by?

Greater attention to water quality is productive for tracing how power and knowledge are interconnected in particular waterscapes (Nustad and Swanson, 2022). This thesis uses careful attention to more-than-human relations to highlight the silences and contingencies of water quality measurement and evaluation. The ways of measuring and evaluating water quality that are dominant in these waterscapes represent a conjunction of knowledge and power that sustains expertise and human exceptionalism. In alignment with broader political ecology scholarship, I hold that the expertise of water scientists deserves critical scrutiny. Possessing technical knowledge too often constitutes a licence to diagnose and respond to waterscape problems with a veneer of objectivity. The alternative is a more democratic shaping of waterscapes, giving greater regard to the knowledge and concerns of those who live in them.

For water quality scientists and others working with water quality data, this thesis is a call to consider how water quality knowledge is made meaningful. To be involved in judging water quality is to be part of a political apparatus which too easily disavows the harm of poor water quality. Chapter 5 urges a more careful approach to generalisation, and a shift away from standards and efficiency as the only word in determining adequate water quality. At the same time, moving beyond these approaches raises new challenges and questions (Shapiro, Zakariya and Roberts, 2017). Asking these difficult questions and using them to orient research differently can be an anti-colonial response to the colonial histories of many water quality methods and knowledges.

To close with a provocative generalisation (Fine, 2006), the forms of constructed wetland and ecological science that this thesis engages with are part of a broader edifice of 'integrated water resource management' and 'environmental management' that offers only a limited conceptual space for non-human life. The result is an impoverished understanding of water justice, whose consequences for both other-than-human and human life are increasingly undeniable.

Studying land- and waterscapes differently

This thesis develops and demonstrates a more-than-human analysis of waterscapes. I describe how hydrosocial scholarship's attunement to the assemblages and power relations that shape waterscapes can be combined with the recognition that water sustains more-than-human communities. This is an important lens for the study of water infrastructure in general, and constructed wetlands in particular. A more-than-human analysis is important on both ethical and pragmatic grounds. An ethical orientation to a more-than-human waterscape takes up critiques of human exceptionalism (Haraway, 2008; Tsing, 2014; Srinivasan and Kasturirangan, 2016; Tschakert *et al.*, 2021) and follows the work of scholars who have suggested that obligations to a more-than-human community ought to be an orienting approach to water relations (McGregor, 2009; Neimanis, 2017; Todd, 2017; Strang, 2018; Estes, 2019; Liboiron, 2021). There is no water politics which doesn't impact on other-than-human beings in some fashion. On the other hand, in describing this orientation to more-than-human waterscapes as pragmatic I argue that, even if challenging human exceptionalism is not your aim, there are important waterscape dynamics that come into focus more clearly by attending to more-than-human relations. The questionably universal logics of water quality metrics and the differentiated vulnerabilities created by water infrastructures are both revealed by paying attention to how people and other beings are knotted in waterscapes.

To describe more-than-human waterscapes, this thesis negotiates different kinds of water knowledge and different methods for tracing waterscape processes. By combining typical human geography methods with those from environmental sciences I have been able to offer novel analyses. I am not the first to argue that critical water research has untapped potential to draw from methods across disciplines (Krause and Strang, 2016; Mollinga, 2020; Wear *et al.*, 2021; Rusca *et al.*, 2022). My methodological approach also connects to broader discussions about novel methods in more-than-human and animal geographies. My use of structured ecological surveys, camera trap recordings and qualitative observation illustrates the combination of data sources that can be used to attune to landscape, as well as waterscape, processes. Yet, as this thesis shows, working with hydrological and ecological science methods entails working with tensions. Environmental science – as with any discipline – is characterised by certain modes of investigation and description, which don't always align with the normative aims of waterscape analyses. I have integrated basic ecological and hydraulic methods into a methodology quite different from where they are typically practised. These methodological experiments have provided partial perspectives on waterscape processes. It is often the contradictions between the findings of different methods that are most valuable for my analysis. Careful and critical engagement with ecological science is essential if hydrosocial research is to build a deeper understanding of more-than-human waterscapes.

Towards multispecies water justice

In examining the politics of water quality and the frictions of multispecies habitability, I have placed more-than-human relations at the centre of my analysis, while considering the contingent histories that shape contemporary waterscapes. My analyses demonstrate how richer concepts of water justice are possible, which aim to remake waterscapes as spaces of more-than-human flourishing. As diverse struggles for water justice are fought in countless waterscapes, it is important to recognise that human exceptionalism is not inevitable. I hope audiences of this work gain an appreciation of how waterscapes and landscapes are sustained by more-than-human relations and that they consider how this might entail obligations to the waterscapes they are part of.

Bibliography

Abbasi, H.N. *et al.* (2019) "Nutrient removal in hybrid constructed wetlands: spatial-seasonal variation and the effect of vegetation," *Water science and technology: a journal of the International Association on Water Pollution Research*, 79(10), pp. 1985–1994.

Abend, G. (2008) "The meaning of 'theory,'" *Sociological Theory*, 26(2), pp. 173–199.

Abrahamsson, S. *et al.* (2015) "Living with Omega-3: New Materialism and Enduring Concerns," *Environment and planning. D, Society & space*, 33(1), pp. 4–19.

Acevedo Guerrero, T. (2018) "Water infrastructure: A terrain for studying nonhuman agency, power relations, and socioeconomic change," *Wiley Interdisciplinary Reviews: Water*, 5(5), p. e1298.

Acharya, A. (2015) "The cultural politics of waterscapes," in *The International Handbook of Political Ecology*. Cheltenham, UK: Edward Elgar Publishing.

Acharya, A. (2019) "A political ecology of small things? The curious case of RO-based water purifiers, Bhuj, India," in. *RGS-IBG Annual International Conference*.

Aga, A. (2021) "Farm Protests in India Are Writing the Green Revolution's Obituary," *Scientific American*, 24 January. Available at: https://www.scientificamerican.com/article/farm-protests-in-india-are-writing-the-green-revolutions-obituary/ (Accessed: October 12, 2021).

Agrawal, R. (2013) "Hydropower Projects in Uttarakhand: Displacing People and Destroying Lives," *Economic and political weekly*, 48(29), pp. 14–16.

Ahlborg, H. and Nightingale, A.J. (2018) "Theorizing power in political ecology: the 'where' of power in resource governance projects," *Journal of Political Ecology*, 25(1), pp. 381–401.

Aigo, J. del C. *et al.* (2020) "Waterscapes in Wallmapu: Lessons from Mapuche Perspectives," *Geographical review*, pp. 1–19.

Aijaz, A. and Akhter, M. (2020) "From Building Dams to Fetching Water: Scales of Politicization in the Indus Basin," *Water*, 12(5), p. 1351.

Allen, A. (2021) "Feminist Perspectives on Power," *The Stanford Encyclopedia of Philosophy*. Winter 2021. Edited by E.N. Zalta. Metaphysics Research Lab, Stanford University. Available at: https://plato.stanford.edu/archives/win2021/entries/feminist-power/.

Alley, K.D., Barr, J. and Mehta, T. (2018) "Infrastructure disarray in the clean Ganga and clean India campaigns," *WIREs. Water*, 5(6), p. e1310.

American Public Health Association (2005) *Standard Methods for the Examination of Water & Wastewater*. Washington, D.C: American Public Health Association.

Amezaga, J.M., Santamaría, L. and Green, A.J. (2002) "Biotic wetland connectivity—supporting a new approach for wetland policy," *Acta Oecologica*, 23(3), pp. 213–222.

Anand, N. (2017) *Hydraulic city: Water and the infrastructures of citizenship in Mumbai*. Durham, NC: Duke University Press.

Anand, N. (2022) "TOXICITY 1: On ambiguity and sewage in Mumbai's urban sea," *International journal of urban and regional research* [Preprint]. doi:10.1111/1468-2427.13093.

Anand, N., Gupta, A. and Appel, H. (2018) *The Promise of Infrastructure*. Durham, NC: Duke University Press.

Angel, J. and Loftus, A. (2019) "With-against-and-beyond the human right to water," *Geoforum; journal of physical, human, and regional geosciences*, 98, pp. 206–213.

Ankrah, N.Y.D. *et al.* (2020) "Syntrophic splitting of central carbon metabolism in host cells bearing functionally different symbiotic bacteria," *The ISME journal*, 14(8), pp. 1982–1993.

Arce-Nazario, J. (2018) "The Science and Politics of Water Quality," in Lave, R., Biermann, C., and Lane, S.N. (eds.) *The Palgrave Handbook of Critical Physical Geography*. Cham: Palgrave Macmillan, pp. 465–483.

Armiero, M., Barca, S. and Velicu, I. (2019) *Undisciplining Political Ecology: A Minifesto, Undisciplined Environments*. Available at: https://undisciplinedenvironments.org/2019/10/01/undisciplining-political-ecology-a-minifesto/ (Accessed: February 23, 2022).

Ashbolt, N.J., Grabow, W.O.K. and Snozzi, M. (2001) "Indicators of microbial water quality," in Fewtrell, L. and Bartram, J. (eds.) *Water Quality: Guidelines, Standards and Health*. London: IWA Publishing.

Aubriot, O. *et al.* (2018) "Water technology, knowledge and power. Addressing them simultaneously: Water technology, knowledge, and power," *Wiley Interdisciplinary Reviews: Water*, 5(1), p. e1261.

Augusto Pádua, J. (2012) "Pitfalls and Opportunities in the Use of the Biodiversity Concept as a Political Tool for Forest Conservation in Brazil," in Martin, G., Mincyte, D., and Münster, U. (eds.) *Why Do We Value Diversity? Biocultural Diversity in a Global Context*. Munich: Rachel Carson Centre (Perspectives).

Ausden, M. and Drake, M. (2006) 'Invertebrates', in *Ecological Census Techniques: A Handbook*. Cambridge University Press, pp. 214–249.

Bakker, K. (2003) "Archipelagos and networks: urbanization and water privatization in the South," *The Geographical journal*, 169(4), pp. 328–341.

Bakker, K. (2012) "Water: Political, biopolitical, material," *Social studies of science*, 42(4), pp. 616–623.

Balian, E.V. *et al.* (2008) "The Freshwater Animal Diversity Assessment: an overview of the results," in Balian, E.V. et al. (eds.) *Freshwater Animal Diversity Assessment*. Dordrecht: Springer Netherlands, pp. 627–637.

Balibar, É., Mezzadra, S. and Samaddar, R. (eds.) (2012) *The Borders of Justice*. Temple University Press.

Barad, K. (2007) *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham, NC: Duke University Press.

Barnagarwala, T. (no date) *Special report: Why is India seeing a massive dengue outbreak this year?* Available at: https://scroll.in/article/1011940/special-report-why-is-india-seeing-a-massive-dengue-outbreak-this-year (Accessed: June 23, 2022).

Barnaud, C. *et al.* (2021) "Is forest regeneration good for biodiversity? Exploring the social dimensions of an apparently ecological debate," *Environmental science & policy*, 120, pp. 63–72.

Barnes, J. (2017) "States of maintenance: Power, politics, and Egypt's irrigation infrastructure," *Environment and planning. D, Society & space*, 35(1), pp. 146–164.

Barnes, J. and Alatout, S. (2012) "Water worlds: Introduction to the special issue of Social Studies of Science," *Social studies of science*, 42(4), pp. 483–488.

Barnett, J. (2020) "Global environmental change II: Political economies of vulnerability to climate change," *Progress in human geography*, 44(6), pp. 1172–1184.

Barry, A. and Born, G. (2013) *Interdisciplinarity: Reconfigurations of the Social and Natural Sciences*. Edited by A. Barry and G. Born. Routledge.

Barua, M. (2021) "Infrastructure and non-human life: A wider ontology," *Progress in human geography*, 45(6), pp. 1467–1489.

Bastian, M. *et al.* (2016) *Participatory Research in More-than-Human Worlds*. Taylor & Francis.

Battin, J. (2004) "When Good Animals Love Bad Habitats: Ecological Traps and the Conservation of Animal Populations," *Conservation biology: the journal of the Society for Conservation Biology*, 18(6), pp. 1482–1491.

Battistoni, A. (2017) "Bringing in the Work of Nature: From Natural Capital to Hybrid Labor," *Political theory*, 45(1), pp. 5–31.

Batzer, D.P. and Wu, H. (2020) "Ecology of Terrestrial Arthropods in Freshwater Wetlands," *Annual review of entomology*, 65, pp. 101–119.

Baviskar, A. (2007) *Waterscapes: The Cultural Politics of a Natural Resource*. Delhi: Permanent Black.

Beattie, J. and Morgan, R. (2017) "Engineering Edens on This 'Rivered Earth'? A Review Article on Water Management and Hydro-Resilience in the British Empire, 1860-1940s," *Environment and history*, 23(1), pp. 39–63.

Begon, M., Townsend, C.R. and Harper, J.L. (2005) *Ecology: From individuals to ecosystems* [PDF]. 4th ed. London, England: Blackwell Publishing.

Beisel, U. (2015) "Markets and Mutations: mosquito nets and the politics of disentanglement in global health," *Geoforum; journal of physical, human, and regional geosciences*, 66, pp. 146–155.

Beisel, U. and Wergin, C. (2022) "Understanding Multispecies Mobilities: From mosquito eradication to coexistence," in Hall, M. and Tamïr, D. (eds.) *Mosquitopia: The Place of Pests in a Healthy World*. Taylor and Francis.

de la Bellacasa, M.P. (2017) *Matters of Care: Speculative Ethics in More than Human Worlds*. Minneapolis: U of Minnesota Press (Posthumanities, 41).

Benchamin, D., R., S. and Kurup, B.S. (2021) "Utility of caddisflies (Insecta: Trichoptera) as indicators of water quality in Kallada River, Kerala, India," *International Journal of River Basin Management*, pp. 1–7.

Bennett, J. (2009) *Vibrant Matter: A Political Ecology of Things*. Durham, NC: Duke University Press.

Berg, B.L. and Lune, H. (2017) *Qualitative research methods for the social sciences*. Pearson.

Bernardes, F.S. *et al.* (2019) "Relationship between microbial community and environmental conditions in a constructed wetland system treating greywater," *Ecological engineering*, 139, p. 105581.

BESG (2016) *White-breasted Waterhen – feeding behaviour*. Available at: https://besgroup.org/2014/01/12/white-breasted-waterhen-%E2%80%93-feeding-behaviour/ (Accessed: January 12, 2022).

Bevins, V. (2020) *The Jakarta Method: Washington's Anticommunist Crusade and the Mass Murder Program that Shaped Our World*. PublicAffairs.

Bharucha, Z.P. (2019) "This is what Nature has become: Tracing climate and water narratives in India's rainfed drylands," *Geoforum; journal of physical, human, and regional geosciences*, 101, pp. 285–293.

Biermann, C. and Mansfield, B. (2014) "Biodiversity, Purity, and Death: Conservation Biology as Biopolitics," *Environment and planning. D, Society & space*, 32(2), pp. 257–273.

Bird Rose, D. (2007) "Justice and Longing," in Potter, E. et al. (eds.) *Fresh water: New perspectives on water in Australia*. Carlton: Melbourne University Press, pp. 8–20.

Birkenholtz, T. (2009) "Irrigated Landscapes, Produced Scarcity, and Adaptive Social Institutions in Rajasthan, India," *Annals of the Association of American Geographers. Association of American Geographers*, 99(1), pp. 118–137.

Birkenholtz, T. (2013) "'On the Network, off the Map': Developing Intervillage and Intragender Differentiation in Rural Water Supply," *Environment and planning. D, Society & space*, 31(2), pp. 354–371.

Birkinshaw, M., Grieser, A. and Tan, J. (2021) "How does community-managed infrastructure scale up from rural to urban? An example of co-production in community water projects in Northern Pakistan," *Environment and urbanization*, 33(2), pp. 496–518.

Bodelier, P.L.E. and Dedysh, S.N. (2013) "Microbiology of wetlands," *Frontiers in microbiology*, 4, p. 79.

Boelens, R. *et al.* (2016) "Hydrosocial territories: a political ecology perspective," *Water International*, 41(1), pp. 1–14.

Boelens, R., Vos, J. and Perreault, T. (2018) "Introduction: The Multiple Challenges and Layers of Water Justice Struggles," in *Water Justice*. Cambridge University Press, pp. 1–32.

Booth, K. and Williams, S. (2014) "A more-than-human political moment (and other natural catastrophes)," *Space and Polity*, 18(2), pp. 182–195.

BORDA (2016) *Prefab DEWATS: Lessons Learnt from Afghanistan, Indonesia and India*. BORDA. Available at: https://www.borda.org/wp-content/uploads/2018/09/03.-BoK_Prefab_Spring-2016.pdf.

Bouleau, G. (2014) "The co-production of science and waterscapes: The case of the Seine and the Rhône Rivers, France," *Geoforum; journal of physical, human, and regional geosciences*, 57, pp. 248–257.

Bowker, G.C. (2008) "Time, money, and biodiversity," in *Global Assemblages*. Oxford, UK: Blackwell Publishing Ltd, pp. 107–123.

Bowsher, J. and Reeves-Evison, T. (2019) "On Capital's Watch: Derivative Ecology and the Temporal Logic of Biodiversity Credits," *New Formations*, 99(99), pp. 33–51.

Brands, E. (2014) "Prospects and challenges for sustainable sanitation in developed nations: a critical review," *Environmental Review*, 22(4), pp. 346–363.

Braskerud, B.C. (2002) "Factors affecting phosphorus retention in small constructed wetlands treating agricultural non-point source pollution," *Ecological engineering*, 19(1), pp. 41–61.

Braun, B. (2015) "From critique to experiment?: Rethinking political ecology for the Anthropocene," in Perreault, T., Bridge, G., and McCarthy, J. (eds.) *The Routledge handbook of political ecology*. Routledge, pp. 102–114.

Braun, V. and Clarke, V. (2006) "Using thematic analysis in psychology," *Qualitative research in psychology*, 3(2), pp. 77–101.

Brisson, J. *et al.* (2020) "Plant diversity effect on water quality in wetlands: a meta-analysis based on experimental systems," *Ecological applications: a publication of the Ecological Society of America*, 30(4), p. e02074.

British Trust for Ornithology (2018) *BTO/JNCC/RSPB BREEDING BIRD SURVEY INSTRUCTIONS*. Available at: https://www.bto.org/sites/default/files/bbs_instructions_2018.pdf.

British Trust for Ornithology (BTO) (no date) *European robin guide: diet, habitat and species facts, Discover Wildlife*. Available at: https://www.discoverwildlife.com/animal-facts/birds/facts-about-robins/ (Accessed: March 7, 2022).

Brix, H. (1994a) "Functions of Macrophytes in Constructed Wetlands," *Water science and technology: a journal of the International Association on Water Pollution Research*, 29(4), pp. 71–78.

Brix, H. (1994b) "Use of constructed wetlands in water pollution control: historical development, present status, and future perspectives," *Water science and technology: a journal of the International Association on Water Pollution Research*, 30(8), pp. 209–223.

Brix, H. (1997) "Do macrophytes play a role in constructed treatment wetlands?," *Water science and technology: a journal of the International Association on Water Pollution Research*, 35(5), pp. 11–17.

Brix, H., Schierup, H.H. and Arias, C.A. (2007) "Twenty years experience with constructed wetland systems in Denmark--what did we learn?," *Water science and technology: a journal of the International Association on Water Pollution Research*, 56(3), pp. 63–68.

Bruun Jensen, C. (2017) "The Umwelten of Infrastructure: A Stroll along (and inside) Phnom Penh's Sewage Pipes," *Jinbun* , 47, pp. 147–159.

Bryant, R.L. (2015) *The International Handbook of Political Ecology*. Edward Elgar Publishing.

Budds, J. (2016) "Whose scarcity? The hydrosocial cycle and the changing waterscape of La Ligua river basin, Chile," in Boykoff, M.T., Goodman, M.K., and Evered, K.T. (eds.) *Contentious Geographies*. Abingdon: Routledge, pp. 81–100.

Budds, J. and Hinojosa, L. (2012) "Restructuring and rescaling water governance in mining contexts: The co-production of waterscapes in Peru," *Water Alternatives*, 5(1), pp. 119–137.

Budds, J. and Sultana, F. (2013) "Exploring Political Ecologies of Water and Development," *Environment and planning. D, Society & space*, 31(2), pp. 275–279.

Buller, H. (2008) "Safe from the Wolf: Biosecurity, Biodiversity, and Competing Philosophies of Nature," *Environment & planning A*, 40(7), pp. 1583–1597.

Bureau of Indian Standards (1973) *IS 7022: Glossary of Terms Relating to Water Sewage and Industrial Effluents, Part 1*. 7022. Available at: https://ia601602.us.archive.org/11/items/gov.law.is.7022.1.1973/is.7022.1.1973.pdf (Accessed: January 22, 2020).

Bureau of Indian Standards (2012) *IS 10500: Drinking water - Specification*. 10500. Available at: http://cgwb.gov.in/Documents/WQ-standards.pdf.

Butler, J. (2012) "Precarious Life, Vulnerability, and the Ethics of Cohabitation," *The Journal of Speculative Philosophy*, 26(2), pp. 134–151.

Buvaneshwari, S. *et al.* (2017) "Groundwater resource vulnerability and spatial variability of nitrate contamination: Insights from high density tubewell monitoring in a hard rock aquifer," *The Science of the total environment*, 579, pp. 838–847.

Calheiros, C.S.C. *et al.* (2019) "Diverse Arbuscular Mycorrhizal Fungi (AMF) Communities Colonize Plants Inhabiting a Constructed Wetland for Wastewater Treatment," *WATER*, 11(8), p. 1535.

Calvo, P. *et al.* (2020) "Plants are intelligent, here's how," *Annals of botany*, 125(1), pp. 11–28.

Cardinale, B.J. *et al.* (2007) "Impacts of plant diversity on biomass production increase through time because of species complementarity," *Proceedings of the National Academy of Sciences of the United States of America*, 104(46), pp. 18123–18128.

Carse, A. (2012) "Nature as infrastructure: Making and managing the Panama Canal watershed," *Social studies of science*, 42(4), pp. 539–563.

Carson, R. (1962) *Silent Spring*. Houghton Mifflin Harcourt.

Carvalho, L. *et al.* (2019) "Protecting and restoring Europe's waters: An analysis of the future development needs of the Water Framework Directive," *The Science of the total environment*, 658, pp. 1228–1238.

Castellazzi, P. *et al.* (2018) "Quantitative mapping of groundwater depletion at the water management scale using a combined GRACE/InSAR approach," *Remote sensing of environment*, 205, pp. 408–418.

Castree, N. (2005) "The epistemology of particulars: Human geography, case studies and 'context,'" *Geoforum; journal of physical, human, and regional geosciences*, 36(5), pp. 541–544.

Celermajer, D. *et al.* (2020) "Justice Through a Multispecies Lens," *Contemporary Political Theory*, 19(3), pp. 475–512.

Celermajer, D. *et al.* (2021) "Multispecies justice: theories, challenges, and a research agenda for environmental politics," *Environmental politics*, 30(1–2), pp. 119–140.

Central Pollution Control Board (2010) *Pollution Control Acts, Rules and Notifications issued thereunder*. Delhi: Central Pollution Control Board (Pollution Control Law).

Central Pollution Control Board (2018) *RIVER STRETCHES FOR RESTORATION OF WATER QUALITY (State wise and Priority wise)*. CPCB. Available at: https://nrcd.nic.in/writereaddata/FileUpload/River_STRETCHES_Sept_2018.pdf.

Central Water Commission (2017) "Annex 2: Designated Best Uses of Water." Available at: http://cwc.gov.in/sites/default/files/annexure-2.pdf.

Chandra, K. *et al.* (2017) "Current Status of Freshwater Biodiversity of India: An Overview," in *Current Status of Freshwater Biodiversity in India*. Zoological Survey of India, pp. 1–25.

Chandrasekaran, K. *et al.* (2021) *Nature-based solutions: a wolf in sheep's clothing*. Friends of the Earth International. Available at: https://www.foei.org/wp-content/uploads/2021/10/Nature-based-solutions_a-wolf-in-sheeps-clothing-1.pdf.

Chen, C.-C., Lin, K.-H. and Yang, Y.-H. (2019) "Effect of Call Types on White-Breasted Waterhen (Amaurornis phoenicurus) Response to Playbacks on Pratas Island, Taiwan," *Waterbirds / The Waterbird Society*, 42(3), p. 321.

Chen, Y. *et al.* (2015) "Effects of plant biomass on bacterial community structure in constructed wetlands used for tertiary wastewater treatment," *Ecological engineering*, 84, pp. 38–45.

