Thinking with Groundwater from Chennai: Materials, Processes, Experimental Knowledge

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https://doi.org/10.34737/vq130

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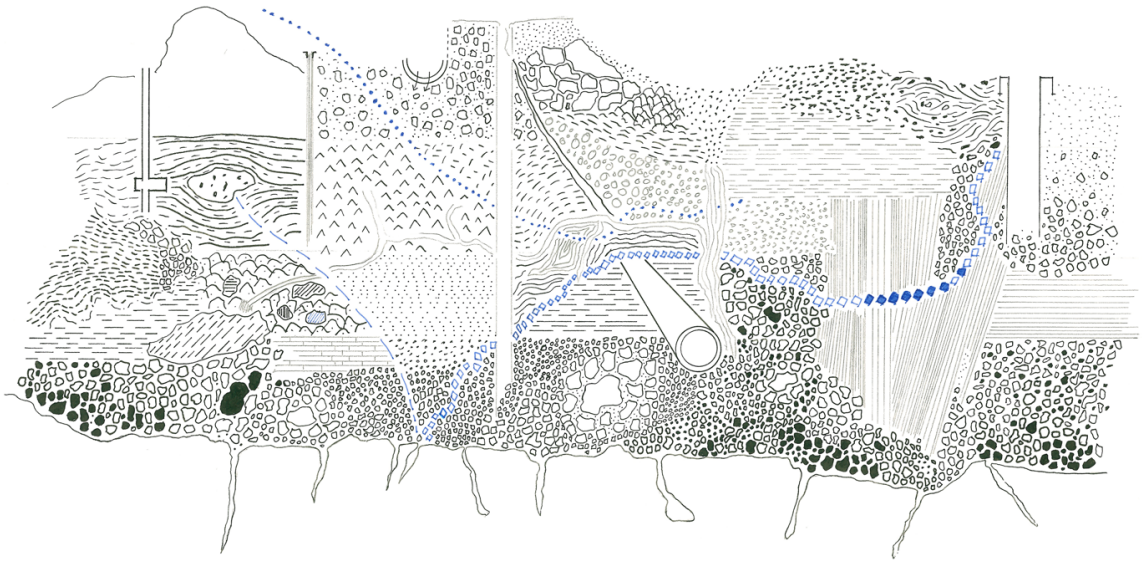
Materials, Processes, Experimental Knowledge



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2021

Submitted in partial fulfilment of the requirements of the degree of Doctor of Philosophy

Declaration

I declare that the material contained in this thesis is my own work. Wherever information has been derived from other sources, this has been indicated.

This is not actual representation.

We cannot say what is happening inside,

we are just representing,

that is what I mean.[1]

[1] Anandaruban P., Chennai, 17 July 2018. Interview by the author.

Abstract

The (under)ground or (sub)terranean environment is a thick, complex, three-dimensional space of 'nothing but change' whose utility is essential to sustaining urban life above it. Living with these grounds is living in conditions of unstable hydrogeological emergence. This thesis looks at the multiple, specific, and contradictory ways in which the materiality of groundwater is understood and intervened in: different knowledges and knowledge practices as ways of knowing groundwater in Chennai, South India.

First, I ask what groundwater is, and how I might approach it. Through a series of case studies, I develop a methodology for researching groundwater, confronting the problem of how to research and write something that I cannot access. This means talking to different people who access groundwater in different ways, assembling multiple and contradictory accounts in a way that acknowledges and keeps hold of the intra-active tension between materiality and representation. My means of access are the multiple ways that different people, professions, and institutions get at groundwater, as well my own representational practices as further means of grasping at something always at a distance.

Through this I ask, what knowledges exist? How are these different knowledges co-produced, and how are they enacted or re-inscribed through scientific, professional, and everyday practices? How, therefore, can thinking with groundwater from Chennai help to read changing city and changing climate together? The format is processual and iterative: I do not set out to clean up the steps by which research methods, analysis, and theory co-evolve. Each chapter is an experiment with ways of knowing groundwater.

Throughout these different points of view, it is impossible to say quite what groundwater *is*, other than a set of relations that move in and between the urban climate. These relations appear and are drawn into focus as registers through which to bring together accounts of diverse phenomena. Instead of as a discernible object, I begin to make sense of groundwater as a relational substance, one which is not background to the city's ongoing reproduction, but is both substantially altered by and co-constitutive of lively urban assemblages.