Chhotray, V. (2011) *The Anti-politics Machine in India: State, Decentralization, and Participatory Watershed Development*. Anthem Press.

Choudhary, A.K. and Kumar, P. (2020) "Constructed Wetland: A Green Technology for Wastewater Treatment," in Singh, A. et al. (eds.) *Environmental Microbiology and Biotechnology: Volume 1: Biovalorization of Solid Wastes and Wastewater Treatment*. Singapore: Springer Singapore, pp. 335–363.

Clairmont, L.K. and Slawson, R.M. (2020) "Contrasting Water Quality Treatments Result in Structural and Functional Changes to Wetland Plant-Associated Microbial Communities in Lab-Scale Mesocosms," *Microbial ecology*, 79(1), pp. 50–63.

Clarke, E. and Baldwin, A.H. (2002) "Responses of wetland plants to ammonia and water level," *Ecological engineering*, 18(3), pp. 257–264.

Coffey, D. and Spears, D. (2017) *Where India Goes: Abandoned Toilets, Stunted Development and the Costs of Caste*. HarperCollins.

Colilert (no date) *IDEXX US*. Available at: https://www.idexx.com/en/water/water-products-services/colilert/ (Accessed: June 1, 2020).

Collard, R.-C. and Dempsey, J. (2017) "Capitalist Natures in Five Orientations," *Capitalism Nature Socialism*, 28(1), pp. 78–97.

Collard, R.-C., Dempsey, J. and Sundberg, J. (2015) "A Manifesto for Abundant Futures," *Annals of the Association of American Geographers. Association of American Geographers*, 105(2), pp. 322–330.

Connelly, S. and Anderson, C. (2007) "Studying water: reflections on the problems and possibilities of interdisciplinary working," *Interdisciplinary science reviews: ISR*, 32(3), pp. 213–220.

Constable, M. *et al.* (2003) "An Ecological Risk Assessment of Ammonia in the Aquatic Environment," *Human and Ecological Risk Assessment: An International Journal*, 9(2), pp. 527–548.

Cope, M. (2010) "Coding transcripts and diaries," in Clifford, N., French, S., and Valentine, G. (eds.) *Key Methods in Geography*. London: Sage.

Correia, J.E. (2022) "Between Flood and Drought: Environmental Racism, Settler Waterscapes, and Indigenous Water Justice in South America's Chaco," *Annals of the Association of American Geographers. Association of American Geographers*, pp. 1–21.

Cousins, I.T. *et al.* (2022) "Outside the Safe Operating Space of a New Planetary Boundary for Per- and Polyfluoroalkyl Substances (PFAS)," *Environmental science & technology* [Preprint]. doi:10.1021/acs.est.2c02765.

Cousins, J.J. (2021) "Justice in nature-based solutions: Research and pathways," *Ecological economics: the journal of the International Society for Ecological Economics*, 180, p. 106874.

Cullet, P. and Gupta, J. (2009) "Evolution of water law and policy in India," in *The Evolution of the Law and Politics of Water*, Springer. pp. 159–175.

Dale, P.E.R. and Knight, J.M. (2008) "Wetlands and mosquitoes: a review," *Wetlands Ecology and Management*, 16(4), pp. 255–276.

Damania, R. *et al.* (2019) *Quality Unknown: The Invisible Water Crisis*. The World Bank. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/32245/9781464814594.pdf?sequence=8&isAllowed=y (Accessed: September 13, 2021).

Davies, A. (2021) "The coloniality of infrastructure: Engineering, landscape and modernity in Recife," *Environment and planning. D, Society & space*, 39(4), pp. 740–757.

Davis, J. *et al.* (2019) "Anthropocene, Capitalocene, … Plantationocene?: A Manifesto for Ecological Justice in an Age of Global Crises," *Geography Compass*, 13(5), p. e12438.

De Coss Corzo, J.A. (2019) "Waterworks: labour, infrastructure and the making of urban water in Mexico City." Available at: http://etheses.lse.ac.uk/4128/ (Accessed: March 1, 2021).

De Coss-Corzo, A. (2020) "Patchwork: Repair labor and the logic of infrastructure adaptation in Mexico City," *Environment and planning. D, Society & space*, p. 0263775820938057.

De Martis, G. *et al.* (2016) "Can Artificial Ecosystems Enhance Local Biodiversity? The Case of a Constructed Wetland in a Mediterranean Urban Context," *Environmental management*, 57(5), pp. 1088–1097.

Deacon, C. *et al.* (2021) "Patterns in macroinvertebrate taxonomic richness and community assembly among urban wetlands in Cape Town, South Africa: implications for wetland management," *Urban Ecosystems*, 24(5), pp. 1061–1072.

Deb, D. (2006) "Development against freedom and sustainability," *Capitalism Nature Socialism*, 17(3), pp. 49–70.

Deb Roy, R. (2017) *Malarial Subjects: Empire, Medicine and Nonhumans in British India, 1820–1909*. Cambridge, UK: Cambridge University Press.

DeLyser, D. (2010) *The SAGE Handbook of Qualitative Geography*. SAGE Publications.

Department of Environmental Quality (2016) *Bacteria: A naturally occurring phenomenon*. Michigan. Available at: https://www.michigan.gov/-/media/Project/Websites/egle/Documents/Programs/WRD/Inland-Lakes-and-Streams/Naturally-Occurring-Phenomenon-Bacteria.pdf.

Deshpande, R.S. and Shah, K. (2010) "Globalisation, agrarian crisis and farmers' suicides: Illusion and reality," in Deshpande, R.S. and Arora, S. (eds.) *Agrarian Crisis and Farmer Suicides*. New Delhi: Sage, pp. 118–148.

Despret, V. (2021) *Living as a Bird*. John Wiley & Sons.

Dharmadhikary, S. (2017) "Setting Environmental Standards: Comparing Processes in Thermal Power Plants in India, US, and EU," *Economic and Political Weekly* [Preprint].

Dittmer, J. (2010) “Textual and discourse analysis,” in *The SAGE Handbook of Qualitative Geography*. London: SAGE, pp. 274–286.

Doherty, J. (2019) “Filthy Flourishing: Para-Sites, Animal Infrastructure, and the Waste Frontier in Kampala,” *Current anthropology*, 60(S20), pp. S321–S332.

Doolittle, A. (2015) “The best of many worlds: methodological pluralism in political ecology,” in Bryant, R.L. (ed.) *The International Handbook of Political Ecology*. Edward Elgar, pp. 515–529.

Douglas, M. (1966) *Purity and danger: An analysis of concepts of pollution and taboo*. Routledge.

Dowling, R., Lloyd, K. and Suchet-Pearson, S. (2017) “Qualitative methods II: ‘More-than-human’ methodologies and/in praxis,” *Progress in human geography*, 41(6), pp. 823–831.

Dugatkin, L.A. (2019) “Buffon, Jefferson and the theory of New World degeneracy,” *Evolution: Education and Outreach*, 12(1), pp. 1–8.

Durand, L. and Sundberg, J. (2022) “Monster plants: the vegetal political ecology of Lacandonia schismatica,” *Journal of Political Ecology*, 29(1). doi:10.2458/jpe.2399.

Durant, A.C. and Donini, A. (2019) “Development of Aedes aegypti (Diptera: Culicidae) mosquito larvae in high ammonia sewage in septic tanks causes alterations in ammonia excretion, ammonia transporter expression, and osmoregulation,” *Scientific reports*, 9(1), p. 19028.

Easterling, K. (2014) *Extrastatecraft: The Power of Infrastructure Space*. Verso Books.

Eckburg, P.B. *et al.* (2005) “Diversity of the human intestinal microbial flora,” *Science*, 308(5728), pp. 1635–1638.

van der Eerden, L.J.M. (1982) “Toxicity of ammonia to plants,” *Agriculture and Environment*, 7(3), pp. 223–235.

Ellis, R. *et al.* (2020) *Decentralised Wastewater Treatment: Sustainable Innovation for Rural Communities*. James Hutton Institute.

van Elsas, J.D. *et al.* (2011) “Survival of Escherichia coli in the environment: fundamental and public health aspects,” *The ISME journal*, 5(2), pp. 173–183.

zu Ermgassen, S.O.S.E. *et al.* (2021) “Exploring the ecological outcomes of mandatory biodiversity net gain using evidence from early-adopter jurisdictions in England,” *Conservation letters*, 14(6). doi:10.1111/conl.12820.

Escobar, A. (1998) “Whose Knowledge, Whose nature? Biodiversity, Conservation, and the Political Ecology of Social Movements,” *Journal of Political Ecology*, 5(1), pp. 53–82.

Estes, N. (2019) *Our History Is the Future: Standing Rock Versus the Dakota Access Pipeline, and the Long Tradition of Indigenous Resistance*. Verso Books.

Evans, B. and Reid, J. (2015) “Exhausted by resilience: response to the commentaries,” *Resilience*, 3(2), pp. 154–159.

Faeth, S.H., Bang, C. and Saari, S. (2011) “Urban biodiversity: patterns and mechanisms,” *Annals of the New York Academy of Sciences*, 1223, pp. 69–81.

Fairley, W. (1895) “The Main Drainage and Sewage-Disposal of Edinburgh,” *Minutes of the Proceedings of the Institution of Civil Engineers*, 121, pp. 226–238.

Fang, J. *et al.* (2019) "Effects of emergent aquatic plants on nitrogen transformation processes and related microorganisms in a constructed wetland in northern China," *Plant and soil*, 443(1), pp. 473–492.

Fang, W.-T. *et al.* (2020) "Clustered Constructed Wetland Systems in Metropolitan Taipei," *Wetland Science and Practice*, 37(2), pp. 96–107.

Faulwetter, J.L. *et al.* (2009) "Microbial processes influencing performance of treatment wetlands: A review," *Ecological engineering*, 35(6), pp. 987–1004.

Fine, M. (2006) "Bearing Witness: Methods for Researching Oppression and Resistance—A Textbook for Critical Research," *Social justice research*, 19(1), pp. 83–108.

Fischer, H.W. and Ali, S.S. (2019) "Reshaping the public domain: Decentralization, the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), and trajectories of local democracy in rural India," *World development*, 120, pp. 147–158.

Flaminio, S., Rouillé-Kielo, G. and Le Visage, S. (2022) "Waterscapes and hydrosocial territories: Thinking space in political ecologies of water," *Progress in Environmental Geography*, pp. 1–25.

Fleming, J. (2017) "Toward vegetal political ecology: Kyrgyzstan's walnut–fruit forest and the politics of graftability," *Geoforum; journal of physical, human, and regional geosciences*, 79, pp. 26–35.

Food and Agriculture Organisation (no date) *Canna Lilly, Ecocrop*. Available at: http://ecocrop.fao.org/ecocrop/srv/en/cropView?id=2228 (Accessed: March 26, 2019).

Forsyth, T. (2008) "Political ecology and the epistemology of social justice," *Geoforum; journal of physical, human, and regional geosciences*, 39(2), pp. 756–764.

Foucault, M. (1972) *The Archaeology of Knowledge*. Pantheon Books.

Foucault, M., Davidson, A.I. and Burchell, G. (2008) *The Birth of Biopolitics: Lectures at the Collège de France, 1978-1979*. Springer.

Fraser, N. (2010) "Who counts? Dilemmas of justice in a postwestphalian world," *Antipode*, 41, pp. 281–297.

Freeman, B.G., Tobias, J.A. and Schluter, D. (2019) "Behavior influences range limits and patterns of coexistence across an elevational gradient in tropical birds," *Ecography*, 42(11), pp. 1832–1840.

French, A. (2019) "Webs and Flows: Socionatural Networks and the Matter of Nature at Peru's Lake Parón," *Annals of the Association of American Geographers. Association of American Geographers*, 109(1), pp. 142–160.

Friedrichsen, C.N. *et al.* (2020) "Impact of mental models on constructed wetland maintenance in semi-arid India," *Water Practice and Technology*, 15(4), pp. 1144–1157.

Furniss, T.J., Larson, A.J. and Lutz, J.A. (2017) "Reconciling niches and neutrality in a subalpine temperate forest," *Ecosphere* , 8(6), p. e01847.

Gabrys, J. (2012) "Becoming Urban: Sitework from a Moss-Eye View," *Environment & planning A*, 44(12), pp. 2922–2939.

Gabrys, J. (2018) "Sensing Lichens," *Third Text*, 32(2–3), pp. 350–367.

Gan, E., Tsing, A. and Sullivan, D. (2018) “Using Natural History in the Study of Industrial Ruins,” *Journal of Ethnobiology*, 38(1), pp. 39–54.

Gandhi, J.K., Tatu, K. and Kamboj, R.D. (2018) “A Review of Studies on Bacterial and Fungal Diversity in Wetland Ecosystems,” *Research & Reviews: A Journal of Microbiology and Virology*, 8(1), pp. 25–38.

Gandy, M. (2008) “Landscapes of Disaster: Water, Modernity, and Urban Fragmentation in Mumbai,” *Environment & planning A*, 40(1), pp. 108–130.

Gandy, M. (2013) “Marginalia: Aesthetics, Ecology, and Urban Wastelands,” *Annals of the Association of American Geographers. Association of American Geographers*, 103(6), pp. 1301–1316.

Gandy, M. (2014) *The Fabric of Space: Water, Modernity, and the Urban Imagination*. MIT Press.

Gandy, M. (2019) “The fly that tried to save the world: Saproxylic geographies and other-than-human ecologies,” *Transactions of the Institute of British Geographers*, 44(2), pp. 392–406.

Gandy, M. (2022a) “Ghosts and monsters: Reconstructing nature on the site of the Berlin Wall,” *Transactions* [Preprint]. doi:10.1111/tran.12562.

Gandy, M. (2022b) “Urban political ecology: a critical reconfiguration,” *Progress in human geography*, 46(1), pp. 21–43.

Gardner, T.A. *et al.* (2009) “Prospects for tropical forest biodiversity in a human-modified world,” *Ecology letters*, 12(6), pp. 561–582.

Garlick, B. (2019) “Cultural geographies of extinction: Animal culture among Scottish ospreys,” *Transactions* , 44(2), pp. 226–241.

Gearey, M., Church, A. and Ravenscroft, N. (2020) *English Wetlands: Spaces of nature, culture, imagination*. Springer International Publishing.

Geiger, M. and Hovorka, A.J. (2015) “Animal performativity: Exploring the lives of donkeys in Botswana,” *Environment and planning. D, Society & space*, 33(6), pp. 1098–1117.

Ghosh, D. (2005) *Ecology and traditional wetland practice: lessons from wastewater utilisation in the East Calcutta Wetlands*. Worldview.

Ghosh, D. (2014) *Ecosystem management: towards merging theory and practice*. Nimby Books.

Ghosh, D. and Sen, S. (1987) “Ecological History of Calcutta’s Wetland Conversion,” *Environmental Conservation*, 14(3). Available at: http://dhrubajyoti.net/publ/East%20Calcutta%20Wetland_1.pdf.

Ghosh, S. (2018) “Wastewater-Fed Aquaculture in East Kolkata Wetlands: State of the Art and Measures to Protect Biodiversity,” in Jana, B.B., Mandal, R.N., and Jayasankar, P. (eds.) *Wastewater Management Through Aquaculture*. Singapore: Springer Singapore, pp. 119–137.

Ghosh, S.K. and Rahi, M. (2019) “Malaria elimination in India-The way forward,” *Journal of vector borne diseases*, 56(1), pp. 32–40.

Gibb, C. (2018) “A critical analysis of vulnerability,” *International Journal of Disaster Risk Reduction*, 28, pp. 327–334.

Gill, F.B. (2007) *Ornithology*. Third. New York: W H Freeman.

Ginn, F. (2014) "Sticky lives: slugs, detachment and more-than-human ethics in the garden," *Transactions of the Institute of British Geographers*, 39(4), pp. 532–544.

Ginn, F., Beisel, U. and Barua, M. (2014) "Flourishing with awkward creatures: Togetherness, vulnerability, killing," *Environmental Humanities*, 4(1), pp. 113–123.

Giraud, E.H. (2019) *What Comes after Entanglement?: Activism, Anthropocentrism, and an Ethics of Exclusion*. Durham, NC: Duke University Press.

Gomez, B. and Jones, J.P., Iii (2010) *Research Methods in Geography: A Critical Introduction*. John Wiley & Sons.

Gondhalekar, D. and Drewes, J.E. (2021) "Infrastructure Shaming and Consequences for Management of Urban WEF Security Nexus in China and India," *WATER*, 13(3), p. 267.

Gorostiza, S. and Sauri, D. (2017) "Dangerous assemblages: Salts, trihalomethanes and endocrine disruptors in the water palimpsest of the Llobregat River, Catalonia," *Geoforum; journal of physical, human, and regional geosciences*, 81, pp. 153–162.

Götz, J.M. and Middleton, C. (2020) "Ontological politics of hydrosocial territories in the Salween River basin, Myanmar/Burma," *Political geography*, 78, p. 102115.

Goyal, V.C. *et al.* (2020) "Ecological health and water quality of village ponds in the subtropics limiting their use for water supply and groundwater recharge," *Journal of environmental management*, 277, p. 111450.

Goyal, V.C. and Singh, O. (2018) *Water Conservation and Management in a Village of Haridwar District (Uttarakhand)*. National Institute of Hydrology.

Graeber, D. (2013) "It is value that brings universes into being," *HAU: Journal of Ethnographic Theory*, 3(2), pp. 219–243.

Gramaglia, C. and Mélard, F. (2019) "Looking for the Cosmopolitical Fish: Monitoring Marine Pollution with Anglers and Congers in the Gulf of Fos, Southern France," *Science, technology & human values*, 44(5), pp. 814–842.

Gramaglia, C. and Sampaio da Silva, D. (2012) "Researching water quality with non-humans. An ANT account," in Passoth, J.-H., Peuker, B., and Schillmeie, M. (eds.) *Agency without Actors? New Approaches to Collective Action*,. London: Routledge.

Grebenshchykova, Z. *et al.* (2020) "Establishment and potential use of woody species in treatment wetlands," *International journal of phytoremediation*, 22(3), pp. 295–304.

Greenway, M., Dale, P. and Chapman, H. (2003) "An assessment of mosquito breeding and control in four surface flow wetlands in tropical-subtropical Australia," *Water science and technology: a journal of the International Association on Water Pollution Research*, 48(5), pp. 249–256.

Gregson, N. *et al.* (2015) "Interrogating the circular economy: the moral economy of resource recovery in the EU," *Economy and society*, 44(2), pp. 218–243.

Guest, G., Bunce, A. and Johnson, L. (2006) "How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability," *Field methods*, 18(1), pp. 59–82.

HACH (2015) *Oxygen Demand, Biochemical*. Available at: https://uk.hach.com/asset-get.download.jsa?id=7639984157.

Haddaway, N.R. *et al.* (2019) "What ecotechnologies exist for recycling carbon and nutrients from domestic wastewater? A systematic map protocol," *Environmental Evidence*, 8(1), p. 1.

Hall, M. and Tamïr, D. (eds.) (2022) *Mosquitopia: The Place of Pests in a Healthy World*. Taylor & Francis.

Hamlin, C. (1990) *A Science of Impurity: Water Analysis in Nineteenth Century Britain*. University of California Press.

Hammer, M.J. (2013) *Water and wastewater technology*. 7th ed. London, England: Pearson Education.

Hanson, A.-M. and Buechler, S. (2015) "Towards a feminist political ecology of women, global change, and vulnerable waterscapes," in Hanson, A.-M. and Buechler, S. (eds.) *A Political Ecology of Women, Water and Global Environmental Change*. Abingdon: Taylor and Francis.

Haraway, D. (1991) *Simians, cyborgs, and women*. Routledge.

Haraway, D.J. (1988) "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective," *Feminist studies*, 14(3), pp. 575–599.

Haraway, D.J. (2008) *When Species Meet*. Minneapolis, MN: University of Minnesota Press.

Haraway, D.J. (2016) *Staying with the Trouble: Making Kin in the Chthulucene*. Durham, NC: Duke University Press.

Hardiman, D. (1998) "Well Irrigation in Gujarat: Systems of Use, Hierarchies of Control," *Economic and political weekly*, 33(25), pp. 1533–1544.

Harpole, W. (2010) *Neutral Theory of Species Diversity*. Available at: https://www.nature.com/scitable/knowledge/library/neutral-theory-of-species-diversity-13259703/ (Accessed: June 17, 2022).

Harris, L. *et al.* (2016) *Water justice: Key concepts, debates and research agendas*. Available at: https://open.library.ubc.ca/collections/facultyresearchandpublications/52383/items/1.0347545.

Harris-Lovett, S., Lienert, J. and Sedlak, D.L. (2018) "Towards a New Paradigm of Urban Water Infrastructure: Identifying Goals and Strategies to Support Multi-Benefit Municipal Wastewater Treatment," *WATER*, 10(9), p. 1127.

Hawkes, F.M. and Hopkins, R.J. (2022) "The mosquito: An introduction," in Hall, M. and Tamïr, D. (eds.) *Mosquitopia: The Place of Pests in a Healthy World*. Taylor and Francis.

Hayward, M.W. and Kerley, G.I.H. (2009) "Fencing for conservation: Restriction of evolutionary potential or a riposte to threatening processes?," *Biological conservation*, 142(1), pp. 1–13.

Head, L. *et al.* (2014) "Vegetal politics: belonging, practices and places," *Social & Cultural Geography*, 15(8), pp. 861–870.

Head, L. and Atchison, J. (2009) "Cultural ecology: emerging human-plant geographies," *Progress in human geography*, 33(2), pp. 236–245.

Head, L., Atchison, J. and Phillips, C. (2015) "The distinctive capacities of plants: re-thinking difference via invasive species," *Transactions* , 40(3), pp. 399–413.

Headley, T.R. and Kadlec, R.H. (2007) "Conducting hydraulic tracer studies of constructed wetlands: a practical guide," *Ecohydrology & Hydrobiology*, 7(3), pp. 269–282.

Heffernan, M. (2008) “Histories of geography,” in Valentine, G. et al. (eds.) *Key Concepts in Geography*. UK: Sage.

Helmreich, S. (2015) *Sounding the limits of life: Essays in the anthropology of biology and beyond*. Princeton, NJ: Princeton University Press (Princeton Studies in Culture and Technology, 7).

Hering, D. *et al.* (2010) “The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future,” *The Science of the total environment*, 408(19), pp. 4007–4019.

Hetherington, K. (ed.) (2019) *Infrastructure, Environment, and Life in the Anthropocene*. Duke University Press (Experimental Futures).

Heynen, N., Kaika, M. and Swyngedouw, E. (2006) “Urban political ecology: politicizing the production of urban natures,” in Heynen, N., Kaika, M., and Swyngedouw, E. (eds.) *In the Nature of Cities: Urban Political Ecology and the Politics of Urban Metabolism*. Taylor and Francis, pp. 1–20.

Hickey, S. and Mohan, G. (2004) *Participation--From Tyranny to Transformation?: Exploring New Approaches to Participation in Development*. Zed Books.

Hinchliffe, S. and Whatmore, S. (2006) “Living cities: Towards a politics of conviviality,” *Science as culture*, 15(2), pp. 123–138.

Hitchings, R. and Latham, A. (2020) “Qualitative methods II: On the presentation of ‘geographical ethnography,’” *Progress in human geography*, 44(5), pp. 972–980.

Hodgetts, T. and Lorimer, J. (2015) “Methodologies for animals’ geographies: cultures, communication and genomics,” *cultural geographies*, 22(2), pp. 285–295.

Holden, P. and Gregory, R. (2021) *RSPB Handbook of British Birds: Fifth edition*. Bloomsbury Publishing.

Holmberg, T. (2021) “Animal waste work. The case of urban sewage management in Sweden,” *Contemporary Social Science*, 16(1), pp. 14–28.

Houston, D. *et al.* (2018) “Make kin, not cities! Multispecies entanglements and ‘becoming-world’ in planning theory,” *Planning Theory*, 17(2), pp. 190–212.

Hu, B. *et al.* (2021) “Employ of arbuscular mycorrhizal fungi for pharmaceuticals ibuprofen and diclofenac removal in mesocosm-scale constructed wetlands,” *Journal of hazardous materials*, 409, p. 124524.

Hu, G. *et al.* (2016) “Mass seasonal bioflows of high-flying insect migrants,” *Science*, 354(6319), pp. 1584–1587.

Hubbell, S.P. (2001) *The Unified Neutral Theory of Biodiversity and Biogeography (MPB-32)*. Princeton University Press.

Hustak, C. and Myers, N. (2012) “Involutionary momentum: Affective ecologies and the sciences of plant/insect encounters,” *Differences*, 23(3), pp. 74–118.

Hutchings, P. (2018) “Community Management or Coproduction? The Role of State and Citizens in Rural Water Service Delivery in India,” *Water Alternatives*, 11(2), pp. 357–374.

Imperial Gazetteer of India (1909) *Imperial Gazetteer of India*. Oxford: Clarendon Press.

Ingold, T. (2011) *Being Alive: Essays on movement, knowledge and description*. Abingdon: Routledge.

Ingold, T. (2017) "Anthropology contra ethnography," *HAU: Journal of Ethnographic Theory*, 7(1), pp. 21–26.

International development (no date) *Scottish Government*. Available at: https://www.gov.scot/policies/international-development/ (Accessed: April 20, 2022).

Irwin, R.E. *et al.* (2010) "Nectar Robbing: Ecological and Evolutionary Perspectives," *Annual review of ecology, evolution, and systematics*, 41(1), pp. 271–292.

Jackson, S. (2018) "Indigenous Peoples and Water Justice in a Globalizing World," in *The Oxford Handbook of Water Politics and Policy*. Oxford: Oxford University Press.

Jamwal, P. *et al.* (2021) "Evaluating the performance of horizontal sub-surface flow constructed wetlands: A case study from southern India," *Ecological engineering*, 162, p. 106170.

Jang, J. *et al.* (2017) "Environmental Escherichia coli: ecology and public health implications-a review," *Journal of applied microbiology*, 123(3), pp. 570–581.

Jasanoff, S. (2004) "The idiom of co-production," in Jasanoff, S. (ed.) *States of knowledge: The co-production of science and social order*. London: Routledge, pp. 1–12.

Jasanoff, S. and Kim, S.-H. (2015) *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*. University of Chicago Press.

Jegathesan, M. (2021) "Black feminist plots before the plantationocene and anthropology's 'regional closets,'" *Feminist Anthropology*, 2(1), pp. 78–93.

Jewitt, S. (2011) "Geographies of shit: Spatial and temporal variations in attitudes towards human waste," *Progress in human geography*, 35(5), pp. 608–626.

Johnson, E.R. (2017) "At the limits of species being: Sensing the anthropocene," *The South Atlantic quarterly*, 116(2), pp. 275–292.

Joronen, M. and Rose, M. (2021) "Vulnerability and its politics: Precarity and the woundedness of power," *Progress in human geography*, 45(6), pp. 1402–1418.

Jouanneau, S. *et al.* (2014) "Methods for assessing biochemical oxygen demand (BOD): a review," *Water research*, 49, pp. 62–82.

Kadlec, R.H. (2000) "The inadequacy of first-order treatment wetland models," *Ecological engineering*, 15(1), pp. 105–119.

Kadlec, R.H. and Wallace, S. (2008) *Treatment wetlands*. Boca Raton, FL: CRC press.

Kala, C.P. (2014) "Deluge, disaster and development in Uttarakhand Himalayan region of India: Challenges and lessons for disaster management," *International Journal of Disaster Risk Reduction*, 8, pp. 143–152.

Kamath, A. and Wesner, A.B. (2020) "Animal territoriality, property and access: a collaborative exchange between animal behaviour and the social sciences," *Animal behaviour*, 164, pp. 233–239.

Kanngieser, A. and Todd, Z. (2020) "3. From environmental case study to environmental kin study," *History and theory*, 59(3), pp. 385–393.

Karpouzoglou, T. (2012) *'Our power rests in numbers' The role of expert-led policy processes in addressing water quality: the case of peri-urban areas in the national capital region of Delhi, India*. University of Sussex. Available at: http://sro.sussex.ac.uk/id/eprint/43304/1/Karpouzoglou%2C_Timothy.pdf.

Karpouzoglou, T. and Vij, S. (2017) "Waterscape: a perspective for understanding the contested geography of water," *Wiley Interdisciplinary Reviews: Water*, 4(3), p. e1210.

Karpouzoglou, T. and Zimmer, A. (2016) "Ways of knowing the wastewaterscape: Urban political ecology and the politics of wastewater in Delhi, India," *Habitat international*, 54, pp. 150–160.

Kataki, S. *et al.* (2021) "Constructed wetland, an eco-technology for wastewater treatment: A review on types of wastewater treated and components of the technology (macrophyte, biolfilm and substrate)," *Journal of environmental management*, 283, p. 111986.

Keeling, A. (2005) "Urban Waste Sinks as a Natural Resource: The Case of the Fraser River," *Urban history review. Revue d'histoire urbaine*, 34(1), pp. 58–70.

Keilsohn, W., Narango, D.L. and Tallamy, D.W. (2018) "Roadside habitat impacts insect traffic mortality," *Journal of insect conservation*, 22(2), pp. 183–188.

Kemerink-Seyoum, J.S. *et al.* (2019) "Attention to Sociotechnical Tinkering with Irrigation Infrastructure as a Way to Rethink Water Governance," *WATER*, 11(8), p. 1670.

Khalili, L. (2021) *Apocalyptic Infrastructures*, *Noema*. Available at: https://www.noemamag.com/apocalyptic-infrastructures/ (Accessed: September 10, 2021).

Kingsford, R.T. (2000) "Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia," *Austral ecology*, 25(2), pp. 109–127.

Kirksey, E. (2020) "Chemosociality in Multispecies Worlds," *Environmental Humanities*, 12(1), pp. 23–50.

Kirsop-Taylor, N. and Russel, D. (2022) "Agencies navigating the political at the science-to-policy interface for nature-based solutions," *Environmental science & policy*, 127, pp. 303–310.

Kivaisi, A.K. (2001) "The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review," *Ecological engineering*, 16(4), pp. 545–560.

Klein, J.T. (2014) "Discourses of transdisciplinarity: Looking Back to the Future," *Futures*, 63, pp. 68–74.

Kneitz, A. (2012) "Polluted Water," in Kneitz, A. and Landry, M. (eds.) *On Water: Perceptions, Politics, Perils*. (RCC Perspectives), pp. 71–76.

Knight, R.L. *et al.* (2003) "Strategies for effective mosquito control in constructed treatment wetlands," *Ecological engineering*, 21(4), pp. 211–232.

Kochhar, R. (2020) "The virus in the rivers: histories and antibiotic afterlives of the bacteriophage at the sangam in Allahabad," *Notes and records of the Royal Society of London*, 74(4), pp. 625–651.

Konnerup, D., Koottatep, T. and Brix, H. (2009) "Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with Canna and Heliconia," *Ecological engineering*, 35(2), pp. 248–257.

Krause, F. and Strang, V. (2016) "Thinking Relationships Through Water," *Society & natural resources*, 29(6), pp. 633–638.

Krueger, T. *et al.* (2016) "A transdisciplinary account of water research," *WIREs. Water*, 3(3), pp. 369–389.

Kumar, J.L.G. and Zhao, Y.Q. (2011) "A review on numerous modeling approaches for effective, economical and ecological treatment wetlands," *Journal of environmental management*, 92(3), pp. 400–406.

Kumar, Paritosh *et al.* (2020) "Chromium removal efficiency of plant, microbe and media in experimental VSSF constructed wetlands under monocropped and co-cropped conditions," *Environmental science and pollution research international*, 27(2), pp. 2071–2086.

L. Collins, S. *et al.* (2020) "Groundwater connectivity of a sheared gneiss aquifer in the Cauvery River basin, India," *Hydrogeology journal*, 28(4), pp. 1371–1388.

Laborde, S. and Jackson, S. (2022) "Living Waters or Resource? Ontological differences and the governance of waters and rivers," *Local Environment*, 27(3), pp. 357–374.

LaDuke, W. and Cowen, D. (2020) "Beyond Wiindigo infrastructure," *The South Atlantic quarterly*, 119(2), pp. 243–268.

de Laet, M. and Mol, A. (2000) "The Zimbabwe Bush Pump: Mechanics of a Fluid Technology," *Social studies of science*, 30(2), pp. 225–263.

Lamers, L.P.M. *et al.* (2012) "Microbial transformations of nitrogen, sulfur, and iron dictate vegetation composition in wetlands: a review," *Frontiers in microbiology*, 3, p. 156.

Larkin, B. (2013) "The Politics and Poetics of Infrastructure," *Annual review of anthropology*, 42(1), pp. 327–343.

Latour, B. (1987) *Science in Action: How to Follow Scientists and Engineers Through Society*. Harvard University Press.

Lave, R. *et al.* (2014) "Intervention: Critical physical geography," *The Canadian geographer. Geographe canadien*, 58(1), pp. 1–10.

Lave, R. (2015) "Reassembling the Structural: Political ecology and Actor-Network Theory," in Perreault, T., Bridge, G., and McCarthy, J. (eds.) *The Routledge Handbook of Political Ecology*. Routledge.

Lave, R., Biermann, C. and Lane, S.N. (eds.) (2018) *The Palgrave Handbook of Critical Physical Geography*. London: Palgrave.

Law, J. (2019) "Material semiotics" [Preprint]. Available at: http://www.heterogeneities.net/publications/Law2019MaterialSemiotics.pdf.

Lawrence, A.M. (2022) "Listening to plants: Conversations between critical plant studies and vegetal geography," *Progress in human geography*, 46(2), pp. 629–651.

Lefebvre, H. (1991) *The production of space*. Blackwell.

Lekshmi, B. *et al.* (2020) "Enhancement of Water Reuse by Treating Wastewater in Constructed Wetlands: Minimization of Nutrients and Fecal Coliform," in *Sustainable Environmental Geotechnics*. Springer International Publishing, pp. 213–223.

Lele, S. *et al.* (2013) "Ecosystem Services: Origins, Contributions, Pitfalls, and Alternatives," *Conservation and Society*, 11(4), p. 343.

Lele, S., Jamwal, P. and Mahesh, M. (2021) "Challenges in Regulating Water Pollution in India: Standards, Monitoring, Enforcement and Accountability," *Economic and Political Weekly* [Preprint].

Lemke, T. (2018) "An Alternative Model of Politics? Prospects and Problems of Jane Bennett's Vital Materialism," *Theory, Culture & Society*, 35(6), pp. 31–54.

Leonardelli, I., Kemerink-Seyoum, J. and Zwarteveen, M. (2022) "Obliqueness as a feminist mode of analysing waterscapes: Learning to think with overflows," *Environment and Planning E: Nature and Space*, p. 25148486221117724.

Levain, A. *et al.* (2020) "Green out of the blue, or how (not) to deal with overfed oceans," *Environment and society*, 11(1), pp. 115–142.

Levins, R. and Lewontin, R.C. (1985) *The Dialectical Biologist*. Harvard University Press.

Lewis, J.A. and Ernstson, H. (2019) "Contesting the coast: Ecosystems as infrastructure in the Mississippi River Delta," *Progress in planning*, 129, pp. 1–30.

Li, L., Zheng, B. and Liu, L. (2010) "Biomonitoring and Bioindicators Used for River Ecosystems: Definitions, Approaches and Trends," *Procedia Environmental Sciences*, 2, pp. 1510–1524.

Li, T.M. (2005) "Beyond 'the state' and failed schemes," *American anthropologist*, 107(3), pp. 383–394.

Li, T.M. (2007) *The Will to Improve: Governmentality, Development, and the Practice of Politics*. Duke University Press.

Li, T.M. (2015) "Governing rural Indonesia: convergence on the project system," *Critical Policy Studies*, 10(1), pp. 79–94.

Li, T.M. (2019) "Politics, Interrupted," *Anthropological Theory*, 19(1), pp. 29–53.

Liamputtong, P. (2011) *Focus Group Methodology: Principles and Practice*. London: SAGE.

Liboiron, M. (2021) *Pollution Is Colonialism*. Duke University Press.

Liboiron, M. and Lepawsky, J. (2022) *Discard Studies: Wasting, Systems, and Power*. MIT Press.

Liboiron, M., Tironi, M. and Calvillo, N. (2018) "Toxic politics: Acting in a permanently polluted world," *Social studies of science*, 48(3), pp. 331–349.

Lien, M.E. and Law, J. (2011) "'Emergent Aliens': On Salmon, Nature, and Their Enactment," *Ethnos*, 76(1), pp. 65–87.

Linton, J. (2010) *What Is Water?: The History of a Modern Abstraction*. UBC Press.

Linton, J. (2014) "Modern water and its discontents: a history of hydrosocial renewal," *Wiley Interdisciplinary Reviews: Water*, 1(1), pp. 111–120.

Linton, J. and Budds, J. (2014) "The hydrosocial cycle: Defining and mobilizing a relational-dialectical approach to water," *Geoforum; journal of physical, human, and regional geosciences*, 57, pp. 170–180.

Linton, J. and Krueger, T. (2020) "The ontological fallacy of the Water Framework Directive: Implications and alternatives," *Water alternatives*, 13(3), p. 513.

Liquete, C. *et al*. (2016) "Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits," *Ecosystem Services*, 22, pp. 392–401.

Locke, P. and Munster, U. (2015) *Multispecies ethnography*. Oxford University Press Oxford.

Loreau, M. (2010) "Linking biodiversity and ecosystems: towards a unifying ecological theory," *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 365(1537), pp. 49–60.

Lorimer, J. (2008) "Living Roofs and Brownfield Wildlife: Towards a Fluid Biogeography of UK Nature Conservation," *Environment & planning A*, 40(9), pp. 2042–2060.

Lorimer, J. (2010) "Moving image methodologies for more-than-human geographies," *Cultural geographies*, 17(2), pp. 237–258.

Lorimer, J. (2015a) "Biodiversity as Biopolitics: Cutting Up Wildlife and Choreographing Conservation in the United Kingdom," in *Wildlife in the Anthropocene: Conservation after Nature*. University of Minnesota Press, pp. 57–76.

Lorimer, J. (2015b) "Introduction," in *Wildlife in the Anthropocene: Conservation after Nature*. University of Minnesota Press, pp. 1–18.

Lorimer, J., Hodgetts, T. and Barua, M. (2019) "Animals' atmospheres," *Progress in human geography*, 43(1), pp. 26–45.

Louca, S., Parfrey, L.W. and Doebeli, M. (2016) "Decoupling function and taxonomy in the global ocean microbiome," *Science*, 353(6305), pp. 1272–1277.

Lowe, C. (2006) *Wild profusion: Biodiversity conservation in an Indonesian archipelago*. Princeton, NJ: Princeton University Press (In-Formation).

Lucassen, J. (2006) "The Brickmakers' Strikes on the Ganges Canal in 1848 – 1849," *International review of social history / International Instituut voor Sociale Geschiedenis, Amsterdam*, 51(S14), pp. 47–83.

Lukes, S. (2004) *Power: A Radical View*. Macmillan International Higher Education.

Lulka, D. (2009) "The residual humanism of hybridity: retaining a sense of the earth," *Transactions of the Institute of British Geographers*, 34(3), pp. 378–393.

Luo, P. *et al*. (2019) "Nitrogen removal performance and needed area estimation of surface-flow constructed wetlands using a probabilistic approach," *Journal of environmental management*, 255, p. 109881.

Lyons, K. (2018) "Chemical warfare in Colombia, evidentiary ecologies and senti-actuando practices of justice," *Social studies of science*, 48(3), pp. 414–437.

Maiga, Y., von Sperling, M. and Mihelcic, J. (2017) "Constructed Wetlands," in Haas, C., Mihelcic, J.R., and Verbyla, M.E. (eds.) *Global Water Pathogens Project. Part 4: Management Of Risk from Excreta and Wastewater*. Michigan State University.

Man, Y. *et al*. (2020) "Responses of rhizosphere and bulk substrate microbiome to wastewater-borne sulfonamides in constructed wetlands with different plant species," *The Science of the total environment*, 706, p. 135955.

Mann, G. (2009) "Should political ecology be Marxist? A case for Gramsci's historical materialism," *Geoforum; journal of physical, human, and regional geosciences*, 40(3), pp. 335–344.

Marder, M. (2012) “Plant intentionality and the phenomenological framework of plant intelligence,” *Plant signaling & behavior*, 7(11), pp. 1365–1372.

Masi, F., Rizzo, A. and Regelsberger, M. (2018) “The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm,” *Journal of environmental management*, 216, pp. 275–284.

Massey, D.B. (2005) *For Space*. Thousand Oaks, CA: SAGE Publications.

Massoud, M.A., Tarhini, A. and Nasr, J.A. (2009) “Decentralized approaches to wastewater treatment and management: applicability in developing countries,” *Journal of environmental management*, 90(1), pp. 652–659.

Mateer, J.C.D. (2017) *Neoliberal water management in Northwestern India: impacts and experiences of the shifting hydro-social cycle*. PhD. University of Victoria. Available at: http://dspace.library.uvic.ca/handle/1828/8448.

Mattissek, A. (2018) “Geographic Methods: Discourse Analysis.” doi:10.1093/obo/9780199874002-0179.

Maucieri, C., Salvato, M. and Borin, M. (2020) “Vegetation contribution on phosphorus removal in constructed wetlands,” *Ecological engineering*, 152, p. 105853.

McFarlane, C. (2008) “Governing the Contaminated City: Infrastructure and Sanitation in Colonial and Post-Colonial Bombay,” *International journal of urban and regional research*, 32(2), pp. 415–435.

McFarlane, C. (2012) “From sanitation inequality to malevolent urbanism: The normalisation of suffering in Mumbai,” *Geoforum; journal of physical, human, and regional geosciences*, 43(6), pp. 1287–1290.

McFarlane, C. (2019) “The urbanization of the sanitation crisis: Placing waste in the city,” *Development and change*, 50(5), pp. 1239–1262.

McGregor, D. (2009) “Honouring Our Relations: An Anishnaabe Perspective on Environmental Justice,” in Agyeman, J. et al. (eds.) *Speaking for Ourselves: Environmental Justice in Canada*. University of British Columbia Press.

McKenzie, M. and Tuck, E. (2016) *Place in research: theory, methodology, and methods*. Routledge (Routledge advances in research methods).

McKittrick, K. (2013) “Plantation Futures,” *Small Axe: A Caribbean Journal of Criticism*, 17(3), pp. 1–15.

McLean, D. (2014) “Lost Edinburgh: The Nor’ Loch,” *The Scotsman*, 27 January. Available at: https://www.scotsman.com/arts-and-culture/lost-edinburgh-nor-loch-1546742 (Accessed: August 26, 2022).

Meehan, K.M. (2014) “Tool-power: Water infrastructure as wellsprings of state power,” *Geoforum; journal of physical, human, and regional geosciences*, 57, pp. 215–224.

Meerow, S. (2020) “The politics of multifunctional green infrastructure planning in New York City,” *Cities* , 100, p. 102621.

Mehta, K. (2003) “Contexts and Constructions of Water Scarcity,” *Economic and political weekly*, 38(48), pp. 5066–5072.

Mehta, L. (2005) *The Politics and Poetics of Water: The Naturalisation of Scarcity in Western India*. Hyderabad: Orient Blackswan.

Mehta, L., Huff, A. and Allouche, J. (2019) "The new politics and geographies of scarcity," *Geoforum; journal of physical, human, and regional geosciences*, 101, pp. 222–230.

Meng, P. *et al.* (2014) "How to increase microbial degradation in constructed wetlands: influencing factors and improvement measures," *Bioresource technology*, 157, pp. 316–326.

Mesa, B. *et al.* (2014) *Searching for success in community management for rural water supplies over 30 years*. Cranfield University.

Millar, K.M. (2017) "Toward a critical politics of precarity," *Sociology compass*, 11(6), p. e12483.

Mishra, A. (1993) *Aaj Bhi Khare Hain Talab (The Ponds are Still Relevant)*. Delhi: Prabhat Prakashan.

Misra, M. (2021) "How Can Delhi Tackle High Ammonia Content In Its Drinking Water?," *SANDRP*, 25 January. Available at: https://sandrp.in/2021/01/25/how-can-delhi-tackle-high-ammonia-content-in-its-drinking-water/ (Accessed: January 25, 2021).

Mitchell, A. (2016) "Beyond Biodiversity and Species: Problematizing Extinction," *Theory, Culture & Society*, 33(5), pp. 23–42.

Mitchell, T. (2002) *Rule of Experts: Egypt, Techno-Politics, Modernity*. University of California Press.

Mitsch, W.J. (2012) "What is ecological engineering?," *Ecological engineering*, 45, pp. 5–12.

Mohapatra, B. *et al.* (2011) "Snakebite mortality in India: a nationally representative mortality survey," *PLoS neglected tropical diseases*, 5(4), p. e1018.

Moi, D.A. *et al.* (2020) "Intermediate Disturbance Hypothesis in Ecology: A Literature Review," *Annales Zoologici Fennici*, 57(1–6), pp. 67–78.

Mollinga, P.P. (2020) "Knowledge, context and problemsheds: a critical realist method for interdisciplinary water studies," *Water International*, 45(5), pp. 388–415.

Moore, J. (2015) *Capitalism in the Web of Life: Ecology and the Accumulation of Capital*. Verso Books.

Moore, J.C. (2013) "Diversity, Taxonomic versus Functional," in Levin, S.A. (ed.) *Encyclopedia of Biodiversity (Second Edition)*. Waltham: Academic Press, pp. 648–656.

Morita, A. (2017) "Multispecies Infrastructure: Infrastructural Inversion and Involutionary Entanglements in the Chao Phraya Delta, Thailand," *Ethnos*, 82(4), pp. 738–757.

Morris, E.K. *et al.* (2014) "Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories," *Ecology and evolution*, 4(18), pp. 3514–3524.

Mosse, D. (1999) "Colonial and contemporary ideologies of 'community management': the case of tank irrigation development in South India," *Modern Asian studies*, 33(2), pp. 303–338.

Mukherjee, J. (2020a) *Not a "wasted" enterprise: political ecologies of wastewater wetlands in Kolkata*, *Undisciplined Environments*. Available at: https://undisciplinedenvironments.org/2020/11/17/not-a-wasted-enterprise-political-ecologies-of-wastewater-wetlands-in-kolkata/ (Accessed: November 27, 2020).

Mukherjee, J. (2020b) "Untamed Practices," in Mukherjee, J. (ed.) *Blue Infrastructures: Natural History, Political Ecology and Urban Development in Kolkata*. Singapore: Springer Singapore, pp. 85–123.

Mukherjee, J. (2022) "'Living systems infrastructure' of Kolkata: exploring co-production of urban nature using historical urban political ecology (HUPE)," *Environment and urbanization*, 34(1), pp. 32–51.

Mukherji, A. (2006) "Political ecology of groundwater: The contrasting case of water-abundant West Bengal and water-scarce Gujarat, India," *Hydrogeology journal*, 14(3), pp. 392–406.

Murphy (2017) "What Can't a Body Do?," *Catalyst: Feminism, Theory, Technoscience*, 3(1), pp. 1–15.

Murphy, M. (2013) "Chemical Infrastructures of the St. Clair River," in Boudia, S. and Jas, N. (eds.) *Toxicants, Health and Regulation Since 1945*.

Murphy, M. (2017) "Alterlife and Decolonial Chemical Relations," *Cultural anthropology: journal of the Society for Cultural Anthropology*, 32(4), pp. 494–503.

Murray, C.G. and Hamilton, A.J. (2010) "REVIEW: Perspectives on wastewater treatment wetlands and waterbird conservation," *The Journal of applied ecology*, 47(5), pp. 976–985.

Muscatelli, A., McKee, E. and McGivern, S. (2020) "Scotland: a world-leading Hydro Nation," *International Journal of Water Resources Development*, 36(2–3), pp. 239–244.

Myers, N. (2017) "Photosynthetic Mattering: Rooting into the Planthroposcene," in Thorsen, L.M. (ed.) *Moving Plants*. Rønnebæksholm Press, pp. 123–129.

Nading, A. (2022) "Eradication against ambivalence," in Hall, M. and Tamïr, D. (eds.) *Mosquitopia*. Routledge, pp. 183–194.

Nading, A. and Fisher, J. (2020) "Family Trees," *Society and Space* [Magazine]. Available at: https://www.societyandspace.org/articles/family-trees (Accessed: February 18, 2021).

Narasimha Reddy, D. and Mishra, S. (2010) *Agrarian Crisis in India*. Oxford: Oxford University Press.

Narayanan, N. (2016) *Snake attacks in India are a real problem that no one is talking about*, *Scroll.in*. Scroll.in. Available at: https://scroll.in/article/804584/when-snakes-attack-india-has-a-huge-human-animal-conflict-problem-that-no-one-is-talking-about (Accessed: September 4, 2019).

Narayanan, Y. and Bindumadhav, S. (2019) "'Posthuman cosmopolitanism' for the Anthropocene in India: Urbanism and human-snake relations in the Kali Yuga," *Geoforum; journal of physical, human, and regional geosciences*, 106, pp. 402–410.