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Preface

This thesis has been developed in relation to the wider ERC-funded research project *Monsoon Assemblages* (MONASS), which has supported my work both financially and intellectually.

In the first respect, MONASS gave me a stipend, and the University of Westminster granted me a fee waiver—both for the duration of my study. The grant also funded my fieldwork, which was carried out independently of MONASS but was informed by the wider project, and aided in part by some of the contacts that the team had already made.

In the second respect, the development of this project took place within a context of a collective study into a monsoonal reading of cities. I benefitted enormously from this shared investigation, and I believe my work also made some contribution to the development of the project as a whole. My initial research proposal in 2016 had attempted to respond to the theoretical framing of MONASS as I understood it, and was concerned with the nature of cities, the urban-rural interface, and sites or places that resisted incorporation or capture by the modernist imagination of urban governance. As the MONASS project developed in its early stages, and through interaction with my supervisors and PhD colleague, I began to take a more material interest in monsoonal matters. I quickly developed a revised proposal responding to the city of Chennai, which had already been defined by the project team as one of three cities that the project would focus on. This meant finding a specific line of enquiry through which the extensive fluidity and ineffable flux of monsoonal matter in Chennai could be explored. After an initial scoping exercise and literature review, in conversation with my supervisors, and supported by their own fieldwork (which had already begun), I identified groundwater as a potential focus in 2017, the first year of my studentship.

At this stage of the project, I had the outstandingly hubristic expectation of using my skills as an architect to 'make sense' of groundwater, and in some way to overcome the contradictions, complexities, and partiality that I saw in accounts of groundwater in Chennai. I imagined I would somehow be able to synthesise all the varying representations of

groundwater and provide a *clearer* picture or account of what was *actually* going on, using the tools and perspective I had uniquely available to me as an architect and researcher. The subtitle of the project at this time was 'reading Chennai through groundwater': describing the idea that I felt there was something to be said about the nature of the city itself by narrating it through the medium of groundwater.

It took some considerable time, and fieldwork, trying to wrest from incompatible sources an unmediated image the nature of groundwater, before I slowly moved into thinking with these complexities as part of groundwater rather than a problem of representation. Theoretical work was important here, but only insofar as it helped me to frame the difficulties I was having with narrating groundwater. Rather, it was the encounter with groundwater itself that has been transformative in shifting the project—towards a form of description that took account of the multiple practices of knowledge-making with groundwater.

Throughout this process, the value added to my PhD experience by being associated with the MONASS project, over and above being a lone PhD researcher, was enormous. Ongoing engagement with the project was through supervision, advisory board meetings, annual symposia, exhibitions, reading groups, and writing. I presented the research annually to an international advisory board who gave invaluable feedback on the project. I co-organised, and chaired a panel at the symposium *Monsoon [+ other] Airs* in 2017, as well as at *Monsoon [+ other] Waters* 2018, and delivered a paper at *Monsoon [+ other] Grounds* in 2019 as part of the development of the second chapter of this thesis. Following that series of symposia, I contributed a short piece to the *Monsoon [+ other] Grounds* publication, and a full paper as part of the MONASS special issue of *GeoHumanities* in June 2021.[2] I contributed material and texts to the project's online exhibition, and a chapter to the forthcoming book *Monsoon as Method*.

This thesis, though quasi-independent of *Monsoon Assemblages*, owes much to the milieu in which I was able to develop my approach to Chennai, groundwater, and the monsoon. Equally, the research has been transformed by the material it is engaged with. It should be read in this light: as the outcome of collective study with people and things.

[2] Anthony Powis, 'Acts of Drawing Something You Cannot See', in *Monsoon [+ other] Grounds*, ed. by Lindsay Bremner and John Cook (London: Monsoon Assemblages, 2020), pp. 89–95. Anthony Powis, 'The Relational Materiality of Groundwater', *GeoHumanities*, 7.1 (2021), 89-112.

Acknowledgements

As noted throughout this thesis, this was a project that relied on the work of others. I am especially indebted to those who welcomed me during my time in Chennai, sharing their time, and their work, in ways that made this project possible. To Sekhar Raghavan at the Rain Centre; Elango Lakshmanan, Anadaruban P., G. Gowrishankar, and V. K. Haritha at the Department of Geology, Anna University; Sudhir Chella Rajan, Indumathi M. Nambi, and Ashwin Mahalingam at IIT Madras; Santha Sheela Nair; Indukanth S. Ragade; Pooja Kumar; Tom Herard; and Veena Srinivasan: I can only hope that I have honestly recounted our exchanges, which were so valuable to me.