National Institute of Hydrology (2021) *Conservation of Ponds in Ibrahimpur-Masahi Village and Performance Evaluation of Natural Treatment System*. Roorkee, India: National Institute of Hydrology.

National Institute of Hydrology (no date) *Ministry of Jal Shakti*. Available at: http://jalshakti-dowr.gov.in/about-us/organisations/national-institute-hydrology (Accessed: July 26, 2022).

National Vector Borne Disease Control Program (2017) *National Strategic Plan: Malaria Elimination in India 2017-2022*. Government of India. Available at: https://nvbdcp.gov.in/WriteReadData/l892s/nsp_2017-2022.pdf.

Neimanis, A. (2013) "feminist subjectivity, watered," *Feminist review*, 103(1), pp. 23–41.

Neimanis, A. (2017) *Bodies of Water: Posthuman Feminist Phenomenology*. Bloomsbury Publishing.

Nelson, S.H. and Bigger, P. (2022) "Infrastructural nature," *Progress in human geography*, 46(1), pp. 86–107.

Neumann, R.P. (2004) "Moral and discursive geographies in the war for biodiversity in Africa," *Political geography*, 23(7), pp. 813–837.

Neville, K.J. and Coulthard, G. (2019) "Transformative water relations: Indigenous interventions in global political economies," *Global environmental politics*, 19(3), pp. 1–15.

Ngata, T. (2018) "Wai māori," in Joy, M. (ed.) *Mountains to Sea: Soliving New Zealand's Freshwater Crisis*. Auckland: Bridget Williams Books.

Nguyen, P.M. *et al.* (2019) "Removal of pharmaceuticals and personal care products using constructed wetlands: effective plant-bacteria synergism may enhance degradation efficiency," *Environmental science and pollution research international*, 26(21), pp. 21109–21126.

Nielsen, K.B. (no date) *Land, agriculture, and dispossession in India: A comparative look at the ongoing farmers' protests and the anti-SEZ movement*, *Terra Nullius: Repossessing the existent*. Available at: https://www.sum.uio.no/forskning/blogg/terra-nullius/kenneth-bo-nielsen/land-agriculture-and-dispossession-in-india.html (Accessed: June 29, 2021).

Nightingale, A. (2003) "A Feminist in the Forest: Situated Knowledges and Mixing Methods in Natural Resource Management," *ACME: An International Journal for Critical Geographies*, 2(1), pp. 77–90.

Niranjana R (2021) "Between fragments and ordering: Engineering water infrastructures in a postcolonial city," *Geoforum; journal of physical, human, and regional geosciences*, 119, pp. 1–10.

Nixon, R. (2011) *Slow Violence and the Environmentalism of the Poor*. Harvard University Press.

Nustad, K.G. and Swanson, H. (2022) "Political ecology and the Foucault effect: A need to diversify disciplinary approaches to ecological management?," *Environment and Planning E: Nature and Space*, 5(2), pp. 924–946.

Öberg, G. (2009) "Facilitating interdisciplinary work: using quality assessment to create common ground," *Higher Education*, 57(4), pp. 405–415.

ODA research and innovation and NERC (2016) *NERC*. Available at: https://webarchive.nationalarchives.gov.uk/ukgwa/20200427091246/https://nerc.ukri.org/press/releases/2016/32-oda/ (Accessed: April 20, 2022).

O'Gorman, E. (2021) *Wetlands in a Dry Land: More-Than-Human Histories of Australia's Murray-Darling Basin*. University of Washington Press.

Ouellet-Plamondon, C. *et al.* (2006) "Artificial aeration to increase pollutant removal efficiency of constructed wetlands in cold climate," *Ecological engineering*, 27(3), pp. 258–264.

Paasche, T.F. and Sidaway, J.D. (2010) "Transecting Security and Space in Maputo," *Environment & planning A*, 42(7), pp. 1555–1576.

Paavola, J. (2002) "Water quality as property: Industrial water pollution and common law in the nineteenth century United States," *Environment and history*, 8(3), pp. 295–318.

Park, K.J. and Cristinacce, A. (2006) "Use of sewage treatment works as foraging sites by insectivorous bats," *Animal conservation*, 9(3), pp. 259–268.

Parsons, M. *et al.* (2019) "Disrupting path dependency: Making room for Indigenous knowledge in river management," *Global environmental change: human and policy dimensions*, 56, pp. 95–113.

Parsons, M. and Fisher, K. (2021) "Historical smellscapes in Aotearoa New Zealand: Intersections between colonial knowledges of smell, race, and wetlands," *Journal of historical geography*, 74, pp. 28–43.

Patnaik, U. and Patnaik, P. (2021) *Capital and Imperialism: Theory, History, and the Present*. NYU Press.

Paxson, H. and Helmreich, S. (2014) "The perils and promises of microbial abundance: novel natures and model ecosystems, from artisanal cheese to alien seas," *Social studies of science*, 44(2), pp. 165–193.

Pedescoll, A. *et al.* (2009) "Practical method based on saturated hydraulic conductivity used to assess clogging in subsurface flow constructed wetlands," *Ecological engineering*, 35(8), pp. 1216–1224.

Peel, M.C. and McMahon, T.A. (2020) "Historical development of rainfall-runoff modeling," *WIREs. Water*, 7(5), p. e1471.

Pennekamp, F. *et al.* (2018) "Biodiversity increases and decreases ecosystem stability," *Nature*, 563(7729), pp. 109–112.

Perkins, H.A. (2007) "Ecologies of actor-networks and (non)social labor within the urban political economies of nature," *Geoforum; journal of physical, human, and regional geosciences*, 38(6), pp. 1152–1162.

Perreault, T., Boelens, R. and Vos, J. (2018a) "Conclusions: Struggles for Justice in a Changing Water World," in *Water Justice*. Cambridge University Press, pp. 346–360.

Perreault, T., Boelens, R. and Vos, J. (2018b) "Introduction: Governmentality, Discourses and Struggles over Imaginaries and Water Knowledge," in *Water Justice*. Cambridge University Press, pp. 276–282.

Perreault, T., Bridge, G. and McCarthy, J. (2015) *The Routledge Handbook of Political Ecology*. Edited by T. Perreault, G. Bridge, and J. McCarthy. Routledge.

Perth & Kinross Council (2014) "Perth & Kinross Council Local Development Plan." Available at: https://www.gov.scot/binaries/content/documents/govscot/publications/factsheet/2018/06/perth-and-kinross-council-planning-authority-core-documents/documents/adopted-ldp-pdf/adopted-ldp-pdf/govscot:document/Adopted%20LDP.pdf.

Phyllobius pomaceus (no date). Available at: https://www.ukbeetles.co.uk/phyllobius-pomaceus (Accessed: January 3, 2022).

Povinelli, E.A. (2016) *Geontologies: A Requiem to Late Liberalism*. Durham, NC: Duke University Press.

Povinelli, E.A. (2021) *Between Gaia and Ground: Four Axioms of Existence and the Ancestral Catastrophe of Late Liberalism*. Duke University Press.

Price, L. (2017) "Animals, Governance and Ecology: Managing the Menace of Venomous Snakes in Colonial India," *Cultural and Social History*, 14(2), pp. 201–217.

Pulido, L. (2016) "Flint, Environmental Racism, and Racial Capitalism," *Capitalism Nature Socialism*, 27(3), pp. 1–16.

Raffles, H. (2011) *Insectopedia*. Vintage.

Rajta, A. *et al.* (2020) "Role of heterotrophic aerobic denitrifying bacteria in nitrate removal from wastewater," *Journal of applied microbiology*, 128(5), pp. 1261–1278.

Ramprasad, C. and Philip, L. (2016) "Surfactants and personal care products removal in pilot scale horizontal and vertical flow constructed wetlands while treating greywater," *Chemical engineering journal* , 284, pp. 458–468.

Randle, S. (2021) "Holding water for the city: Emergent geographies of storage and the urbanization of nature," *Environment and Planning E: Nature and Space*, Advance online publication.

Randle, S. (2022) "Ecosystem duties, green infrastructure, and environmental injustice in Los Angeles," *American anthropologist*, 124(1), pp. 77–89.

Ranganathan, M. (2015) "Storm Drains as Assemblages: The Political Ecology of Flood Risk in Post-Colonial Bangalore: Stormwater Drains as Assemblages," *Antipode*, 47(5), pp. 1300–1320.

Ranganathan, M. and Bratman, E. (2019) "From Urban Resilience to Abolitionist Climate Justice in Washington, DC," *Antipode*, 53, p. 124.

Rao, M. (2020) *Reframing the Environment: Resources, Risk and Resistance in Neoliberal India*. Taylor & Francis.

Rao, S.R. *et al.* (2022) "Exposure to mosquito coil and biomass fuel smoke and respiratory health in rural Tamil Nadu, India," *Journal of public health* , 44(3), pp. 625–633.

"*rationale*" (no date) *Cambridge Dictionary*. Available at: https://dictionary.cambridge.org/dictionary/english/rationale (Accessed: July 18, 2022).

Rehman, N. (2020) *Epidemiological Landscapes: The Spaces and Politics of Mosquito Control in Lahore*. PhD. University of Cambridge.

Reno, J.O. (2014) "Toward a New Theory of Waste: From 'Matter out of Place' to Signs of Life," *Theory, Culture & Society*, 31(6), pp. 3–27.

Rey, J.R. *et al.* (2012) "North American wetlands and mosquito control," *International journal of environmental research and public health*, 9(12), pp. 4537–4605.

Robbins, P. (2007) *Encyclopedia of Environment and Society*. SAGE Publications.

Rockstrom, J. *et al.* (2009) "Planetary boundaries: exploring the safe operating space for humanity," *Ecology and Society*, 14(2), p. 33.

Rogers, A., Castree, N. and Kitchin, R. (2013) *Dictionary of Human Geography*. Oxford University Press.

Rohwer, Y. and Marris, E. (2021) "Ecosystem integrity is neither real nor valuable," *Conservation Science and Practice*, 3(e411). doi:10.1111/csp2.411.

Rose, G. (1997) "Situating knowledges: positionality, reflexivities and other tactics," *Progress in human geography*, 21(3), pp. 305–320.

Rosenthal, L. (2014) *The river pollution dilemma in Victorian England: Nuisance law versus economic efficiency*. London, England: Ashgate Publishing.

Rousseau, D.P.L., Vanrolleghem, P.A. and De Pauw, N. (2004) "Model-based design of horizontal subsurface flow constructed treatment wetlands: a review," *Water research*, 38(6), pp. 1484–1493.

Royal Commission on Sewage Disposal (1915) *Final report of the commissioners appointed to inquire and report what methods of treating and disposing of sewage (including any liquid from any factory or manufacturing process) may properly be adopted. General summary of conclusions and recommendations*. Available at: https://archive.org/details/cu31924003641929/page/n19/mode/2up (Accessed: September 23, 2021).

Rusca, M. *et al.* (2017) "An interdisciplinary political ecology of drinking water quality. Exploring socio-ecological inequalities in Lilongwe's water supply network," *Geoforum; journal of physical, human, and regional geosciences*, 84, pp. 138–146.

Rusca, M. *et al.* (2022) "The Urban Metabolism of Waterborne Diseases: Variegated Citizenship, (Waste)Water Flows, and Climatic Variability in Maputo, Mozambique," *Annals of the Association of American Geographers. Association of American Geographers*, 112(4), pp. 1159–1178.

Rusca, M. and Cleaver, F. (2022) "Unpacking everyday urbanism: Practices and the making of (un)even urban waterscapes," *WIREs. Water*, 9(2), pp. 1–16.

Rusca, M. and Di Baldassarre, G. (2019) "Interdisciplinary Critical Geographies of Water: Capturing the Mutual Shaping of Society and Hydrological Flows," *Water*, 11(10), p. 1973.

Russell, R.C. (1999) "Constructed wetlands and mosquitoes: Health hazards and management options—An Australian perspective," *Ecological engineering*, 12(1), pp. 107–124.

Sagar (2017) *How the Swachh Bharat Mission is heading for failure*. Available at: https://caravanmagazine.in/reportage/swachh-bharat-mission-heading-failure (Accessed: September 27, 2020).

Said, E.W. (1978) *Orientalism*. Pantheon Books.

Said, E.W. (1989) "Representing the Colonized: Anthropology's Interlocutors," *Critical inquiry*, 15(2), pp. 205–225.

Saini, A. (2020) "Want to do better science? Admit you're not objective," *Nature*, 579(7798), p. 175.

Saldana, J. (2021) *The Coding Manual for Qualitative Researchers*. SAGE.

Samsó, R., Meyer, D. and García, J. (2015) "Subsurface Flow Constructed Wetland Models: Review and Prospects," in Vymazal, J. (ed.) *The Role of Natural and Constructed Wetlands in Nutrient Cycling and Retention on the Landscape*. Cham: Springer International Publishing, pp. 149–174.

Sarkar, S. and Dixon, H. (eds.) (2021) *Emerging Science for Sustainable Water Resource Management: A Guide for Water Professionals and Practitioners in India*. UK Centre for Ecology & Hydrology.

Scaramelli, C. (2013) "Making Sense of Water Quality: Multispecies Encounters on the Mystic River," *Worldviews: Global Religions, Culture, and Ecology*, 17(2), pp. 150–160.

Scaramelli, C. (2019) "The Delta is Dead: Moral Ecologies of Infrastructure in Turkey," *Cultural anthropology: journal of the Society for Cultural Anthropology*, 34(3), pp. 388–416.

Scaramelli, C. (2021) *How to Make a Wetland*. Stanford University Press.

Schäfer, M.L. *et al.* (2004) "Biological diversity versus risk for mosquito nuisance and disease transmission in constructed wetlands in southern Sweden," *Medical and veterinary entomology*, 18(3), pp. 256–267.

Schaffer, S. (2013) "How disciplines look," in Barry, A. and Born, G. (eds.) *Interdisciplinarity: Reconfigurations of the social and natural sciences*. Oxon: Routledge, pp. 57–81.

Schlosberg, D. (2004) "Reconceiving Environmental Justice: Global Movements And Political Theories," *Environmental politics*, 13(3), pp. 517–540.

Schmidt, J.J. and Peppard, C.Z. (2014) "Water ethics on a human-dominated planet: rationality, context and values in global governance," *Wiley Interdisciplinary Reviews: Water*, 1(6), pp. 533–547.

Schooler, S.S., McEvoy, P.B. and Coombs, E.M. (2006) "Negative per capita effects of purple loosestrife and reed canary grass on plant diversity of wetland communities," *Diversity & distributions*, 12(4), pp. 351–363.

Schrader, A. *et al.* (2015) *Querying Eco-logics*. Available at: https://technoscienceunit.org/2015/07/24/querying-eco-logics/ (Accessed: March 18, 2021).

Scotland-India research collaboration delivers clean water for primary schools (2018) *James Hutton Institute*. Available at: https://www.hutton.ac.uk/news/scotland-india-research-collaboration-delivers-clean-water-primary-schools (Accessed: April 20, 2022).

Scottish Natural Heritage (2014) *Guidance: Recommended bird survey methods to inform impact assessment of onshore wind farms*. Available at: https://www.nature.scot/sites/default/files/2017-09/Guidance%20note%20-%20Recommended%20bird%20survey%20methods%20to%20inform%20impact%20assessment%20of%20onshore%20windfarms.pdf.

Scottish Water (no date) *Saving Water in Scotland*. Available at: https://www.scottishwater.co.uk/Your-Home/Save-Water/Saving-Water-in-Scotland (Accessed: January 10, 2022).

Secor, A. (2010) "Social surveys, interviews, and focus groups," in Gomez, B. and Jones, J.P., III (eds.) *Research Methods in Geography: A Critical Introduction*. Hoboken, NJ: John Wiley and Sons, pp. 194–206.

Semeraro, T. *et al.* (2015) "A constructed treatment wetland as an opportunity to enhance biodiversity and ecosystem services," *Ecological engineering*, 82, pp. 517–526.

Shao, K. *et al.* (2021) "Bayesian benchmark dose analysis for inorganic arsenic in drinking water associated with bladder and lung cancer using epidemiological data," *Toxicology*, 455, p. 152752.

Shapiro, N., Zakariya, N. and Roberts, J. (2017) "A Wary Alliance: From Enumerating the Environment to Inviting Apprehension," *Engaging Science, Technology, and Society*, 3, pp. 575–602.

Sharma, S. and Kashyap, R.K. (1999) "Purple Sunbird Nectarinia Asiatica (Latham) - a new Pest of Grapes Under Agroclimatic Conditions of Hissar, Haryana," *The Journal of the Bombay Natural History Society*, 96 (1999). Available at: https://www.biodiversitylibrary.org/item/189533 (Accessed: December 11, 2019).

Shiva, V. (2016) *Water wars: Privatization, pollution, and profit*. North Atlantic Books.

Sievers, M. *et al.* (2018) "Impacts of human-induced environmental change in wetlands on aquatic animals," *Biological reviews of the Cambridge Philosophical Society*, 93(1), pp. 529–554.

Silva-Novoa Sanchez, L.M., Kemerink-Seyoum, J.S. and Zwarteveen, M. (2019) "Water Infrastructure Always In-The-Making: Distributing Water and Authority through the Water Supply Network in Moamba, Mozambique," *WATER*, 11(9), p. 1926.

Sims, R. (2021) "Coexisting with Mosquitoes," *Theorizing the Contemporary, Fieldsights*. Available at: https://culanth.org/fieldsights/coexisting-with-mosquitoes (Accessed: January 27, 2021).

Singh, A. and Taylor-Robinson, A.W. (2017) "Vector control interventions to prevent dengue: current situation and strategies for future improvements to management of Aedes in India," *J Infect Dis Pathol*, 2(123), pp. 2–7.

Singh, V. *et al.* (2019) "Bio-assessment of River Ujh using benthic macro-invertebrates as bioindicators, India," *International Journal of River Basin Management*, 17(1), pp. 79–87.

Smith, N. (1984) *Uneven Development: Nature, Capital, and the Production of Space*. Blackwell.

Smith, W. and Dressler, W. (2019) "Governing vulnerability: The biopolitics of conservation and climate in upland Southeast Asia," *Political geography*, 72, pp. 76–86.

SNH, SEPA, Perth and Kinross Council (2016) *Loch Leven Special Protection Area and Ramsar site: Advice to planning applicants in relation to phosphorus and foul drainage in the catchment*. Available at: https://www.pkc.gov.uk/media/37575/Loch-Leven-SPG-Final-2016/pdf/Loch_Leven_SPG_Final_2016.pdf?m=636108416082400000.

Song, X. *et al.* (2020) "Micro-aeration with hollow fiber membrane enhanced the nitrogen removal in constructed wetlands," *Environmental science and pollution research international*, 27(21), pp. 25877–25885.

Soper, K. (2001) "Realism, humanism and the politics of nature," *Theoria*, 48(98), pp. 17–26.

Sopory, S. (2019) *Sensory Biology of Plants*. Springer Nature.

Springer, S. (2021) "Total liberation ecology: Integral anarchism, anthroparchy, and the violence of indifference," in Springer, S. et al. (eds.) *Undoing Human Supremacy: Anarchist Political Ecology in the Face of Anthroparchy*. Oakland, CA: PM Press.

Srinivasan, K. (2019a) "Politicizing Care," *Society and Space* [Magazine]. Available at: https://www.societyandspace.org/articles/politicizing-care (Accessed: April 29, 2021).

Srinivasan, K. (2019b) "Remaking more-than-human society: Thought experiments on street dogs as 'nature,'" *Transactions* , 44(2), pp. 376–391.

Srinivasan, K. (2022a) "Crafting scholarly alliances for multispecies justice," *Dialogues in Human Geography*, 12(1), pp. 79–83.

Srinivasan, K. (2022b) "Re-animalising wellbeing: Multispecies justice after development," *The Sociological review*, 70(2), pp. 352–366.

Srinivasan, K. and Kasturirangan, R. (2016) "Political ecology, development, and human exceptionalism," *Geoforum; journal of physical, human, and regional geosciences*, 75, pp. 125–128.

Srinivasan, V. (2016) *ATREE Comments on the Draft National Water Framework Bill*. ATREE. Available at: https://www.atree.org/sites/default/files/ATREE_Comments_NationalWaterFrameworkBill.pdf.

Strang, V. (2018) "Re-Imagined Communities," in Conca, K. and Weinthal, E. (eds.) *The Oxford Handbook of Water Politics and Policy*. Oxford: Oxford University Press.

Streeter, H.W. (1938) “Natural Stream Purification as Applied to Practical Measures of Stream Pollution Control,” *Sewage works journal*, 10(4), pp. 747–753.

Subramanian, K. (2015) *Revisiting the Green RevolutionIrrigation and Food Production in Twentieth-Century India*. King’s College London. Available at: https://kclpure.kcl.ac.uk/portal/files/54484756/2015_Subramanian_Kapil_1348311_ethesis.pdf.

Sulloway, F.J. (1983) “The legend of Darwin’s finches,” *Nature*, 303, p. 372.

Sultana, F. (2011) “Suffering for water, suffering from water: Emotional geographies of resource access, control and conflict,” *Geoforum; journal of physical, human, and regional geosciences*, 42(2), pp. 163–172.

Sultana, F. (2013) “Water, Technology, and Development: Transformations of Development Technonatures in Changing Waterscapes,” *Environment and planning. D, Society & space*, 31(2), pp. 337–353.

Sultana, F. (2020) “Embodied Intersectionalities of Urban Citizenship: Water, Infrastructure, and Gender in the Global South,” *Annals of the Association of American Geographers. Association of American Geographers*, 110(5), pp. 1407–1424.

Sultana, F. (2022) “The unbearable heaviness of climate coloniality,” *Political geography*, Advance online publication.

Sun, H. *et al.* (2019) “Enhancement of facultative anaerobic denitrifying communities by oxygen release from roots of the macrophyte in constructed wetlands,” *Journal of environmental management*, 246, pp. 157–163.

Sundberg, J. (2011) “Diabolic Caminos in the Desert and Cat Fights on the Río: A Posthumanist Political Ecology of Boundary Enforcement in the United States–Mexico Borderlands,” *Annals of the Association of American Geographers*, 101(2), pp. 318–336.

Sundberg, J. (2014) “Decolonizing posthumanist geographies,” *cultural geographies*, 21(1), pp. 33–47.

Sutar, R.S. *et al.* (2019) “Significance of Constructed Wetlands for Enhancing Reuse of Treated Sewages in Rural India,” in *Waste Management and Resource Efficiency*. Springer Singapore, pp. 1221–1229.

Sutherland, W.J. *et al.* (2004) *Bird Ecology and Conservation: A Handbook of Techniques*. OUP Oxford.

Svarstad, H., Benjaminsen, T.A. and Overå, R. (2018) “Power theories in political ecology,” *Journal of Political Ecology*, 25(1), pp. 350–363.

Swanson, H.A. (2017) “Methods for multispecies anthropology: Thinking with salmon otoliths and scales,” *SA. Sociological analysis*, 61(2), pp. 81–99.

Swyngedouw, E. (1996) “The city as a hybrid: On nature, society and cyborg urbanization,” *Capitalism Nature Socialism*, 7(2), pp. 65–80.

Swyngedouw, E. (2004) *Social Power and the Urbanization of Water: Flows of Power*. Oxford: Oxford University Press (Oxford Geographical and Environmental Studies Series).

Swyngedouw, E. (2010) “Impossible Sustainability and the Post-political Condition,” in Cerreta, M., Concilio, G., and Monno, V. (eds.) *Making Strategies in Spatial Planning: Knowledge and Values*. Dordrecht: Springer Netherlands, pp. 185–205.

Swyngedouw, E. (2015) *Liquid Power: Contested Hydro-Modernities in Twentieth-Century Spain*. MIT Press.

Swyngedouw, E. and Ernstson, H. (2018) “Interrupting the Anthropo-obScene: Immuno-biopolitics and Depoliticizing Ontologies in the Anthropocene,” *Theory, Culture & Society*, 35(6), pp. 3–30.

Taiz, L. *et al.* (2019) “Plants Neither Possess nor Require Consciousness,” *Trends in plant science*, 24(8), pp. 677–687.

Takacs, D. (1996) *The Idea of Biodiversity: Philosophies of Paradise*. Johns Hopkins University Press.

Tanner, C.C. (2001) “Plants as ecosystem engineers in subsurface-flow treatment wetlands,” *Water science and technology: a journal of the International Association on Water Pollution Research*, 44(11–12), pp. 9–17.

Taylor, C.R. *et al.* (2011) “Seasonal effects of 19 plant species on COD removal in subsurface treatment wetland microcosms,” *Ecological engineering*, 37(5), pp. 703–710.

Taylor, K. (2009) “Biological flora of the British isles:Urtica dioicaL,” *The Journal of ecology*, 97(6), pp. 1436–1458.

Taylor, M. and Bhasme, S. (2021) “Between deficit rains and surplus populations: The political ecology of a climate-resilient village in South India,” *Geoforum; journal of physical, human, and regional geosciences*, 126, pp. 431–440.

Taylor, N.G. *et al.* (2021) *Marsh and Swamp Conservation: Global Evidence for the Effects of Interventions to Conserve Marsh and Swamp Vegetation*. University of Cambridge. Available at: https://www.conservationevidence.com/synopsis/pdf/19.

The New York Times (1975) “Bulrushes Being Used in Artificial Marshes to Filter Water,” *The New York Times*, 9 March. Available at: https://www.nytimes.com/1975/03/09/archives/bulrushes-being-used-in-artificial-marshes-to-filter-water.html (Accessed: May 3, 2021).

The Rivers Trust (2020) *New interactive map reveals the truth about sewage pollution*, *The Rivers Trust*. Available at: https://www.theriverstrust.org/2020/07/02/new-interactive-map-reveals-the-truth-about-sewage-pollution/ (Accessed: February 10, 2021).

Theriault, N. *et al.* (2020) “Living protocols: remaking worlds in the face of extinction,” *Social & Cultural Geography*, 21(7), pp. 893–908.

Theriault, N. and Kang, S. (2021) “Toxic research,” *Environment and society*, 12(1), pp. 5–24.

Tickner, D. *et al.* (2020) “Bending the Curve of Global Freshwater Biodiversity Loss: An Emergency Recovery Plan,” *Bioscience*, 70(4), pp. 330–342.

Tobias, J.A. and Pigot, A.L. (2019) “Integrating behaviour and ecology into global biodiversity conservation strategies,” *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 374, p. 20190012.

Todd, Z. (2017) “Fish, Kin and Hope: Tending to Water Violations in amiskwaciwâskahikan and Treaty Six Territory,” *Afterall: A Journal of Art, Context and Enquiry*, 43, pp. 102–107.

Todd, Z. (2018) “Refracting the State Through Human-Fish Relations:,” *Decolonization: Indigeneity, Education & Society*, 7(1), pp. 60–75.

Tondera, K. *et al.* (2021) "Bioaugmentation of treatment wetlands - A review," *The Science of the total environment*, 775, p. 145820.

Tozzi, A., Bouzarovski, S. and Henry, C. (2022) "Colonizing the rains: Disentangling more-than-human technopolitics of drought protection in the archive," *Geoforum; journal of physical, human, and regional geosciences*, 135, pp. 12–24.

Tracy, S.J. (2019) *Qualitative Research Methods: Collecting Evidence, Crafting Analysis, Communicating Impact*. John Wiley & Sons.

Truelove, Y. (2011) "(Re-)Conceptualizing water inequality in Delhi, India through a feminist political ecology framework," *Geoforum; journal of physical, human, and regional geosciences*, 42(2), pp. 143–152.

Truelove, Y. and Cornea, N. (2021) "Rethinking urban environmental and infrastructural governance in the everyday: Perspectives from and of the global South," *Environment and Planning C: Politics and Space*, 39(2), pp. 231–246.

Truu, M. *et al.* (2019) "Bacterial community activity and dynamics in the biofilm of an experimental hybrid wetland system treating greywater," *Environmental science and pollution research international*, 26(4), pp. 4013–4026.

Truu, M., Juhanson, J. and Truu, J. (2009) "Microbial biomass, activity and community composition in constructed wetlands," *The Science of the total environment*, 407(13), pp. 3958–3971.

Tschakert, P. *et al.* (2021) "Multispecies justice: Climate-just futures with, for and beyond humans," *Wiley interdisciplinary reviews. Climate change*, 12(2). doi:10.1002/wcc.699.

Tsing, A. (2012) "Contaminated Diversity in 'Slow Disturbance': Potential Collaborators for a Liveable Earth," in Martin, G., Mincyte, D., and Münster, U. (eds.) *Why Do We Value Diversity? Biocultural Diversity in a Global Context*. Munich: Rachel Carson Centre (Perspectives), pp. 95–97.

Tsing, A. (2013) "More-than-Human Sociality: A Call for Critical Description," in *Anthropology and Nature*. Abingdon: Routledge, pp. 37–52.

Tsing, A.L. (2014) "Strathern beyond the Human: Testimony of a Spore," *Theory, Culture & Society*, 31(2–3), pp. 221–241.

Tsing, A.L. (2015) *The mushroom at the end of the world: On the possibility of life in capitalist ruins*. Princeton, NJ: Princeton University Press. Available at: https://www.degruyter.com/document/doi/10.1515/9781400873548/html.

Tuck, E. (2009) "Suspending damage: A letter to communities," *Harvard educational review*, 79(3), pp. 409–428.

Tuck, E. (2010) "Breaking up with Deleuze: desire and valuing the irreconcilable," *International journal of qualitative studies in education: QSE*, 23(5), pp. 635–650.

Turner, M.D. (2016) "Political ecology II: Engagements with ecology," *Progress in human geography*, 40(3), pp. 413–421.

Ulloa, A. (2020) "The rights of the Wayúu people and water in the context of mining in La Guajira, Colombia: demands of relational water justice," *Human Geography*, 13(1), pp. 6–15.

UN Habitat and WHO (2021) *Progress on Wastewater Treatment: Global Status and Acceleration Needs for SDG Indicator 6.3.1*. Geneva: United Nations Human Settlements Programme (UN-Habitat) and

World Health Organization (WHO). Available at: https://www.unwater.org/app/uploads/2021/09/SDG6_Indicator_Report_631_Progress-on-Wastewater-Treatment_2021_EN.pdf.

Uribe, S. (2019) "Illegible infrastructures: Road building and the making of state-spaces in the Colombian Amazon," *Environment and planning. D, Society & space*, 37(5), pp. 886–904.

Valenzuela, F. and Böhm, S. (2017) "Against wasted politics: a critique of the circular economy," *Ephemera: Theory & Politics in Organization*, 17(1), pp. 23–60.

Valera, L. and Bertolaso, M. (2016) "Understanding Biodiversity from a Relational Viewpoint," *Topicos (Mexico)*, 51, pp. 37–54.

Vansintjan, A. (2021) *Urban Fish Ponds: Low-tech Sewage Treatment for Towns and Cities*, *Low-tech magazine*. Available at: https://www.lowtechmagazine.com/2021/03/urban-fish-ponds-low-tech-sewage-treatment-for-towns-and-cities.html (Accessed: July 14, 2022).

Velicu, I. and Kaika, M. (2017) "Undoing environmental justice: Re-imagining equality in the Rosia Montana anti-mining movement," *Geoforum; journal of physical, human, and regional geosciences*, 84, pp. 305–315.

Verdonschot, P.F.M. and Besse-Lototskaya, A.A. (2014) "Flight distance of mosquitoes (Culicidae): A metadata analysis to support the management of barrier zones around rewetted and newly constructed wetlands," *Limnologica* , 45, pp. 69–79.

Vileisis, A. (1999) *Discovering the Unknown Landscape: A History Of America's Wetlands*. Island Press.

Vissandjée, B., Abdool, S.N. and Dupéré, S. (2002) "Focus groups in rural Gujarat, India: a modified approach," *Qualitative health research*, 12(6), pp. 826–843.

Vymazal, J. (2011) "Constructed wetlands for wastewater treatment: five decades of experience," *Environmental science & technology*, 45(1), pp. 61–69.

Vymazal, J. (2022) "The Historical Development of Constructed Wetlands for Wastewater Treatment," *Land*, 11(2), p. 174.

Vymazal, J., Sládedek, V. and Stach, J. (2001) "Biota participating in wastewater treatment in a horizontal flow constructed wetland," *Water science and technology: a journal of the International Association on Water Pollution Research*, 44(11–12), pp. 211–214.

Wakefield, S. (2020) "Making nature into infrastructure: The construction of oysters as a risk management solution in New York City," *Environment and Planning E: Nature and Space*, 3(3), pp. 761–785.

Wakefield, S., Chandler, D. and Grove, K. (2022) "The asymmetrical anthropocene: resilience and the limits of posthumanism," *cultural geographies*, 29(3), pp. 389–404.

Walker, P.A. (2005) "Political ecology: where is the ecology?," *Progress in human geography*, 29(1), pp. 73–82.

Wang, Q. *et al.* (2019) "Enhancement of COD removal in constructed wetlands treating saline wastewater: Intertidal wetland sediment as a novel inoculation," *Journal of environmental management*, 249, p. 109398.

Wang, S. *et al.* (2019) “Seasonal dynamics of bacterial communities associated with antibiotic removal and sludge stabilization in three different sludge treatment wetlands,” *Journal of environmental management*, 240, pp. 231–237.

Wang, Y. *et al.* (2016) “The inhibition and adaptability of four wetland plant species to high concentration of ammonia wastewater and nitrogen removal efficiency in constructed wetlands,” *Bioresource technology*, 202, pp. 198–205.

Watnick, P. and Kolter, R. (2000) “Biofilm, city of microbes,” *Journal of bacteriology*, 182(10), pp. 2675–2679.

Watts, V. (2013) “Indigenous Place-Thought and Agency Amongst Humans and Non Humans (First Woman and Sky Woman Go On a European World Tour!),” *Decolonization: Indigeneity, Education & Society*, 2(1), pp. 20–34.

Wear, S.L. *et al.* (2021) “Sewage pollution, declining ecosystem health, and cross-sector collaboration,” *Biological conservation*, 255, p. 109010.

Weihrauch, D., Donini, A. and O’Donnell, M.J. (2012) “Ammonia transport by terrestrial and aquatic insects,” *Journal of insect physiology*, 58(4), pp. 473–487.

Wescoat, J.L. (2014) “Searching for Comparative International Water Research: Urban and Rural Water Conservation Research in India and the United States,” *Water Alternatives*, 7(1), pp. 199–219.

Wesselink, A., Kooy, M. and Warner, J. (2017) “Socio-hydrology and hydrosocial analysis: toward dialogues across disciplines,” *Wiley Interdisciplinary Reviews: Water*, 4(2), p. e1196.

West, S. and Schill, C. (2022) “Negotiating the ethical-political dimensions of research methods: a key competency in mixed methods, inter- and transdisciplinary, and co-production research,” *Humanities and Social Sciences Communications*, 9(1), pp. 1–13.

West, S.A. *et al.* (2007) “The Social Lives of Microbes,” *Annual review of ecology, evolution, and systematics*, 38(1), pp. 53–77.

Whatmore, S. (2006) “Materialist returns: practising cultural geography in and for a more-than-human world,” *cultural geographies*, 13(4), pp. 600–609.

Whatmore, S. (2013) “Where Natural and Social Science Meet? Reflections on an experiment in geographical practice,” in Barry, A. and Born, G. (eds.) *Interdisciplinarity: Reconfigurations of the Social and Natural Sciences*. Routledge, pp. 177–193.

Whitaker, R. (1992) *Common Indian Snakes: A Field Guide*. New York, NY: Macmillan.

Whitaker, Z. and Whitaker, R. (1992) *The Snakes Around Us*. Delhi: National Book Trust, India.

Wildfowl & Wetlands Trust (2022) *UK amphibians guide*, *WWT*. Available at: https://www.wwt.org.uk/discover-wetlands/wetland-wildlife/amphibians/ (Accessed: August 7, 2022).

Wilkinson, D.M. (1999) “The disturbing history of intermediate disturbance,” *Oikos* , 84(1), p. 145.

Wilkinson, J.L. *et al.* (2022) “Pharmaceutical pollution of the world’s rivers,” *Proceedings of the National Academy of Sciences of the United States of America*, 119(8), pp. 1–10.

Willcock, S. *et al.* (2021) “Nature provides valuable sanitation services,” *One Earth*, 4(2), pp. 192–201.

Wilson, N.J. *et al.* (2019) "Water is Medicine: Reimagining Water Security through Tr'ondëk Hwëch'in Relationships to Treated and Traditional Water Sources in Yukon, Canada," *WATER*, 11(3), p. 624.

Wintgens, T. *et al.* (2016) *Natural Water Treatment Systems for Safe and Sustainable Water Supply in the Indian Context: Saph Pani*. IWA Publishing.

Woelfle-Erskine, C. (2015) "Rain Tanks, Springs, and Broken Pipes As Emerging Water Commons Along Salmon Creek, CA, USA," *ACME: An International Journal for Critical Geographies*, 14(3), pp. 735–750.

World Health Organization and UN-HABITAT (2018) *Progress on safe treatment and use of wastewater: piloting the monitoring methodology and initial findings for SDG indicator 6.3.1*. Geneva. Available at: https://apps.who.int/iris/bitstream/handle/10665/275967/9789241514897-eng.pdf?ua=1.

World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) (2021) *Progress on household drinking water, sanitation and hygiene 2000-2020: Five years into the SDGs*. Available at: https://www.unwater.org/app/uploads/2021/07/jmp-2021-wash-households-LAUNCH-VERSION.pdf (Accessed: August 12, 2022).

Wu, H. *et al.* (2011) "Nutrient removal in constructed microcosm wetlands for treating polluted river water in northern China," *Ecological engineering*, 37(4), pp. 560–568.

Wu, H. *et al.* (2017) "Effects of root exudates on denitrifier gene abundance, community structure and activity in a micro-polluted constructed wetland," *The Science of the total environment*, 598, pp. 697–703.

Wynter, S. (1971) "Novel and history, plot and plantation," *Savacou*, 5, pp. 95–102.

Yaka, Ö. (2019) "Rethinking justice: Struggles for environmental commons and the notion of Socio-ecological justice," *Antipode*, 51(1), pp. 353–372.

Yang, Q. *et al.* (2007) "Contaminant Removal of Domestic Wastewater by Constructed Wetlands: Effects of Plant Species," *Journal of integrative plant biology*, 49(4), pp. 437–446.

Yin, R.K. (2017) *Case Study Research and Applications: Design and Methods*. SAGE Publications.

Yuan, C. *et al.* (2020) "Woodchips as sustained-release carbon source to enhance the nitrogen transformation of low C/N wastewater in a baffle subsurface flow constructed wetland," *Chemical engineering journal* , 392, p. 124840.

Yusoff, K. (2012) "Aesthetics of loss: biodiversity, banal violence and biotic subjects: Aesthetics of loss," *Transactions* , 37(4), pp. 578–592.

Zenner, C. (2019) "Valuing fresh waters," *Wiley Interdisciplinary Reviews: Water*, 6(3), p. e1343.

Zhang, A. (2020) "Circularity and Enclosures: Metabolizing Waste with the Black Soldier Fly," *Cultural Anthropology*, 35(1), pp. 74-103-74–103.

Zhang, C. *et al.* (2020) "Can Constructed Wetlands be Wildlife Refuges? A Review of Their Potential Biodiversity Conservation Value," *Sustainability: Science Practice and Policy*, 12(4), p. 1442.

Zhang, D.Q. *et al.* (2014) "Application of constructed wetlands for wastewater treatment in developing countries--a review of recent developments (2000-2013)," *Journal of environmental management*, 141, pp. 116–131.

Zheng, Y. *et al.* (2020) "Effects of plants competition on critical bacteria selection and pollutants dynamics in a long-term polyculture constructed wetland," *Bioresource technology*, 316, p. 123927.

Zuo, X., Zhang, H. and Yu, J. (2020) "Microbial diversity for the improvement of nitrogen removal in stormwater bioretention cells with three aquatic plants," *Chemosphere*, 244, p. 125626.

Zwarteveen, M.Z. and Boelens, R. (2014) "Defining, researching and struggling for water justice: some conceptual building blocks for research and action," *Water International*, 39(2), pp. 143–158.

Appendix I: Water quality parameter and method details

Table A.0.1 - Water quality parameters and their significance

Class	Parameter	Parameter explanation and significance
Oxygen demand/ organic matter	Biochemical Oxygen Demand (BOD)	A measure of the organic matter in water. This method measures how much oxygen is absorbed during microbial decomposition of this organic matter over several days. As organic matter is broken down by microbial processes in water, these processes deplete oxygen in the water, therefore high organic matter inputs are a source of poor water quality.
	Chemical Oxygen Demand (COD)	Similar to BOD but using chemical oxidation instead of biological processes. The relation between BOD and COD is unique to each wastewater.
	Organic Carbon (TOC)	A direct measurement of the organic carbon in a water sample. Correlated to chemical oxygen demand.
	Inorganic Carbon (IC)	Inorganic carbon is present in water as a mix of CO2, HCO3 and CO3 ions, with the ratio dependent on the pH of the water.
Nutrients	Total nitrogen (TN)	Nitrogen is a key element for biological organisms. High nitrogen concentrations in waters enable eutrophication. Nitrogen exists in multiple molecular forms within water, including nitrate and ammonia.
	Nitrate nitrogen (NO_3-N)	The main soluble form of nitrogen in water. Available for uptake by plants.
	Ammonia nitrogen (NH_4-N)	Ammonia is excreted by biological organisms and produced by the breakdown of organic matter. Many organisms are sensitive to ammonia levels. It is also transformed by microbial activity into other forms of nitrogen.
	Total phosphorus (TP)	Phosphorus is another key element for biological organisms. Excessive concentrations also contribute to eutrophication.
	Soluble reactive phosphorus (SRP)	The soluble inorganic component of total phosphorus that is available to plants and other organisms for uptake. Also referred to as orthophosphate.
Pathogens	Total coliforms	Coliforms are a class of rod-shaped, Gram-negative bacteria that can ferment lactose. Faeces of warm-blooded animals generally contain high numbers of coliform bacteria.
	E. coli	E. coli is a species of coliform bacteria generally associated with faecal contamination. For more on the social life of E. coli see chapter 5.

Table A.0.2 - Water quality parameters and analysis methods at each site

Class	Parameter	Analysis instruments and method by site		
		Berambadi (from (Ellis *et al.*, 2020))	*Ibrahimpur (from* (Goyal *et al.*, 2020) *and personal observation)*	*Loch Leven (my own analysis)*
Oxygen demand/ organic matter	Biochemical Oxygen Demand (BOD)	YSI Pro DO hand-held meter. Azide-modification titrimetric method	Manometric respirometric method.	
	Chemical Oxygen Demand (COD)	Open reflux method	Dichromate reflux titrimetric method	
	Total Organic Carbon (TOC)	Spectroquant Prove 600. Photometric method		Shimadzu TOC-TN analyser. Combustion and sparging method. TOC = TC - IC
	Inorganic carbon			
Nutrients	Total nitrogen (TN)	Merck Spectroquant Prove 600. Photometric method		Shimadzu TOC-TN analyser
	Nitrate nitrogen (NO_3-N)	Hach, Calorimetric method.	Spectrophotometric methods	SEAL-AQ2 Method: NO3+NO2, EPA-132-A
	Ammonia nitrogen (NH_4-N)	Merck Spectroquant Prove 600. Indophenol blue method		SEAL-AQ2 Alkaline phenate method. EPA-129-A.
	Total phosphorus (TP)	Merck Spectroquant Prove 600. Phosphormolybdenum blue method		SEAL-AQ2 Method: EPA-134-A
	Soluble reactive phosphorus (SRP)			SEAL-AQ2 Method: EPA-134-A
Pathogens	Total coliforms	Idexx Colilert 18, APHA method.		
	E. coli			

Appendix II: Interview topic guides

1. Berambadi project team interviews

Intro	Can you briefly summarise your role in the Berambadi project?
Wastewater treatment	What were the key water treatment goals for this wetland? How were these decided? For water quality standards, what is the logic of treating the drains as standing water that is being discharged into? How and when was information about the treatment performance of the wetland shared with [the school]/[the GP]? Could you explain the 'hand-over' process? What design changes would you suggest if you were doing this project again?
Water reuse	Did the question of reusing water after it had come from the CW play a part in project discussions? (If so, how?)
Vegetation	Could you tell me the story of how producing marketable/valuable vegetation (e.g. crops, flowers etc) was part of the project planning?
General resources	How did the concept of resource production influence the wetland design? In your view, what were some of the limitations that prevented resource production from occurring?
Habitat	Could you explain the planting decision making? Were diverse plantings an option? How did the vulnerability of the plants to drying out get recognised and addressed? How did mosquitoes come into project discussions? How did the fence come into the design process? What is the fence excluding/protecting?

2. Ibrahimpur initial scoping survey

1. *Demographic questions*

1.1 Name:

1.2 Age category: 15-25, 25-35, 35-45, 45-55, 55+

1.3 Number of livestock in household?

2. *Topic questions*

2.1 *Card sorting exercise* - what are the major sources of the wastewater that flows in the open drains?

Could you please rank these wastewater sources in order of importance, if one is not relevant, please put it to the side. You may also add categories if you need to.

- Wastewater from toilet
- Washing clothes
- Animal bathing
- Animal waste
- Vehicles/ whitewash
- Cleaning of pesticide/ fertilisers
- House cleaning
- Kitchen cleaning
- Bathing

2.2 What wastewater issues have you or members of your household been impacted by?

Also fill out tick boxes as reply is given. No prompts.

Unpleasant smells	
Flooding	
Mosquitos	
Trash build-up	
Illness	

2.3 What is the most significant change that you have noticed since this project was completed?

Ask follow-up questions to get more information if required

IBM only: There was flooding by the pond in the last monsoon, what impact did this have on you/your household?

3. *Other comments/questions?*

3. Group interview topic guide

1. Wetland habitat

Introductory question	What wetland animals live around/in the wetland/pond?
Transition	When are they most prevalent? (times of year)
Main questions	Where have you encountered these animals? How do you interact with them? *If the discussion is entirely focused on negative encounters, interviewer to ask, 'are there any good interactions/encounters that you enjoy?'*
Additional question	What is your impression of the Canna lily plant in the wetland?
Follow up questions	Would you like to have something else planted there? What? Why?
Closing question	How should we deal with these animals?

2. Water quality

Introductory question	How satisfied are you with the water quality of the water that you have access to?
Follow up question	What variation is there over the year?
Main question	How do you know if water quality is good or bad?
follow up questions	Where do you get water quality information from? What sensory experiences suggest good/bad water quality? Where does the best/worst water come from? Do deeper powered borewells have better water?
For irrigation	Does the importance of WQ differ depending on the crop?
For household use	Do you use different hand pumps/borewells for different purposes?
Water for livestock	Where do cattle drink? Is there some water that they shouldn't drink?