I am enormously grateful to my supervisors, Lindsay Bremner and Beth Cullen, for their ongoing guidance and support. Their enthusiasm towards this project has given me the confidence to keep pursuing it, and their careful and insightful feedback has enabled me to complete it. I have also been fortunate to receive generous criticism at different stages of the project from Jon Goodbun, Kester Rattenbury, and Nick Beech. These different perspectives have been invaluable in questioning assumptions, and testing ideas.

I owe a lot to the insight and friendship of Harshavardhan Bhat, my PhD colleague, with whom I must have spoken about this process more than anyone else. This has been a personal as well as intellectual journey and it has been a pleasure to make it alongside him. A researcher's development is also supported by a wide and ever-changing network of conferences, reading groups (particularly David Chandler's London Materialisms Reading Group and the Expanded Territories group led by MONASS), and (most importantly) the discussions that followed from these. I thank everyone who has shared these one of these with me, however small it may have seemed.

Throughout the PhD I have taught at the University of Westminster, and I am grateful for the energy of my design students, particularly in recent years as Eric Guibert and I have encouraged them to engage with increasingly complex ideas about designing with emergent processes. Thank you for your commitment to these provocations.

Doing this kind of project is hard, not only for the author but for the people around them. To Jenny, without whom I may never have started it, I am sorry that I cannot offer more than a dedication.

Introduction: Towards a Methodology of Engagement with Groundwater

This thesis lies in the deliquescent (sub)terranea of Chennai, India—materials, processes, and representational practices that together comprise what refer to as groundwater. It proposes *thinking with groundwater from Chennai* as a means of engagement with the intra-active relations of city-climate, material-representation, and knowledge-experiment. If 'the question of how to live in a world shaped by relational entanglements and feedbacks is *the* problematic of contemporary Anthropocene thinking' then groundwater, I propose, is a useful figure with which to think through some of these relational entanglements and feedbacks.[3]

In the following introduction, I develop a methodology for engaging with groundwater, which will be employed throughout the thesis as a means to draw out ways in which groundwater is co-constitutive of wider material relations. The complex, intra-active relationality of groundwater both requires and is productive of new methodologies. To begin, I will first situate the thesis within Chennai's broader hydrogeologic context.

Orientation: From the Ghats to the Plains

The Eastern Ghats is a discontinuous mountain range spanning India's Coromandel Coast, stalking the Bay of Bengal from Odisha near the border with Bengal in the north, through Andhra Pradesh, to eventually meet the Nilgiri Hills near Coimbatore in southern Tamil Nadu. The erratic mountains, as they duck and bob, in and out of the plains, separate the high mass of

[3] David Chandler and Jonathan Pugh, 'Anthropocene Islands: There Are Only Islands after the End of the World', *Dialogues in Human Geography*, 2021, p. 2.

the Indian peninsula from the low-lying coastal regions at an average elevation of around 500m, but frequently well over 1000m—the height that defines the Deccan Plateau.

As a way of thinking with groundwater from Chennai, I start here with the Eastern Ghats. From these mountains comes the material that forms the plains. The main rivers of Tamil Nadu—Pallar, Pennai, and Kaveri—flow from there, carrying matter which by its transmission becomes known to us as alluvium. Irrigated, trenched and bunded, vast fields of sand, appearing so flat, are the temporary rests of this alluvial matter as it slowly descends towards the bay. Between rocky outcrops, now freckled with forts and temples, the plains exert an energy, and bear marks of the massive continental engineering project of surface-water management. The plains are also a space that is deeply three-dimensional. By its very nature, a landscape of overlain sediments is thick, deep, and complex: volume, not surface. Deep topography, also, that is not firm and simple, but shifting, heterogenous, and saturated with life.

To the east of Chennai, the marine topography of the Bay of Bengal extends a narrow continental shelf before dropping sharply to a depth of 3000m.[4] A high degree of upwelling in the coastal area brings deep waters to the surface, and the action of waves and currents drives sediments laterally along the coast. Whether we consider the alluvial plains 'the hinterland of the bay'—as oceanographers might[5]—or conversely the bay as the runoff of the land, it is apparent that the coastline in which Chennai uneasily rests is a process, not a boundary: a 'complex, dynamic and delicate environment which interface both terrestrial and marine forces'.[6]