Appendix III: Sources for rationale chapter analysis

ID	Authors	Title	Year	Journal/Publisher	DOI
1	Vymazal J.	Removal of nutrients in various types of constructed wetlands	2007	Science of the Total Environment	10.1016/j.scitotenv.2006.09.014
2	De-Bashan L.E., Bashan Y.	Recent advances in removing phosphorus from wastewater and its future use as fertilizer (1997-2003)	2004	Water Research	10.1016/j.watres.2004.07.014
3	Brix H.	Do macrophytes play a role in constructed treatment wetlands?	1997	Water Science and Technology	10.1016/S0273-1223(97)00047-4
4	Kivaisi A.K.	The potential for constructed wetlands for wastewater treatment and reuse in developing countries: A review	2001	Ecological Engineering	10.1016/S0925-8574(00)00113-0
5	Vymazal J.	Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment	2005	Ecological Engineering	10.1016/j.ecoleng.2005.07.010
6	Faulwetter J.L., et al.	Microbial processes influencing performance of treatment wetlands: A review	2009	Ecological Engineering	10.1016/j.ecoleng.2008.12.030
7	Vohla C., et al.	Filter materials for phosphorus removal from wastewater in treatment wetlands-A review	2011	Ecological Engineering	10.1016/j.ecoleng.2009.08.003
8	Brix H.	Functions of macrophytes in constructed wetlands	1994	Water Science and Technology	10.2166/wst.1994.0160
9	Sakadevan K., Bavor H.J.	Phosphate adsorption characteristics of soils, slags and zeolite to be used as substrates in constructed wetland systems	1998	Water Research	10.1016/S0043-1354(97)00271-6
10	Akratos C.S., Tsihrintzis V.A.	Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands	2007	Ecological Engineering	10.1016/j.ecoleng.2006.06.013

ID	Authors	Title	Year	Journal/Publisher	DOI
11	Saeed T., Sun G.	A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: Dependency on environmental parameters, operating conditions and supporting media	2012	Journal of Environmental Management	10.1016/j.jenvman.2012.08.011
12	Vymazal J.	The use constructed wetlands with horizontal sub-surface flow for various types of wastewater	2009	Ecological Engineering	10.1016/j.ecoleng.2008.08.016
13	Gersberg R.M., et al.	Role of aquatic plants in wastewater treatment by artificial wetlands	1986	Water Research	10.1016/0043-1354(86)90085-0
14	Tanner C.C.	Plants for constructed wetland treatment systems - A comparison of the growth and nutrient uptake of eight emergent species	1996	Ecological Engineering	10.1016/0925-8574(95)00066-6
15	Reichenberger S., Bach M., Skitschak A., Frede H.-G.	Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness; A review	2007	Science of the Total Environment	10.1016/j.scitotenv.2007.04.046
16	Wu H., Zhang J., Ngo H.H., Guo W., Hu Z., Liang S., Fan J., Liu H.	A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation	2015	Bioresource Technology	10.1016/j.biortech.2014.10.068
17	Drizo A., Frost C.A., Grace J., Smith K.A.	Physico-chemical screening of phosphate-removing substrates for use in constructed wetland systems	1999	Water Research	10.1016/S0043-1354(99)00082-2
18	Arias C.A., Del Bubba M., Brix H.	Phosphorus removal by sands for use as media in subsurface flow constructed reed beds	2001	Water Research	10.1016/S0043-1354(00)00368-7
19	Vymazal J.	The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience	2002	Ecological Engineering	10.1016/S0925-8574(02)00025-3
20	Brix H., Arias C.A.	The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: New Danish guidelines	2005	Ecological Engineering	10.1016/j.ecoleng.2005.07.009
21	Verhoeven J.T.A., Meuleman A.F.M.	Wetlands for wastewater treatment: Opportunities and limitations	1999	Ecological Engineering	10.1016/S0925-8574(98)00050-0
22	Truu M., Juhanson J., Truu J.	Microbial biomass, activity and community composition in constructed wetlands	2009	Science of the Total Environment	10.1016/j.scitotenv.2008.11.036
23	Kadlec R.H.	The inadequacy of first-order treatment wetland models	2000	Ecological Engineering	10.1016/S0925-8574(99)00039-7

ID	Authors	Title	Year	Journal/Publisher	DOI
24	Wu S., Kuschk P., Brix H., Vymazal J., Dong R.	Development of constructed wetlands inperformance intensifications for wastewater treatment: A nitrogen and organic matter targeted review	2014	Water Research	10.1016/j.watres.2014.03.020
25	Persson J., Somes N.L.G., Wong T.H.F.	Hydraulics efficiency of constructed wetlands and ponds	1999	Water Science and Technology	10.1016/S0273-1223(99)00448-5
26	Bachand P.A.M., Horne A.J.	Denitrification in constructed free-water surface wetlands: II. Effects of vegetation and temperature	1999	Ecological Engineering	10.1016/S0925-8574(99)00017-8
27	Knight R.L., Payne Jr. V.W.E., Borer R.E., Clarke Jr. R.A., Pries J.H.	Constructed wetlands for livestock wastewater management	2000	Ecological Engineering	10.1016/S0925-8574(99)00034-8
28	Li Y., Zhu G., Ng W.J., Tan S.K.	A review on removing pharmaceutical contaminants from wastewater by constructed wetlands: Design, performance and mechanism	2014	Science of the Total Environment	10.1016/j.scitotenv.2013.09.018
29	Vymazal J.	The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: A review of a recent development	2013	Water Research	10.1016/j.watres.2013.05.029
30	Rousseau D.P.L., Vanrolleghem P.A., De Pauw N.	Model-based design of horizontal subsurface flow constructed treatment wetlands: A review	2004	Water Research	10.1016/j.watres.2003.12.013
31	Tanner C.C.	Plants as ecosystem engineers in subsurface-flow treatment wetlands	2001	Water Science and Technology	10.2166/wst.2001.0804
32	Spieles D.J., Mitsch W.J.	The effects of season and hydrologic and chemical loading on nitrate retention in constructed wetlands: A comparison of low- and high-nutrient riverine systems	1999	Ecological Engineering	10.1016/S0925-8574(99)00021-X
33	Vymazal J.	Constructed wetlands for treatment of industrial wastewaters: A review	2014	Ecological Engineering	10.1016/j.ecoleng.2014.09.034
34	Matamoros V., García J., Bayona J.M.	Organic micropollutant removal in a full-scale surface flow constructed wetland fed with secondary effluent	2008	Water Research	10.1016/j.watres.2007.08.016

ID	Authors	Title	Year	Journal/Publisher	DOI
35	Calheiros C.S.C., Rangel A.O.S.S., Castro P.M.L.	Constructed wetland systems vegetated with different plants applied to the treatment of tannery wastewater	2007	Water Research	10.1016/j.watres.2007.01.012
36	Cheng S., Grosse W., Karrenbrock F., Thoennessen M.	Efficiency of constructed wetlands in decontamination of water polluted by heavy metals	2002	Ecological Engineering	10.1016/S0925-8574(01)00091-X
37	Del Bubba M., Arias C.A., Brix H.	Phosphorus adsorption maximum of sands for use as media in subsurface flow constructed reed beds as measured by the Langmuir isotherm	2003	Water Research	10.1016/S0043-1354(03)00231-8
38	Brix H.	Use of constructed wetlands in water pollution control: Historical development, present status, and future perspectives	1994	Water Science and Technology	10.2166/wst.1994.0413
39	Brisson J., Chazarenc F.	Maximizing pollutant removal in constructed wetlands: Should we pay more attention to macrophyte species selection?	2009	Science of the Total Environment	10.1016/j.scitotenv.2008.05.047
40	Karathanasis A.D., Potter C.L., Coyne M.S.	Vegetation effects on fecal bacteria, BOD, and suspended solid removal in constructed wetlands treating domestic wastewater	2003	Ecological Engineering	10.1016/S0925-8574(03)00011-9
41	Knowles P., Dotro G., Nivala J., García J.	Clogging in subsurface-flow treatment wetlands: Occurrence and contributing factors	2011	Ecological Engineering	10.1016/j.ecoleng.2010.08.005
42	Drizo A., Forget C., Chapuis R.P., Comeau Y.	Phosphorus removal by electric arc furnace steel slag and serpentinite	2006	Water Research	10.1016/j.watres.2006.02.001
43	Maltais-Landry G., Maranger R., Brisson J., Chazarenc F.	Nitrogen transformations and retention in planted and artificially aerated constructed wetlands	2009	Water Research	10.1016/j.watres.2008.10.040
44	Braskerud B.C.	Factors affecting phosphorus retention in small constructed wetlands treating agricultural non-point source pollution	2002	Ecological Engineering	10.1016/S0925-8574(02)00014-9
45	Konnerup D., Koottatep T., Brix H.	Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with Canna and Heliconia	2009	Ecological Engineering	10.1016/j.ecoleng.2008.04.018
46	Mays P.A., Edwards G.S.	Comparison of heavy metal accumulation in a natural wetland and constructed wetlands receiving acid mine drainage	2001	Ecological Engineering	10.1016/S0925-8574(00)00112-9

ID	Authors	Title	Year	Journal/Publisher	DOI
47	Brix H., Arias C.A., Del Bubba M.	Media selection for sustainable phosphorus removal in subsurface flow constructed wetlands	2001	Water Science and Technology	10.2166/wst.2001.0808
48	Gottschall N., Boutin C., Crolla A., Kinsley C., Champagne P.	The role of plants in the removal of nutrients at a constructed wetland treating agricultural (dairy) wastewater, Ontario, Canada	2007	Ecological Engineering	10.1016/j.ecoleng.2006.06.004
49	Huett D.O., Morris S.G., Smith G., Hunt N.	Nitrogen and phosphorus removal from plant nursery runoff in vegetated and unvegetated subsurface flow wetlands	2005	Water Research	10.1016/j.watres.2005.05.038
50	Kuschk P., et al.	Annual cycle of nitrogen removal by a pilot-scale subsurface horizontal flow in a constructed wetland under moderate climate	2003	Water Research	10.1016/S0043-1354(03)00163-5
51	Tanner C.C., Clayton J.S., Upsdell M.P.	Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands-II. Removal of nitrogen and phosphorus	1995	Water Research	10.1016/0043-1354(94)00140-3
52	Collins K.A., et al.	Opportunities and challenges for managing nitrogen in urban stormwater: A review and synthesis	2010	Ecological Engineering	10.1016/j.ecoleng.2010.03.015
53	Vymazal J., Kröpfelová L.	Removal of organics in constructed wetlands with horizontal sub-surface flow: A review of the field experience	2009	Science of the Total Environment	10.1016/j.scitotenv.2008.08.032
54	Molle P., Liénard A., Boutin C., Merlin G., Iwema A.	How to treat raw sewage with constructed wetlands: An overview of the French systems	2005	Water Science and Technology	10.2166/wst.2005.0277
55	Greenway M., Woolley A.	Constructed wetlands in Queensland: Performance efficiency and nutrient bioaccumulation	1999	Ecological Engineering	10.1016/S0925-8574(98)00053-6
56	Reddy K.R., D'Angelo E.M.	Biogeochemical indicators to evaluate pollutant removal efficiency in constructed wetlands	1997	Water Science and Technology	10.1016/S0273-1223(97)00046-2
57	Zhang D.Q., et al.	Application of constructed wetlands for wastewater treatment in developing countries - A review of recent developments (2000-2013)	2014	Journal of Environmental Management	10.1016/j.jenvman.2014.03.015

ID	Authors	Title	Year	Journal/Publisher	DOI
58	Zhang D., Gersberg R.M., Keat T.S.	Constructed wetlands in China	2009	Ecological Engineering	10.1016/j.ecoleng.2009.07.007
59	Vymazal J.	Emergent plants used in free water surface constructed wetlands: A review	2013	Ecological Engineering	10.1016/j.ecoleng.2013.06.023
60	Zurita F., De Anda J., Belmont M.A.	Treatment of domestic wastewater and production of commercial flowers in vertical and horizontal subsurface-flow constructed wetlands	2009	Ecological Engineering	10.1016/j.ecoleng.2008.12.026
61	Sirivedhin T., Gray K.A.	Factors affecting denitrification rates in experimental wetlands: Field and laboratory studies	2006	Ecological Engineering	10.1016/j.ecoleng.2005.09.001
62	Zhi W., Ji G.	Quantitative response relationships between nitrogen transformation rates and nitrogen functional genes in a tidal flow constructed wetland under C/N ratio constraints	2014	Water Research	10.1016/j.watres.2014.06.035
63	Tanner C.C., Headley T.R.	Components of floating emergent macrophyte treatment wetlands influencing removal of stormwater pollutants	2011	Ecological Engineering	10.1016/j.ecoleng.2010.12.012
64	Ye F., Li Y.	Enhancement of nitrogen removal in towery hybrid constructed wetland to treat domestic wastewater for small rural communities	2009	Ecological Engineering	10.1016/j.ecoleng.2009.03.009
65	Ouellet-Plamondon C., Chazarenc F., Comeau Y., Brisson J.	Artificial aeration to increase pollutant removal efficiency of constructed wetlands in cold climate	2006	Ecological Engineering	10.1016/j.ecoleng.2006.03.006
66	Teiter S., Mander Ü.	Emission of N_2O, N_2, CH_4, and CO_2 from constructed wetlands for wastewater treatment and from riparian buffer zones	2005	Ecological Engineering	10.1016/j.ecoleng.2005.07.011
67	Cooper P.	A review of the design and performance of vertical-flow and hybrid reed bed treatment systems	1999	Water Science and Technology	10.1016/S0273-1223(99)00414-X
68	Tanner C.C., Clayton J.S., Upsdell M.P.	Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands-I. Removal of oxygen demand, suspended solids and faecal coliforms	1995	Water Research	10.1016/0043-1354(94)00139-X

ID	Authors	Title	Year	Journal/Publisher	DOI
69	Tanner C.C., Kadlec R.H., Gibbs M.M., Sukias J.P.S., Nguyen M.L.	Nitrogen processing gradients in subsurface-flow treatment wetlands - Influence of wastewater characteristics	2002	Ecological Engineering	10.1016/S0925-8574(02)00011-3
73	Platzer C., Mauch K.	Soil clogging in vertical flow reed beds - Mechanisms, parameters, consequences and.......solutions?	1997	Water Science and Technology	10.1016/S0273-1223(97)00066-8
74	Verlicchi P., Zambello E.	How efficient are constructed wetlands in removing pharmaceuticals from untreated and treated urban wastewaters? A review	2014	Science of the Total Environment	10.1016/j.scitotenv.2013.10.085
75	Kalin M., Fyson A., Wheeler W.N.	The chemistry of conventional and alternative treatment systems for the neutralization of acid mine drainage	2006	Science of the Total Environment	10.1016/j.scitotenv.2005.11.015
76	Ryan C.C., Tan D.T., Arnold W.A.	Direct and indirect photolysis of sulfamethoxazole and trimethoprim in wastewater treatment plant effluent	2011	Water Research	10.1016/j.watres.2010.10.005
77	Wu H., Zhang J., Li P., Zhang J., Xie H., Zhang B.	Nutrient removal in constructed microcosm wetlands for treating polluted river water in northern China	2011	Ecological Engineering	10.1016/j.ecoleng.2010.11.020
79	Nivala J., Hoos M.B., Cross C., Wallace S., Parkin G.	Treatment of landfill leachate using an aerated, horizontal subsurface-flow constructed wetland	2007	Science of the Total Environment	10.1016/j.scitotenv.2006.12.030
80	Hijosa-Valsero M., et al.	Comprehensive assessment of the design configuration of constructed wetlands for the removal of pharmaceuticals and personal care products from urban wastewaters	2010	Water Research	10.1016/j.watres.2010.04.022
81	Yadav A.K., Dash P., Mohanty A., Abbassi R., Mishra B.K.	Performance assessment of innovative constructed wetland-microbial fuel cell for electricity production and dye removal	2012	Ecological Engineering	10.1016/j.ecoleng.2012.06.029
82	Tanner C.C., Sukias J.P.S., Upsdell M.P.	Organic matter accumulation during maturation of gravel-bed constructed wetlands treating farm dairy wastewaters	1998	Water Research	10.1016/S0043-1354(98)00078-5
83	Khan S., Ahmad I., Shah M.T., Rehman S., Khaliq A.	Use of constructed wetland for the removal of heavy metals from industrial wastewater	2009	Journal of Environmental Management	10.1016/j.jenvman.2009.05.026

ID	Authors	Title	Year	Journal/Publisher	DOI
84	Luederitz V., Eckert E., Lange-Weber M., Lange A., Gersberg R.M.	Nutrient removal efficiency and resource economics of vertical flow and horizontal flow constructed wetlands	2001	Ecological Engineering	10.1016/S0925-8574(01)00075-1
85	Carleton J.N., Grizzard T.J., Godrej A.N., Post H.E.	Factors affecting the performance of stormwater treatment wetlands	2001	Water Research	10.1016/S0043-1354(00)00416-4
86	Fraser L.H., Carty S.M., Steer D.	A test of four plant species to reduce total nitrogen and total phosphorus from soil leachate in subsurface wetland microcosms	2004	Bioresource Technology	10.1016/j.biortech.2003.11.023
87	Werker A.G., Dougherty J.M., McHenry J.L., Van Loon W.A.	Treatment variability for wetland wastewater treatment design in cold climates	2002	Ecological Engineering	10.1016/S0925-8574(02)00016-2
88	Breen P.F.	A mass balance method for assessing the potential of artificial wetlands for wastewater treatment	1990	Water Research	10.1016/0043-1354(90)90024-Z
89	Wu J., Zhang J., Jia W., Xie H., Gu R.R., Li C., Gao B.	Impact of COD/N ratio on nitrous oxide emission from microcosm wetlands and their performance in removing nitrogen from wastewater	2009	Bioresource Technology	10.1016/j.biortech.2009.01.056
91	Fang Z., Song H.-L., Cang N., Li X.-N.	Performance of microbial fuel cell coupled constructed wetland system for decolorization of azo dye and bioelectricity generation	2013	Bioresource Technology	10.1016/j.biortech.2013.06.073
92	Mitsch W.J.	Landscape design and the role of created, restored, and natural riparian wetlands in controlling nonpoint source pollution	1992	Ecological Engineering	10.1016/0925-8574(92)90024-V
93	Dong C.S., Ju S.C., Hong J.L., Jong S.H.	Phosphorus retention capacity of filter media for estimating the longevity of constructed wetland	2005	Water Research	10.1016/j.watres.2005.04.032
95	Dierberg F.E., DeBusk T.A., Jackson S.D., Chimney M.J., Pietro K.	Submerged aquatic vegetation-based treatment wetlands for removing phosphorus from agricultural runoff: Response to hydraulic and nutrient loading	2002	Water Research	10.1016/S0043-1354(01)00354-2
96	Iamchaturapatr J., Yi S.W., Rhee J.S.	Nutrient removals by 21 aquatic plants for vertical free surface-flow (VFS) constructed wetland	2007	Ecological Engineering	10.1016/j.ecoleng.2006.09.010
97	Coveney M.F., Stites D.L., Lowe E.F., Battoe L.E., Conrow R.	Nutrient removal from eutrophic lake water by wetland filtration	2002	Ecological Engineering	10.1016/S0925-8574(02)00037-X

ID	Authors	Title	Year	Journal/Publisher	DOI
99	Kyambadde J., Kansiime F., Gumaelius L., Dalhammar G.	A comparative study of Cyperus papyrus and Miscanthidium violaceum-based constructed wetlands for wastewater treatment in a tropical climate	2004	Water Research	10.1016/j.watres.2003.10.008
100	Gabet-Giraud V., Miège C., Choubert J.M., Ruel S.M., Coquery M.	Occurrence and removal of estrogens and beta blockers by various processes in wastewater treatment plants	2010	Science of the Total Environment	10.1016/j.scitotenv.2010.05.023
101	Zhang T.C., Lampe D.G.	Sulfur:limestone autotrophic denitrification processes for treatment of nitrate-contaminated water: Batch experiments	1999	Water Research	10.1016/S0043-1354(98)00281-4
102	Hijosa-Valsero M., et al.	Assessment of full-scale natural systems for the removal of PPCPs from wastewater in small communities	2010	Water Research	10.1016/j.watres.2009.10.032
104	Ingersoll T.L., Baker L.A.	Nitrate removal in wetland microcosms	1998	Water Research	10.1016/S0043-1354(97)00254-6
105	Hench K.R., et al.	Fate of physical, chemical, and microbial contaminants in domestic wastewater following treatment by small constructed wetlands	2003	Water Research	10.1016/S0043-1354(02)00377-9
108	Mitsch W.J.	What is ecological engineering?	2012	Ecological Engineering	10.1016/j.ecoleng.2012.04.013
109	Hammer D.A., Knight R.L.	Designing constructed wetlands for nitrogen removal	1994	Water Science and Technology	10.2166/wst.1994.0148
110	Gersberg R.M., Elkins B.V., Goldman C.R.	Nitrogen removal in artificial wetlands	1983	Water Research	10.1016/0043-1354(83)90041-6
115	Du B., et al.	Comparison of contaminants of emerging concern removal, discharge, and water quality hazards among centralized and on-site wastewater treatment system effluents receiving common wastewater influent	2014	Science of the Total Environment	10.1016/j.scitotenv.2013.07.126
123	Dong Z., Sun T.	A potential new process for improving nitrogen removal in constructed wetlands-Promoting coexistence of partial-nitrification and ANAMMOX	2007	Ecological Engineering	10.1016/j.ecoleng.2007.04.009

ID	Authors	Title	Year	Journal/Publisher	DOI
126	Carvalho P.N., Basto M.C.P., Almeida C.M.R., Brix H.	A review of plant–pharmaceutical interactions: from uptake and effects in crop plants to phytoremediation in constructed wetlands	2014	Environmental Science and Pollution Research	10.1007/s11356-014-2550-3
127	Chung A.K.C., Wu Y., Tam N.F.Y., Wong M.H.	Nitrogen and phosphate mass balance in a sub-surface flow constructed wetland for treating municipal wastewater	2008	Ecological Engineering	10.1016/j.ecoleng.2007.09.007
131	Song Z., Zheng Z., Li J., Sun X., Han X., Wang W., Xu M.	Seasonal and annual performance of a full-scale constructed wetland system for sewage treatment in China	2006	Ecological Engineering	10.1016/j.ecoleng.2005.10.008
133	Koottatep T., Polprasert C.	Role of plant uptake on nitrogen removal in constructed wetlands located in the tropics	1997	Water Science and Technology	10.1016/S0273-1223(97)00725-7
139	Li L., Li Y., Biswas D.K., Nian Y., Jiang G.	Potential of constructed wetlands in treating the eutrophic water: Evidence from Taihu Lake of China	2008	Bioresource Technology	10.1016/j.biortech.2007.04.001
142	Ansola G., Arroyo P., Sáenz de Miera L.E.	Characterisation of the soil bacterial community structure and composition of natural and constructed wetlands	2014	Science of the Total Environment	10.1016/j.scitotenv.2013.11.125
144	Mitsch W.J., Wise K.M.	Water quality, fate of metals, and predictive model validation of a constructed wetland treating acid mine drainage	1998	Water Research	10.1016/S0043-1354(97)00401-6
150	Dordio A., Carvalho A.J.P., Teixeira D.M., Dias C.B., Pinto A.P.	Removal of pharmaceuticals in microcosm constructed wetlands using Typha spp. and LECA	2010	Bioresource Technology	10.1016/j.biortech.2009.09.001
157	Ji G., Sun T., Zhou Q., Sui X., Chang S., Li P.	Constructed subsurface flow wetland for treating heavy oil-produced water of the Liaohe Oilfield in China	2002	Ecological Engineering	10.1016/S0925-8574(01)00106-9
159	Jing S.-R., Lin Y.-F., Lee D.-Y., Wang T.-W.	Nutrient removal from polluted river water by using constructed wetlands	2001	Bioresource Technology	10.1016/S0960-8524(00)00100-0
161	Kadlec R.H.	Chemical, physical and biological cycles in treatment wetlands	1999	Water Science and Technology	10.1016/S0273-1223(99)00417-5
162	Majer Newman J., Clausen J.C., Neafsey J.A.	Seasonal performance of a wetland constructed to process dairy milkhouse wastewater in Connecticut	1999	Ecological Engineering	10.1016/S0925-8574(99)00028-2

ID	Authors	Title	Year	Journal/Publisher	DOI
163	Hammer D.A.	Designing constructed wetlands systems to treat agricultural nonpoint source pollution	1992	Ecological Engineering	10.1016/0925-8574(92)90025-W
166	Ong S.-A., Uchiyama K., Inadama D., Ishida Y., Yamagiwa K.	Performance evaluation of laboratory scale up-flow constructed wetlands with different designs and emergent plants	2010	Bioresource Technology	10.1016/j.biortech.2010.04.032
167	Gopal B.	Natural and constructed wetlands for wastewater treatment: Potentials and problems	1999	Water Science and Technology	10.1016/S0273-1223(99)00468-0
169	Adrados B., Sánchez O., Arias C.A., Becares E., Garrido L., Mas J., Brix H., Morató J.	Microbial communities from different types of natural wastewater treatment systems: Vertical and horizontal flow constructed wetlands and biofilters	2014	Water Research	10.1016/j.watres.2014.02.011
174	Meng P., Pei H., Hu W., Shao Y., Li Z.	How to increase microbial degradation in constructed wetlands: Influencing factors and improvement measures	2014	Bioresource Technology	10.1016/j.biortech.2014.01.095
175	Travis M.J., Wiel-Shafran A., Weisbrod N., Adar E., Gross A.	Greywater reuse for irrigation: Effect on soil properties	2010	Science of the Total Environment	10.1016/j.scitotenv.2010.03.005
183	Villaseñor J., Capilla P., Rodrigo M.A., Cañizares P., Fernández F.J.	Operation of a horizontal subsurface flow constructed wetland - Microbial fuel cell treating wastewater under different organic loading rates	2013	Water Research	10.1016/j.watres.2013.09.005
184	Dong X., Reddy G.B.	Soil bacterial communities in constructed wetlands treated with swine wastewater using PCR-DGGE technique	2010	Bioresource Technology	10.1016/j.biortech.2009.09.071
191	Vymazal J., Kröpfelová L.	A three-stage experimental constructed wetland for treatment of domestic sewage: First 2 years of operation	2011	Ecological Engineering	10.1016/j.ecoleng.2010.03.004
200	Lee C.-Y., Lee C.-C., Lee F.-Y., Tseng S.-K., Liao C.-J.	Performance of subsurface flow constructed wetland taking pretreated swine effluent under heavy loads	2004	Bioresource Technology	10.1016/j.biortech.2003.08.012
205	Uggetti E., Ferrer I., Llorens E., García J.	Sludge treatment wetlands: A review on the state of the art	2010	Bioresource Technology	10.1016/j.biortech.2009.11.102

ID	Authors	Title	Year	Journal/Publisher	DOI
209	Ann Y., Reddy K.R., Delfino J.J.	Influence of chemical amendments on phosphorus immobilization in soils from a constructed wetland	1999	Ecological Engineering	10.1016/S0925-8574(99)00026-9
212	Calheiros C.S.C., et al.	Use of constructed wetland systems with Arundo and Sarcocornia for polishing high salinity tannery wastewater	2012	Journal of Environmental Management	10.1016/j.jenvman.2011.10.003
213	Trang N.T.D., Konnerup D., Schierup H.-H., Chiem N.H., Tuan L.A., Brix H.	Kinetics of pollutant removal from domestic wastewater in a tropical horizontal subsurface flow constructed wetland system: Effects of hydraulic loading rate	2010	Ecological Engineering	10.1016/j.ecoleng.2009.11.022
215	Chang J.-J., Wu S.-Q., Dai Y.-R., Liang W., Wu Z.-B.	Treatment performance of integrated vertical-flow constructed wetland plots for domestic wastewater	2012	Ecological Engineering	10.1016/j.ecoleng.2012.03.019
222	Ghaitidak D.M., Yadav K.D.	Characteristics and treatment of greywater-a review	2013	Environmental Science and Pollution Research	10.1007/s11356-013-1533-0
225	Bachand P.A.M., Horne A.J.	Denitrification in constructed free-water surface wetlands: I. Very high nitrate removal rates in a macrocosm study	1999	Ecological Engineering	10.1016/S0925-8574(99)00016-6
230	Kadlec R.H.	Overview: Surface flow constructed wetlands	1995	Water Science and Technology	10.1016/0273-1223(95)00599-4
231	Avila C., Reyes C., Bayona J.M., García J.	Emerging organic contaminant removal depending on primary treatment and operational strategy in horizontal subsurface flow constructed wetlands: Influence of redox	2013	Water Research	10.1016/j.watres.2012.10.005
237	Ong S.-A., Uchiyama K., Inadama D., Ishida Y., Yamagiwa K.	Treatment of azo dye Acid Orange 7 containing wastewater using up-flow constructed wetland with and without supplementary aeration	2010	Bioresource Technology	10.1016/j.biortech.2010.07.034
239	Liu S., Song H., Wei S., Yang F., Li X.	Bio-cathode materials evaluation and configuration optimization for power output of vertical subsurface flow constructed wetland - Microbial fuel cell systems	2014	Bioresource Technology	10.1016/j.biortech.2014.05.104
241	Zhi W., Ji G.	Constructed wetlands, 1991-2011: A review of research development, current trends, and future directions	2012	Science of the Total Environment	10.1016/j.scitotenv.2012.09.064

ID	Authors	Title	Year	Journal/Publisher	DOI
250	Winston R.J., et al.	Evaluation of floating treatment wetlands as retrofits to existing stormwater retention ponds	2013	Ecological Engineering	10.1016/j.ecoleng.2013.01.023
251	Wen Y., Chen Y., Zheng N., Yang D., Zhou Q.	Effects of plant biomass on nitrate removal and transformation of carbon sources in subsurface-flow constructed wetlands	2010	Bioresource Technology	10.1016/j.biortech.2010.04.068
254	Shehzadi M., Afzal M., Khan M.U., Islam E., Mobin A., Anwar S., Khan Q.M.	Enhanced degradation of textile effluent in constructed wetland system using Typha domingensis and textile effluent-degrading endophytic bacteria	2014	Water Research	10.1016/j.watres.2014.03.064
258	Ding Y., Song X., Wang Y., Yan D.	Effects of dissolved oxygen and influent COD/N ratios on nitrogen removal in horizontal subsurface flow constructed wetland	2012	Ecological Engineering	10.1016/j.ecoleng.2012.06.002
260	Chon K., Chang J.-S., Lee E., Lee J., Ryu J., Cho J.	Abundance of denitrifying genes coding for nitrate (narG), nitrite (nirS), and nitrous oxide (nosZ) reductases in estuarine versus wastewater effluent-fed constructed wetlands	2011	Ecological Engineering	10.1016/j.ecoleng.2009.04.005
262	Chen J., Wei X.-D., Liu Y.-S., Ying G.-G., Liu S.-S., He L.-Y., Su H.-C., Hu L.-X., Chen F.-R., Yang Y.-Q.	Removal of antibiotics and antibiotic resistance genes from domestic sewage by constructed wetlands: Optimization of wetland substrates and hydraulic loading	2016	Science of the Total Environment	10.1016/j.scitotenv.2016.04.176
273	Huang X., Liu C., Li K., Su J., Zhu G., Liu L.	Performance of vertical up-flow constructed wetlands on swine wastewater containing tetracyclines and tet genes	2015	Water Research	10.1016/j.watres.2014.11.048
280	Yi X., Tran N.H., Yin T., He Y., Gin K.Y.-H.	Removal of selected PPCPs, EDCs, and antibiotic resistance genes in landfill leachate by a full-scale constructed wetlands system	2017	Water Research	10.1016/j.watres.2017.05.008
285	Kabra A.N., Khandare R.V., Govindwar S.P.	Development of a bioreactor for remediation of textile effluent and dye mixture: A plant-bacterial synergistic strategy	2013	Water Research	10.1016/j.watres.2012.11.007
286	Tee H.-C., Lim P.-E., Seng C.-E., Nawi M.A.M.	Newly developed baffled subsurface-flow constructed wetland for the enhancement of nitrogen removal	2012	Bioresource Technology	10.1016/j.biortech.2011.11.032
287	Wu S., Austin D., Liu L., Dong R.	Performance of integrated household constructed wetland for domestic wastewater treatment in rural areas	2011	Ecological Engineering	10.1016/j.ecoleng.2011.02.002

ID	Authors	Title	Year	Journal/Publisher	DOI
296	Elgood Z., Robertson W.D., Schiff S.L., Elgood R.	Nitrate removal and greenhouse gas production in a stream-bed denitrifying bioreactor	2010	Ecological Engineering	10.1016/j.ecoleng.2010.03.011
302	Zhou X., Wang X., Zhang H., Wu H.	Enhanced nitrogen removal of low C/N domestic wastewater using a biochar-amended aerated vertical flow constructed wetland	2017	Bioresource Technology	10.1016/j.biortech.2017.05.072
303	Zhao Y.J., Liu B., Zhang W.G., Ouyang Y., An S.Q.	Performance of pilot-scale vertical-flow constructed wetlands in responding to variation in influent C/N ratios of simulated urban sewage	2010	Bioresource Technology	10.1016/j.biortech.2009.10.002
306	Srivastava P., Yadav A.K., Mishra B.K.	The effects of microbial fuel cell integration into constructed wetland on the performance of constructed wetland	2015	Bioresource Technology	10.1016/j.biortech.2015.05.072
328	Ghosh D., Gopal B.	Effect of hydraulic retention time on the treatment of secondary effluent in a subsurface flow constructed wetland	2010	Ecological Engineering	10.1016/j.ecoleng.2010.04.017
331	Song H.-L., Nakano K., Taniguchi T., Nomura M., Nishimura O.	Estrogen removal from treated municipal effluent in small-scale constructed wetland with different depth	2009	Bioresource Technology	10.1016/j.biortech.2009.01.045
350	Fuchs V.J., Mihelcic J.R., Gierke J.S.	Life cycle assessment of vertical and horizontal flow constructed wetlands for wastewater treatment considering nitrogen and carbon greenhouse gas emissions	2011	Water Research	10.1016/j.watres.2010.12.021
368	Krzeminski P., et al.	Performance of secondary wastewater treatment methods for the removal of contaminants of emerging concern implicated in crop uptake and antibiotic resistance spread: A review	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.08.130
371	Zhou S., Hosomi M.	Nitrogen transformations and balance in a constructed wetland for nutrient-polluted river water treatment using forage rice in Japan	2008	Ecological Engineering	10.1016/j.ecoleng.2007.10.004
378	Song K.-Y., Zoh K.-D., Kang H.	Release of phosphate in a wetland by changes in hydrological regime	2007	Science of the Total Environment	10.1016/j.scitotenv.2006.11.035
379	Sawaittayothin V., Polprasert C.	Nitrogen mass balance and microbial analysis of constructed wetlands treating municipal landfill leachate	2007	Bioresource Technology	10.1016/j.biortech.2006.02.002

ID	Authors	Title	Year	Journal/Publisher	DOI
386	White S.A., Cousins M.M.	Floating treatment wetland aided remediation of nitrogen and phosphorus from simulated stormwater runoff	2013	Ecological Engineering	10.1016/j.ecoleng.2013.09.020
403	Liang W., Wu Z.-B., Cheng S.-P., Zhou Q.-H., Hu H.-Y.	Roles of substrate microorganisms and urease activities in wastewater purification in a constructed wetland system	2003	Ecological Engineering	10.1016/j.ecoleng.2003.11.002
432	Ijaz A., Shabir G., Khan Q.M., Afzal M.	Enhanced remediation of sewage effluent by endophyte-assisted floating treatment wetlands	2015	Ecological Engineering	10.1016/j.ecoleng.2015.07.025
437	Singh S., et al.	Performance of an anaerobic baffled reactor and hybrid constructed wetland treating high-strength wastewater in Nepal-A model for DEWATS	2009	Ecological Engineering	10.1016/j.ecoleng.2008.10.019
438	Jayaweera M.W., Kasturiarachchi J.C., Kularatne R.K.A., Wijeyekoon S.L.J.	Contribution of water hyacinth (Eichhornia crassipes (Mart.) Solms) grown under different nutrient conditions to Fe-removal mechanisms in constructed wetlands	2008	Journal of Environmental Management	10.1016/j.jenvman.2007.01.013
439	Ji G.D., Sun T.H., Ni J.R.	Surface flow constructed wetland for heavy oil-produced water treatment	2007	Bioresource Technology	10.1016/j.biortech.2006.01.017
449	Richardson C.J., Flanagan N.E., Ho M., Pahl J.W.	Integrated stream and wetland restoration: A watershed approach to improved water quality on the landscape	2011	Ecological Engineering	10.1016/j.ecoleng.2010.09.005
452	Lu S.Y., Wu F.C., Lu Y.F., Xiang C.S., Zhang P.Y., Jin C.X.	Phosphorus removal from agricultural runoff by constructed wetland	2009	Ecological Engineering	10.1016/j.ecoleng.2008.10.002
456	Juwarkar A.S., Oke B., Juwarkar A., Patnaik S.M.	Domestic wastewater treatment through constructed wetland in India	1995	Water Science and Technology	10.1016/0273-1223(95)00637-0
505	Taylor C.R., Hook P.B., Stein O.R., Zabinski C.A.	Seasonal effects of 19 plant species on COD removal in subsurface treatment wetland microcosms	2011	Ecological Engineering	10.1016/j.ecoleng.2010.05.007
507	Leverenz H.L., Haunschild K., Hopes G., Tchobanoglous G., Darby J.L.	Anoxic treatment wetlands for denitrification	2010	Ecological Engineering	10.1016/j.ecoleng.2010.03.014

ID	Authors	Title	Year	Journal/Publisher	DOI
539	Sansanayuth P., et al.	Shrimp pond effluent : Pollution problems and treatment by constructed wetlands	1996	Water Science and Technology	10.1016/S0273-1223(96)00825-6
545	Weber K.P., Legge R.L.	Dynamics in the bacterial community-level physiological profiles and hydrological characteristics of constructed wetland mesocosms during start-up	2011	Ecological Engineering	10.1016/j.ecoleng.2010.03.016
548	Lee M.S., Drizo A., Rizzo D.M., Druschel G., Hayden N., Twohig E.	Evaluating the efficiency and temporal variation of pilot-scale constructed wetlands and steel slag phosphorus removing filters for treating dairy wastewater	2010	Water Research	10.1016/j.watres.2010.05.020
557	Wang C.-Y., Sample D.J.	Assessment of the nutrient removal effectiveness of floating treatment wetlands applied to urban retention ponds	2014	Journal of Environmental Management	10.1016/j.jenvman.2014.02.008
568	Carlson J.C., et al.	Presence and hazards of nutrients and emerging organic micropollutants from sewage lagoon discharges into Dead Horse Creek, Manitoba, Canada	2013	Science of the Total Environment	10.1016/j.scitotenv.2012.11.100
575	Billore S.K., et al.	Treatment of a molasses based distillery effluent in a constructed wetland in central India	2001	Water Science and Technology	10.1007/s11356-019-04832-9
584	Aslam M.M., Malik M., Baig M.A., Qazi I.A., Iqbal J.	Treatment performances of compost-based and gravel-based vertical flow wetlands operated identically for refinery wastewater treatment in Pakistan	2007	Ecological Engineering	10.1016/j.ecoleng.2007.01.002
593	Lynch J., Fox L.J., Owen Jr. J.S., Sample D.J.	Evaluation of commercial floating treatment wetland technologies for nutrient remediation of stormwater	2015	Ecological Engineering	10.1016/j.ecoleng.2014.11.001
597	Sims A., Gajaraj S., Hu Z.	Seasonal population changes of ammonia-oxidizing organisms and their relationship to water quality in a constructed wetland	2012	Ecological Engineering	10.1016/j.ecoleng.2011.12.021
621	Wang H., Zhong H., Bo G.	Existing forms and changes of nitrogen inside of horizontal subsurface constructed wetlands	2018	Environmental Science and Pollution Research	10.1007/s11356-017-0477-1
664	Chang N.-B., Xuan Z., Marimon Z., Islam K., Wanielista M.P.	Exploring hydrobiogeochemical processes of floating treatment wetlands in a subtropical stormwater wet detention pond	2013	Ecological Engineering	10.1016/j.ecoleng.2013.01.019

ID	Authors	Title	Year	Journal/Publisher	DOI
665	Rai U.N., et al.	Constructed wetland as an ecotechnological tool for pollution treatment for conservation of Ganga river	2013	Bioresource Technology	10.1016/j.biortech.2013.09.005
672	Zhou X., Liang C., Jia L., Feng L., Wang R., Wu H.	An innovative biochar-amended substrate vertical flow constructed wetland for low C/N wastewater treatment: Impact of influent strengths	2018	Bioresource Technology	10.1016/j.biortech.2017.09.044
679	Kadlec R.H., Zmarthie L.A.	Wetland treatment of leachate from a closed landfill	2010	Ecological Engineering	10.1016/j.ecoleng.2010.04.013
713	Khatiwada N.R., Polprasert C.	Kinetics of fecal coliform removal in constructed wetlands	1999	Water Science and Technology	10.1016/S0273-1223(99)00446-1
729	Rai U.N., Upadhyay A.K., Singh N.K., Dwivedi S., Tripathi R.D.	Seasonal applicability of horizontal sub-surface flow constructed wetland for trace elements and nutrient removal from urban wastes to conserve Ganga River water quality at Haridwar, India	2015	Ecological Engineering	10.1016/j.ecoleng.2015.04.039
746	Kantawanichkul S., et al.	Wastewater treatment by tropical plants in vertical-flow constructed wetlands	1999	Water Science and Technology	10.1016/S0273-1223(99)00462-X
755	Nguyen M.T., Jasper J.T., Boehm A.B., Nelson K.L.	Sunlight inactivation of fecal indicator bacteria in open-water unit process treatment wetlands: Modeling endogenous and exogenous inactivation rates	2015	Water Research	10.1016/j.watres.2015.06.043
779	Hussain S.A., Prasher S.O., Patel R.M.	Removal of ionophoric antibiotics in free water surface constructed wetlands	2012	Ecological Engineering	10.1016/j.ecoleng.2011.12.006
799	Sehar S., Sumera, Naeem S., Perveen I., Ali N., Ahmed S.	A comparative study of macrophytes influence on wastewater treatment through subsurface flow hybrid constructed wetland	2015	Ecological Engineering	10.1016/j.ecoleng.2015.04.009
818	Polprasert C., Dan N.P., Thayalakumaran N.	Application of constructed wetlands to treat some toxic wastewaters under tropical conditions	1996	Water Science and Technology	10.1016/S0273-1223(96)00834-7
832	Valipour A., Kalyan Raman V., Ghole V.S.	A new approach in wetland systems for domestic wastewater treatment using Phragmites sp.	2009	Ecological Engineering	10.1016/j.ecoleng.2009.08.004

ID	Authors	Title	Year	Journal/Publisher	DOI
941	Ijaz A., Iqbal Z., Afzal M.	Remediation of sewage and industrial effluent using bacterially assisted floating treatment wetlands vegetated with Typha domingensis	2016	Water Science and Technology	10.2166/wst.2016.405
964	Luo P., Liu F., Zhang S., Li H., Yao R., Jiang Q., Xiao R., Wu J.	Nitrogen removal and recovery from lagoon-pretreated swine wastewater by constructed wetlands under sustainable plant harvesting management	2018	Bioresource Technology	10.1016/j.biortech.2018.03.017
965	Li X., Zhang M., Liu F., Chen L., Li Y., Li Y., Xiao R., Wu J.	Seasonality distribution of the abundance and activity of nitrification and denitrification microorganisms in sediments of surface flow constructed wetlands planted with Myriophyllum elatinoides during swine wastewater treatment	2018	Bioresource Technology	10.1016/j.biortech.2017.06.102
990	Si Z., Song X., Wang Y., Cao X., Zhao Y., Wang B., Chen Y., Arefe A.	Intensified heterotrophic denitrification in constructed wetlands using four solid carbon sources: Denitrification efficiency and bacterial community structure	2018	Bioresource Technology	10.1016/j.biortech.2018.07.029
991	Arden S., Ma X.	Constructed wetlands for greywater recycle and reuse: A review	2018	Science of the Total Environment	10.1016/j.scitotenv.2018.02.218
992	Du L., Trinh X., Chen Q., Wang C., Wang H., Xia X., Zhou Q., Xu D., Wu Z.	Enhancement of microbial nitrogen removal pathway by vegetation in Integrated Vertical-Flow Constructed Wetlands (IVCWs) for treating reclaimed water	2018	Bioresource Technology	10.1016/j.biortech.2017.10.074
995	Arivoli A., Mohanraj R., Seenivasan R.	Application of vertical flow constructed wetland in treatment of heavy metals from pulp and paper industry wastewater	2015	Environmental Science and Pollution Research	10.1007/s11356-015-4594-4
1013	Chandra R., Yadav S., Bharagava R.N., Murthy R.C.	Bacterial pretreatment enhances removal of heavy metals during treatment of post-methanated distillery effluent by Typha angustata L.	2008	Journal of Environmental Management	10.1016/j.jenvman.2007.05.001
1048	Fu G., Yu T., Huangshen L., Han J.	The influence of complex fermentation broth on denitrification of saline sewage in constructed wetlands by heterotrophic nitrifying/aerobic denitrifying bacterial communities	2018	Bioresource Technology	10.1016/j.biortech.2017.11.057
1055	Badhe N., Saha S., Biswas R., Nandy T.	Role of algal biofilm in improving the performance of free surface, up-flow constructed wetland	2014	Bioresource Technology	10.1016/j.biortech.2014.07.050

ID	Authors	Title	Year	Journal/Publisher	DOI
1074	Kasak K., Truu J., Ostonen I., Sarjas J., Oopkaup K., Paiste P., Kõiv-Vainik M., Mander Ü., Truu M.	Biochar enhances plant growth and nutrient removal in horizontal subsurface flow constructed wetlands	2018	Science of the Total Environment	10.1016/j.scitotenv.2018.05.146
1159	Billore S.K., Prashant, Sharma J.K.	Treatment performance of artificial floating reed beds in an experimental mesocosm to improve the water quality of river Kshipra	2009	Water Science and Technology	10.2166/wst.2009.731
1172	Liu T., Xu S., Lu S., Qin P., Bi B., Ding H., Liu Y., Guo X., Liu X.	A review on removal of organophosphorus pesticides in constructed wetland: Performance, mechanism and influencing factors	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.10.087
1173	Masi F., Rizzo A., Regelsberger M.	The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm	2018	Journal of Environmental Management	10.1016/j.jenvman.2017.11.086
1174	Xie T., Jing Z., Hu J., Yuan P., Liu Y., Cao S.	Degradation of nitrobenzene-containing wastewater by a microbial-fuel-cell-coupled constructed wetland	2018	Ecological Engineering	10.1016/j.ecoleng.2017.12.018
1213	Shrestha R.R., Haberl R., Laber J., Manandhar R., Mader J.	Application of constructed wetlands for wastewater treatment in Nepal	2001	Water Science and Technology	10.2166/wst.2001.0855
1215	Xianfa L., Chuncai J.	Constructed wetland systems for water pollution control in North China	1995	Water Science and Technology	10.1016/0273-1223(95)00638-9
1219	Corbella C., Puigagut J.	Improving domestic wastewater treatment efficiency with constructed wetland microbial fuel cells: Influence of anode material and external resistance	2018	Science of the Total Environment	10.1016/j.scitotenv.2018.03.084
1259	Ashraf S., Naveed M., Zahir Z.A., Afzal M., Rehman K.	Plant-endophyte synergism in constructed wetlands enhances the remediation of tannery effluent	2018	Water Science and Technology	10.2166/wst.2018.004
1300	Yang Y., Zhencheng X., Kangping H., Junsan W., Guizhi W.	Removal efficiency of the constructed wetland wastewater treatment system at Bainikeng, Shenzhen	1995	Water Science and Technology	10.1016/0273-1223(95)00602-8

ID	Authors	Title	Year	Journal/Publisher	DOI
1303	Xie H., Yang Y., Liu J., Kang Y., Zhang J., Hu Z., Liang S.	Enhanced triclosan and nutrient removal performance in vertical up-flow constructed wetlands with manganese oxides	2018	Water Research	10.1016/j.watres.2018.05.061
1305	Gao L., Zhou W., Wu S., He S., Huang J., Zhang X.	Nitrogen removal by thiosulfate-driven denitrification and plant uptake in enhanced floating treatment wetland	2018	Science of the Total Environment	10.1016/j.scitotenv.2017.10.073
1306	Hua G., Cheng Y., Kong J., Li M., Zhao Z.	High-throughput sequencing analysis of bacterial community spatiotemporal distribution in response to clogging in vertical flow constructed wetlands	2018	Bioresource Technology	10.1016/j.biortech.2017.07.061
1307	He S., Wang Y., Li C., Li Y., Zhou J.	The nitrogen removal performance and microbial communities in a two-stage deep sequencing constructed wetland for advanced treatment of secondary effluent	2018	Bioresource Technology	10.1016/j.biortech.2017.06.150
1340	Ge Z., Wei D., Zhang J., Hu J., Liu Z., Li R.	Natural pyrite to enhance simultaneous long-term nitrogen and phosphorus removal in constructed wetland: Three years of pilot study	2019	Water Research	10.1016/j.watres.2018.10.037
1341	Vymazal J., Březinová T.D.	Removal of nutrients, organics and suspended solids in vegetated agricultural drainage ditch	2018	Ecological Engineering	10.1016/j.ecoleng.2018.04.013
1342	Prum C., Dolphen R., Thiravetyan P.	Enhancing arsenic removal from arsenic-contaminated water by Echinodorus cordifolius–endophytic Arthrobacter creatinolyticus interactions	2018	Journal of Environmental Management	10.1016/j.jenvman.2018.02.060
1344	Zhang L., Sun Z., Xie J., Wu J., Cheng S.	Nutrient removal, biomass accumulation and nitrogen-transformation functional gene response to different nitrogen forms in enhanced floating treatment wetlands	2018	Ecological Engineering	10.1016/j.ecoleng.2017.12.021
1345	Nuel M., Laurent J., Bois P., Heintz D., Wanko A.	Seasonal and ageing effect on the behaviour of 86 drugs in a full-scale surface treatment wetland: Removal efficiencies and distribution in plants and sediments	2018	Science of the Total Environment	10.1016/j.scitotenv.2017.10.061
1379	Panswad T., Chavalparit O.	Water quality and occurrences of protozoa and metazoa in two constructed wetlands treating different wastewaters in Thailand	1997	Water Science and Technology	10.1016/S0273-1223(97)00726-9
1380	Yu H., Tay J.-H., Wilson F.	A sustainable municipal wastewater treatment process for tropical and subtropical regions in developing countries	1997	Water Science and Technology	10.1016/S0273-1223(97)00197-2