This environment is also inextricably of the monsoon, a set of interrelated seasonal phenomena, and associated behaviours, rhythms, waves, and uncertainties. The rains of the retreating north-eastern monsoon are the main source of water supply to the city: percolating rainfall (re)saturates, washes, and swells the ground, whilst the runoff from fast-flowing rivers, accelerated by artificial standardisations, alters the salinity and temperature of the ocean.[7] Everything about the city depends upon this region, and the complex relations in and between land and climate—from the Ghats, to the plains, and to the bay. Chennai, characterised by its wide beaches, is not a fixed point, but a shifting zone where alluvial matter cannot form deltaic

[4] The shallow part of the shelf (up to 200 m) is less than 45 km wide. M. J. Varkey, V. S. N. Murthy, and A. Suryanarayana, 'Physical Oceanography of the Bay of Bengal', *Oceanography and Marine Biology: An Annual Review*, 34 (1996), 1–70.
[5] Varkey, Murthy, and Suryanarayana.
[6] S. Kaliraj, N. Chandrasekar, and N. S. Magesh, 'Impacts of Wave Energy and Littoral Currents on Shoreline Erosion/Accretion along the South-West Coast of Kanyakumari, Tamil Nadu Using DSAS and Geospatial Technology', *Environmental Earth Sciences*, 71.10 (2014), 4523–42.
[7] Bhoga Mandala Sayana Vutla and S. Ravichandran, 'Groundwater Quality and Role of the Monsoon in Chennai City, South India', *Asian Journal of Chemistry*, 23.10 (2011), 4659–64.

solids because of the force of the sea. It is a point of balance, in constant tension to either side. Thinking about Chennai through both the Eastern Ghats, and the Bay of Bengal, is a way of beginning to read urban processes outside of disciplinary and bounded narratives.

I do so with a realisation of how difficult this relational network is to comprehend (primarily from a distance), but also the understanding that—even when close—the alluvial ground shifts and changes, and is very hard to hold onto. I start here from an outward view, gradually zooming in and defining the questions that this thesis hopes to address, approaching Chennai geologically, and geographically—and in the process describing the salience of groundwater as an object of enquiry.

Geologic Basis of the Peninsula Region

The plateau and the plains comprise the peninsula region of South India, distinct from the mountainous regions of the north, and the Indo-Gangetic plains between. Since the Cambrian period, the peninsula has been a continental fragment, and ever since has been an area of land. Therefore, unlike the northern regions, which have lain under the sea for a greater part of their history, 'no considerable marine sediment of later age than Cambrian was ever deposited in the interior of this land-mass'.[8] The lithographic strata have also stayed relatively stable, retaining their horizontal structure. Mountains in the peninsula region are 'relicts': parts of the land that have somehow escaped the weathering that has stripped away (denuded) the earth around them, leaving them as protrusions.[9] This is significant, and in contrast to mountains such as the Himalayas, formed by tectonic fold and overthrust: relatively recent bursts of geologic force that continue to act. The plateau, a wedge of rock rising from north to south, is referred to as a 'peneplain' or 'horst': a raised block of roughly equal height in both ridges and summits.[10] It acts like a 'shield', being an old and relatively stable portion of the earth's crust, despite these geologically ancient rocks undergoing much crushing and metamorphism.[11]

Chennai (formerly Madras) sits upon and within a young low-lying coastal plain held between the Eastern Ghats, at the edge of plateau in the west, and the shallow Bay of Bengal, to the east.[12]

[8] D. N. Wadia, *Geology of India* (London: Macmillan and Co., Limited, 1919), p. 2.
[9] M. S. Krishnan, *Geology of India and Burma* (Madras: Higginbothams, 1956).
[10] Wadia; Sumner W. Cushing, 'The East Coast of India', *Bulletin of the American Geographical Society*, 45.2 (1913), 81–92.
[11] Krishnan.
[12] To offer a rough order of magnitude for 'young': most of the fluvial deposits are of the recent Quaternary period (less than 2.5 million years ago), including Holocene (since 12,000 years ago) and late-Pleistocene (less than 1 million years ago). Some boulder gravels are of the late Neogene period (up to 5 million years ago). The Charnockite rock, in contrast, is pre-Cambrian, or over 500 million years old.