ID	Authors	Title	Year	Journal/Publisher	DOI
1382	Yin H., Shen W.	Using reed beds for winter operation of wetland treatment system for wastewater	1995	Water Science and Technology	10.1016/0273-1223(95)00611-7
1385	Wang Y., Lin Z., Wang Y., Huang W., Wang J., Zhou J., He Q.	Sulfur and iron cycles promoted nitrogen and phosphorus removal in electrochemically assisted vertical flow constructed wetland treating wastewater treatment plant effluent with high S/N ratio	2019	Water Research	10.1016/j.watres.2018.12.005
1425	Hou J., Wang X., Wang J., Xia L., Zhang Y., Li D., Ma X.	Pathway governing nitrogen removal in artificially aerated constructed wetlands: Impact of aeration mode and influent chemical oxygen demand to nitrogen ratios	2018	Bioresource Technology	10.1016/j.biortech.2018.02.042
1471	Liu F.-F., Fan J., Du J., Shi X., Zhang J., Shen Y.	Intensified nitrogen transformation in intermittently aerated constructed wetlands: Removal pathways and microbial response mechanism	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.10.037
1472	Nivala J., et al.	Dynamics of emerging organic contaminant removal in conventional and intensified subsurface flow treatment wetlands	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.08.339
1473	Zheng X., Jin M., Zhou X., Chen W., Lu D., Zhang Y., Shao X.	Enhanced removal mechanism of iron carbon micro-electrolysis constructed wetland on C, N, and P in salty permitted effluent of wastewater treatment plant	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.08.195
1475	Yakar A., Türe C., Türker O.C., Vymazal J., Saz Ç.	Impacts of various filtration media on wastewater treatment and bioelectric production in up-flow constructed wetland combined with microbial fuel cell (UCW-MFC)	2018	Ecological Engineering	10.1016/j.ecoleng.2018.03.016
1476	Saz Ç., Türe C., Türker O.C., Yakar A.	Effect of vegetation type on treatment performance and bioelectric production of constructed wetland modules combined with microbial fuel cell (CW-MFC) treating synthetic wastewater	2018	Environmental Science and Pollution Research	10.1007/s11356-018-1208-y
1517	Polprasert C., Khatiwada N.R., Bhurtel J.	A model for organic matter removal in free water surface constructed wetlands	1998	Water Science and Technology	10.1016/S0273-1223(98)00423-5
1521	Kasprzyk M., Gajewska M.	Phosphorus removal by application of natural and semi-natural materials for possible recovery according to assumptions of circular economy and closed circuit of P	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.09.034

ID	Authors	Title	Year	Journal/Publisher	DOI
1522	Freeman A.I., Surridge B.W.J., Matthews M., Stewart M., Haygarth P.M.	New approaches to enhance pollutant removal in artificially aerated wastewater treatment systems	2018	Science of the Total Environment	10.1016/j.scitotenv.2018.01.261
1535	Upadhyay A.K., Bankoti N.S., Rai U.N.	Studies on sustainability of simulated constructed wetland system for treatment of urban waste: Design and operation	2016	Journal of Environmental Management	10.1016/j.jenvman.2016.01.004
1567	Khatiwada N.R., Polprasert C.	Assessment of effective specific surface area for free water surface constructed wetlands	1999	Water Science and Technology	10.1016/S0273-1223(99)00443-6
1574	Mendes L.R.D., Tonderski K., Iversen B.V., Kjaergaard C.	Phosphorus retention in surface-flow constructed wetlands targeting agricultural drainage water	2018	Ecological Engineering	10.1016/j.ecoleng.2018.05.022
1576	Xu X., Mills G.L.	Do constructed wetlands remove metals or increase metal bioavailability?	2018	Journal of Environmental Management	10.1016/j.jenvman.2018.04.014
1621	Walaszek M., Bois P., Laurent J., Lenormand E., Wanko A.	Urban stormwater treatment by a constructed wetland: Seasonality impacts on hydraulic efficiency, physico-chemical behavior and heavy metal occurrence	2018	Science of the Total Environment	10.1016/j.scitotenv.2018.04.325
1622	Park J.B.K., Craggs R.J., Tanner C.C.	Eco-friendly and low-cost Enhanced Pond and Wetland (EPW) system for the treatment of secondary wastewater effluent	2018	Ecological Engineering	10.1016/j.ecoleng.2018.05.029
1624	Petrie B., Rood S., Smith B.D., Proctor K., Youdan J., Barden R., Kasprzyk-Hordern B.	Biotic phase micropollutant distribution in horizontal sub-surface flow constructed wetlands	2018	Science of the Total Environment	10.1016/j.scitotenv.2018.02.242
1626	Ilyas H., Masih I.	The effects of different aeration strategies on the performance of constructed wetlands for phosphorus removal	2018	Environmental Science and Pollution Research	10.1007/s11356-017-1071-2
1674	Shrestha R.R., Haberl R., Laber J.	Constructed Wetland technology transfer to Nepal	2001	Water Science and Technology	10.2166/wst.2001.0701
1677	Tang S.-y.	Experimental study of a constructed wetland for treatment of acidic wastewater from an iron mine in China	1993	Ecological Engineering	10.1016/0925-8574(93)90018-B

ID	Authors	Title	Year	Journal/Publisher	DOI
1682	Flores L., García J., Pena R., Garfí M.	Constructed wetlands for winery wastewater treatment: A comparative Life Cycle Assessment	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.12.348
1684	Shuai W., Jaffé P.R.	Anaerobic ammonium oxidation coupled to iron reduction in constructed wetland mesocosms	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.08.189
1719	Chandra R., Naresh Bharagava R., Kapley A., Purohit H.J.	Characterization of Phragmites cummunis rhizosphere bacterial communities and metabolic products during the two stage sequential treatment of post methanated distillery effluent by bacteria and wetland plants	2012	Bioresource Technology	10.1016/j.biortech.2011.09.132
1741	Kołecka K., Gajewska M., Stepnowski P., Caban M.	Spatial distribution of pharmaceuticals in conventional wastewater treatment plant with Sludge Treatment Reed Beds technology	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.07.439
1742	Gorito A.M., Ribeiro A.R., Gomes C.R., Almeida C.M.R., Silva A.M.T.	Constructed wetland microcosms for the removal of organic micropollutants from freshwater aquaculture effluents	2018	Science of the Total Environment	10.1016/j.scitotenv.2018.06.371
1747	Hansen A.M., Kraus T.E.C., Bachand S.M., Horwath W.R., Bachand P.A.M.	Wetlands receiving water treated with coagulants improve water quality by removing dissolved organic carbon and disinfection byproduct precursors	2018	Science of the Total Environment	10.1016/j.scitotenv.2017.11.205
1814	Tondera K., Ruppelt J.P., Pinnekamp J., Kistemann T., Schreiber C.	Reduction of micropollutants and bacteria in a constructed wetland for combined sewer overflow treatment after 7 and 10 years of operation	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.09.174
1818	Herrera-Melián J.A., Guedes-Alonso R., Borreguero-Fabelo A., Santana-Rodríguez J.J., Sosa-Ferrera Z.	Study on the removal of hormones from domestic wastewaters with lab-scale constructed wetlands with different substrates and flow directions	2018	Environmental Science and Pollution Research	10.1007/s11356-017-9307-8
1829	Patil Y.M., Munavalli G.R.	Performance evaluation of an Integrated On-site Greywater Treatment System in a tropical region	2016	Ecological Engineering	10.1016/j.ecoleng.2016.06.078
1873	Garcia Chanc L.M., Van Brunt S.C., Majsztrik J.C., White S.A.	Short- and long-term dynamics of nutrient removal in floating treatment wetlands	2019	Water Research	10.1016/j.watres.2019.05.012

ID	Authors	Title	Year	Journal/Publisher	DOI
1874	Rahman M.M., Roberts K.L., Grace M.R., Kessler A.J., Cook P.L.M.	Role of organic carbon, nitrate and ferrous iron on the partitioning between denitrification and DNRA in constructed stormwater urban wetlands	2019	Science of the Total Environment	10.1016/j.scitotenv.2019.02.225
1880	Garcia Chance L.M., White S.A.	Aeration and plant coverage influence floating treatment wetland remediation efficacy	2018	Ecological Engineering	10.1016/j.ecoleng.2018.07.011
1883	Drake C.W., Jones C.S., Schilling K.E., Amado A.A., Weber L.J.	Estimating nitrate-nitrogen retention in a large constructed wetland using high-frequency, continuous monitoring and hydrologic modeling	2018	Ecological Engineering	10.1016/j.ecoleng.2018.03.014
1925	Rana S., Jana J., Bag S.K., Mukherjee Roy S., Biswas J.K., Ganguly Lahiri S., Sarkar Paria D., Jana B.B.	Performance of constructed wetlands in the reduction of cadmium in a sewage treatment cum fish farm at Kalyani, West Bengal, India	2011	Ecological Engineering	10.1016/j.ecoleng.2011.08.002
1952	Shingare R.P., Thawale P.R., Raghunathan K., Mishra A., Kumar S.	Constructed wetland for wastewater reuse: Role and efficiency in removing enteric pathogens	2019	Journal of Environmental Management	10.1016/j.jenvman.2019.05.157
1953	Kiiskila J.D., Sarkar D., Panja S., Sahi S.V., Datta R.	Remediation of acid mine drainage-impacted water by vetiver grass (Chrysopogon zizanioides): A multiscale long-term study	2019	Ecological Engineering	10.1016/j.ecoleng.2019.01.018
1957	Liang Y.L., Kraus T.E.C., Silva L.C.R., Bachand P.A.M., Bachand S.M., Doane T.A., Horwath W.R.	Effects of ferric sulfate and polyaluminum chloride coagulation enhanced treatment wetlands on Typha growth, soil and water chemistry	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.07.341
1962	Nesbit T.A., Mitsch W.J.	Hurricane and seasonal effects on hydrology and water quality of a subtropical urban stormwater wetland	2018	Ecological Engineering	10.1016/j.ecoleng.2018.05.041
1965	Ajaero C., Peru K.M., Simair M., Friesen V., O'Sullivan G., Hughes S.A., McMartin D.W., Headley J.V.	Fate and behavior of oil sands naphthenic acids in a pilot-scale treatment wetland as characterized by negative-ion electrospray ionization Orbitrap mass spectrometry	2018	Science of the Total Environment	10.1016/j.scitotenv.2018.03.079

ID	Authors	Title	Year	Journal/Publisher	DOI
1989	Das Gupta A., Sarkar S., Ghosh P., Saha T., Sil A.K.	Phosphorous dynamics of the aquatic system constitutes an important axis for waste water purification in natural treatment pond(s) in East Kolkata Wetlands	2016	Ecological Engineering	10.1016/j.ecoleng.2016.01.056
2046	Biagi K.M., Oswald C.J., Nicholls E.M., Carey S.K.	Increases in salinity following a shift in hydrologic regime in a constructed wetland watershed in a post-mining oil sands landscape	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.10.341
2050	Sardana A., Cottrell B., Soulsby D., Aziz T.N.	Dissolved organic matter processing and photoreactivity in a wastewater treatment constructed wetland	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.08.138
2052	Kumar S., Dutta V.	Constructed wetland microcosms as sustainable technology for domestic wastewater treatment: an overview	2019	Environmental Science and Pollution Research	10.1007/s11356-019-04816-9
2056	Bock E.M., Coleman B.S.L., Easton Z.M.	Performance of an under-loaded denitrifying bioreactor with biochar amendment	2018	Journal of Environmental Management	10.1016/j.jenvman.2018.03.111
2057	Verma R., Suthar S.	Performance assessment of horizontal and vertical surface flow constructed wetland system in wastewater treatment using multivariate principal component analysis	2018	Ecological Engineering	10.1016/j.ecoleng.2018.02.022
2119	Spangler J.T., Sample D.J., Fox L.J., Owen J.S., Jr., White S.A.	Floating treatment wetland aided nutrient removal from agricultural runoff using two wetland species	2019	Ecological Engineering	10.1016/j.ecoleng.2018.12.017
2121	Button M., Cosway K., Sui J., Weber K.	Impacts and fate of triclosan and sulfamethoxazole in intensified re-circulating vertical flow constructed wetlands	2019	Science of the Total Environment	10.1016/j.scitotenv.2018.08.395
2130	Stumpner E.B., et al.	Sediment accretion and carbon storage in constructed wetlands receiving water treated with metal-based coagulants	2018	Ecological Engineering	10.1016/j.ecoleng.2017.10.016
2149	Kumar M., Singh R.	Performance evaluation of semi continuous vertical flow constructed wetlands (SC-VF-CWs) for municipal wastewater treatment	2017	Bioresource Technology	10.1016/j.biortech.2017.02.026

ID	Authors	Title	Year	Journal/Publisher	DOI
2204	Bachand S.M., Kraus T.E.C., Stern D., Liang Y.L., Horwath W.R., Bachand P.A.M.	Aluminum- and iron-based coagulation for in-situ removal of dissolved organic carbon, disinfection byproducts, mercury and other constituents from agricultural drain water	2019	Ecological Engineering	10.1016/j.ecoleng.2019.02.015
2211	Tao W.	Microbial removal and plant uptake of nitrogen in constructed wetlands: mesocosm tests on influencing factors	2018	Environmental Science and Pollution Research	10.1007/s11356-018-3543-4
2234	Zamorano M.F., Piccone T., Chimney M.J.	Effects of short-duration hydraulic pulses on the treatment performance of a periphyton-based treatment wetland	2018	Ecological Engineering	10.1016/j.ecoleng.2017.11.004
2283	Sonavane P.G., Munavalli G.R.	Modeling nitrogen removal in a constructed wetland treatment system	2009	Water Science and Technology	10.2166/wst.2009.319
2299	Kurihara Y., Suzuki T.	Removal of heavy metals and sewage sludge using the mud snail, Cipangopaludina chinensis malleata REEVE, in paddy fields as artificial wetlands	1987	Water Science and Technology	10.2166/wst.1987.0157
2313	Spangler J.T., Sample D.J., Fox L.J., Albano J.P., White S.A.	Assessing nitrogen and phosphorus removal potential of five plant species in floating treatment wetlands receiving simulated nursery runoff	2019	Environmental Science and Pollution Research	10.1007/s11356-018-3964-0
2318	D'Acunha B., Johnson M.S.	Water quality and greenhouse gas fluxes for stormwater detained in a constructed wetland	2019	Journal of Environmental Management	10.1016/j.jenvman.2018.10.106
2329	Hendrikse M., et al.	Treatment of oil sands process-affected waters using a pilot-scale hybrid constructed wetland	2018	Ecological Engineering	10.1016/j.ecoleng.2018.02.009
2446	Rehman F., Pervez A., Mahmood Q., Nawab B.	Wastewater remediation by optimum dissolve oxygen enhanced by macrophytes in constructed wetlands	2017	Ecological Engineering	10.1016/j.ecoleng.2017.01.030
2561	Prashant, Billore S.K., Sharma J.K., Singh N., Ram H.	Treatment of wastewater and restoration of aquatic systems through an eco-technology based constructed treatment wetlands - A successful experience in Central India	2013	Water Science and Technology	10.2166/wst.2013.401

ID	Authors	Title	Year	Journal/Publisher	DOI
2597	Saeed T., Majed N., Khan T., Mallika H.	Two-stage constructed wetland systems for polluted surface water treatment	2019	Journal of Environmental Management	10.1016/j.jenvman.2019.109379
2685	Rajasekhar B., et al.	Comprehensive treatment of urban wastewaters using electrochemical advanced oxidation process	2020	Journal of Environmental Management	10.1016/j.jenvman.2020.110469
2722	Batool A.	Metal accumulation from leachate by polyculture in crushed brick and steel slag using pilot-scale constructed wetland in the climate of Pakistan	2019	Environmental Science and Pollution Research	10.1007/s11356-019-06211-w
2743	Tai Tang V., Pakshirajan K.	Novel advanced porous concrete in constructed wetlands: Preparation, characterization and application in urban storm runoff treatment	2018	Water Science and Technology	10.2166/wst.2018.528
2747	Sharma P.K., Minakshi D., Rani A., Malaviya P.	Treatment efficiency of vertical flow constructed wetland systems operated under different recirculation rates	2018	Ecological Engineering	10.1016/j.ecoleng.2018.07.004
2783	Dhangar K., Kumar M.	Tricks and tracks in removal of emerging contaminants from the wastewater through hybrid treatment systems: A review	2020	Science of the Total Environment	10.1016/j.scitotenv.2020.140320
2786	Rampuria A., Gupta A.B., Brighu U.	Nitrogen transformation processes and mass balance in deep constructed wetlands treating sewage, exploring the anammox contribution	2020	Bioresource Technology	10.1016/j.biortech.2020.123737
2810	Saeed T., Miah M.J., Majed N., Hasan M., Khan T.	Pollutant removal from landfill leachate employing two-stage constructed wetland mesocosms: co-treatment with municipal sewage	2020	Environmental Science and Pollution Research	10.1007/s11356-020-09208-y
2899	Kumar M., Singh R.	Assessment of pollutant removal processes and kinetic modelling in vertical flow constructed wetlands at elevated pollutant loading	2019	Environmental Science and Pollution Research	10.1007/s11356-019-05019-y
2924	Bista K.R., Khatiwada N.R., Khyaju S.	Kinetics of organic matter and ammonia removal in horizontal reed beds treating wastewater in Nepal	2015	Water Science and Technology	10.2166/wst.2015.410

ID	Authors	Title	Year	Journal/Publisher	DOI
H1	Kivaisi AK	The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review	2001	Ecol Eng	
H2	Kadlec RH, Wallace S	Treatment wetlands	2008	CRC press	
H3	Smith BR	Re-thinking wastewater landscapes: combining innovative strategies to address tomorrow's urban wastewater treatment challenges	2009	Water Sci Technol	
H4	Gutterer B, Sasse L, Panzerbieter T, Reckerzügel T	Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries: A Practical Guide	2009	WEDC and BORDA	
H5	Bunting SW, Pretty J, Edwards P	Wastewater-fed aquaculture in the East Kolkata Wetlands, India: anachronism or archetype for resilient ecocultures?: Wastewater-fed aquaculture in the EKW	2010	Reviews in Aquaculture	
H6	Hoffmann H, Platzer C, Winker M, von Muench E	Technology review of constructed wetlands: Subsurface flow constructed wetlands for greywater and domestic wastewater treatment	2011	Deutsche Gesellschaft für Internationale Zusammenarbeit	
H7	Grant SB, et al.	Taking the "waste" out of "wastewater" for human water security and ecosystem sustainability	2012	Science	
H8	Ministry of Drinking Water & Sanitation	National Rural Drinking Water Programme Guidelines 2013	2013	Government of India	
H9	Zhang DQ, Jinadasa KBSN, Gersberg RM, Liu Y, Ng WJ, Tan SK	Application of constructed wetlands for wastewater treatment in developing countries–a review of recent developments (2000-2013)	2014	J Environ Manage	
H10	Brands E	Prospects and challenges for sustainable sanitation in developed nations: a critical review	2014	Environ Rev	
H11	Ministry of Drinking Water and Sanitation	Technological Options for Solid and Liquid Waste Management in Rural Areas	2015	Government of India	
H12	Wintgens T, Nattorp A, Elango L, Asolekar SR	Natural Water Treatment Systems for Safe and Sustainable Water Supply in the Indian Context: Saph Pani	2016	IWA Publishing	

ID	Authors	Title	Year	Journal/Publisher	DOI
H13	Masi F, Rizzo A, Regelsberger M	The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm	2018	J Environ Manage	
H14	Harris-Lovett S, Lienert J, Sedlak DL	Towards a New Paradigm of Urban Water Infrastructure: Identifying Goals and Strategies to Support Multi-Benefit Municipal Wastewater Treatment	2018	Water	
H15	Cunningham C, Gharipour M	Pipe Dreams: Urban Wastewater Treatment for Biodiversity Protection	2018	Urban Science	
H16	WWAP (United Nations World Water Assessment Programme)/UN-Water	The United Nations World Water Development Report 2018: Nature-Based Solutions for Water	2018	WWAP (United Nations World Water Assessment Programme)/UN-Water	
H17	Constructed Wetland Association, UK	Summary of Conference: CWA Annual Conference 2019	2019	Constructed Wetland Association	
H18	Department of Biotechnology, Ministry of Science and Technology	Manual on Constructed Wetlands as an Alternative Technology for Sewage Management in India	2019	Central Pollution Control Board	
H19	Lin Y, et al	The Potential of Constructed Wetland Plants for Bioethanol Production	2019	Bioenergy Res	
H20	Yenkie KM	Integrating the three E's in wastewater treatment: efficient design, economic viability, and environmental sustainability	2019	Curr Opin Chem Eng	
H21	Boano F, et al	A review of nature-based solutions for greywater treatment: applications, hydraulic design, and environmental benefits	2019	Sci Total Environ	
H22	Government of India	Jal Shakti Abhiyan	2019	Government of India	
H23	Daee M, et al.	Performance of pilot Horizontal Roughing Filter as polishing stage of waste stabilization ponds in developing regions and modelling verification	2019	Ecol Eng	
H24	Sutar RS, et al.	Significance of Constructed Wetlands for Enhancing Reuse of Treated Sewages in Rural India	2019	Waste Water Recycling and Management	

ID	Authors	Title	Year	Journal/Publisher	DOI
H25	Sushmitha MB, et al.	Efficient Grey Water Treatment and Reuse Options for India–A Review	2019	Waste Water Recycling and Management	
H26	Verma R, Sengupta S, Anand S	Toolkit: Managing Faecal Sludge in Rural Areas	2020	Centre for Science and Environment	
H27	Lekshmi B, et al.	Circular Economy Approach to Women Empowerment Through Reusing Treated Rural Wastewater Using Constructed Wetlands	2020	Chapter in "Waste Management as Economic Industry Towards Circular Economy", Springer Singapore	
H28	Kaur R, et al.	Chapter 5 - Constructed wetlands for the removal of organic micro-pollutants	2020	Chapter in "Current Developments in Biotechnology and Bioengineering", Elsevier	
H29	Sharma S, et al.	Reuse of Washing Machine Effluent Using Constructed Wetland: The Circular Economy of Sanitation	2020	Chapter in "Recent Trends in Waste Water Treatment and Water Resource Management", Springer Singapore	
H30	Langergraber G, et al.	Design approach for treatment wetlands	2020	Chapter in "Wetland Technology: Practical Information on the Design and Application of Treatment Wetlands", IWA Press	
H31	Moreira FD, Oliveira Dias EH	Constructed wetlands applied in rural sanitation: a review	2020	Environ Res	
H32	Green W, Ho G	Small scale sanitation technologies	2005	Water Sci Technol	

Appendix IV: Project documents used as data sources

Berambadi

ATREE (2019) CW and Water Quality Notes from Social Science team

A combined document with notes from field visits from 2017-19, prepared for me by the Social Research team of the project.

ATREE (2018) *Baseline water quality monitoring report*

Report with water quality data from water sources around Berambadi.

ATREE (2016) Wetland Vegetation Options

Document prepared as part of the process of selecting plants for the wetland.

Ellis, R. *et al.* (2020) *Decentralised Wastewater Treatment: Sustainable Innovation for Rural Communities*. James Hutton Institute.

The final project report for the Berambadi project, with evaluations of the constructed wetland performance.

Jamwal, P. *et al.* (2021) "Evaluating the performance of horizontal sub-surface flow constructed wetlands: A case study from southern India," *Ecological engineering*, 162, p. 106170.

Paper published by the Berambadi project team presenting the water quality results from the constructed wetland and interpretation of these results.

Yeluripati, J (2019) *Monitoring and maintaining wetland plants*, James Hutton Institute

Document outlining relevant concerns for the maintenance of wetland plants, including susceptibility to diseases.

Ibrahimpur

Goyal, V.C. *et al.* (2020) "Ecological health and water quality of village ponds in the subtropics limiting their use for water supply and groundwater recharge," *Journal of environmental management*, 277, p. 111450.

Report presenting results from monitoring of the Ibrahimpur pond and another pond in the vicinity, useful for seeing how water quality was evaluated.

Goyal, V.C. and Singh, O. (2018) *Water Conservation and Management in a Village of Haridwar District (Uttarakhand)*. National Institute of Hydrology.

Interim report from the Ibrahimpur project, with water quality results, constructed wetland design, and water use statistics for Ibrahimpur village.

NIH (2020) *Conservation of Ponds in Ibrahimpur-Masahi Village and Performance Evaluation of Natural Treatment System – Final Report*

Final report from the Ibrahimpur project, similar data to Goyal and Singh (2018).

Goyal, V.C. and Singh, O. (2018) 'Water Conservation and Management in Ibrahimpur Masahi Village of Haridwar District (Uttarakhand)'.

Presentation slides presenting key details of the constructed wetland project including design details.

NIH (2018), *Rainwater Harvesting Report*

Report prepared as part of the constructed wetland building project, with details about the catchment and village statistics.