The steep face of the Eastern Ghats was the ancient sea wall of the Peninsula, although in reality 'this chain, as a whole, has no existence, but is composed, to the southward, of the eastern scarp of the Mysore plateau […] and or several short isolated ridges of metamorphic rocks, separated from each other by broad plains, and having in reality but little connexion [sic] with each other'.[13] The mountains come to meet the coast near Chennai, and 'In places the hills approach the sea, leaving only a comparatively narrow belt of sandy foreshore'.[14] The lower Carnatic plains are later formations, mostly of alluvial deposits from the deltas of west-to-east rivers running down an average fall of two metres per kilometre from the base of plateau.[15]

Figure 1. Palar delta on the way to Chennai, near Arcot, 2018. Photograph by the author.

[13] H. B. Medlicott and W. T. Blanford, *A Manual of The Geology Of India, Part I* (Calcutta: Government of India, 1879), p. iv.
[14] Medlicott and Blanford, p. 422.
[15] The term 'Carnatic' is of varied use, most widely used now to describe a style of music relating to a broad, south-Indian culture. In much of the early, colonial literature 'Carnatic' geographically refers to the low-lying areas extending northwards into Andhra Pradesh, and southwards to Kanyakumari.

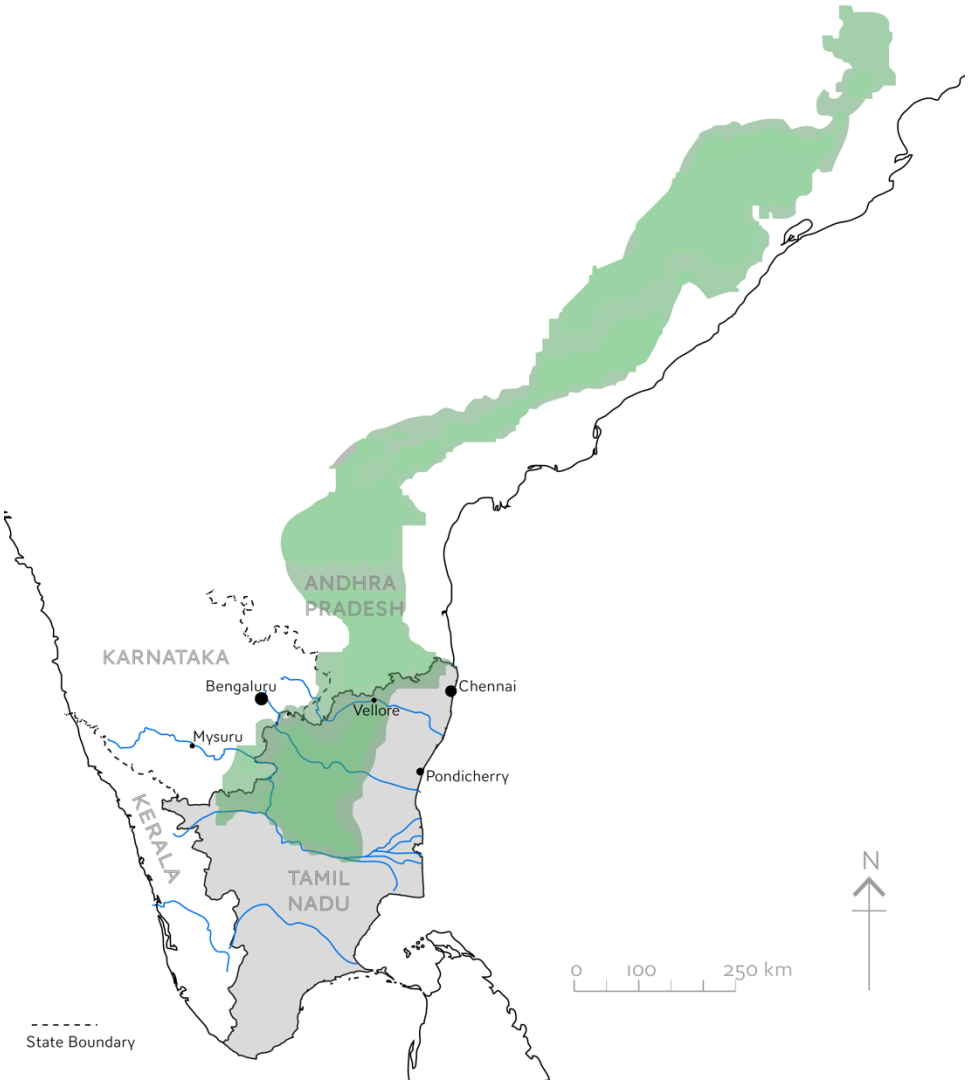

Figure 2. Tamil Nadu (grey) as the southern terminus of the Eastern Ghats (green). Drawing by the author.

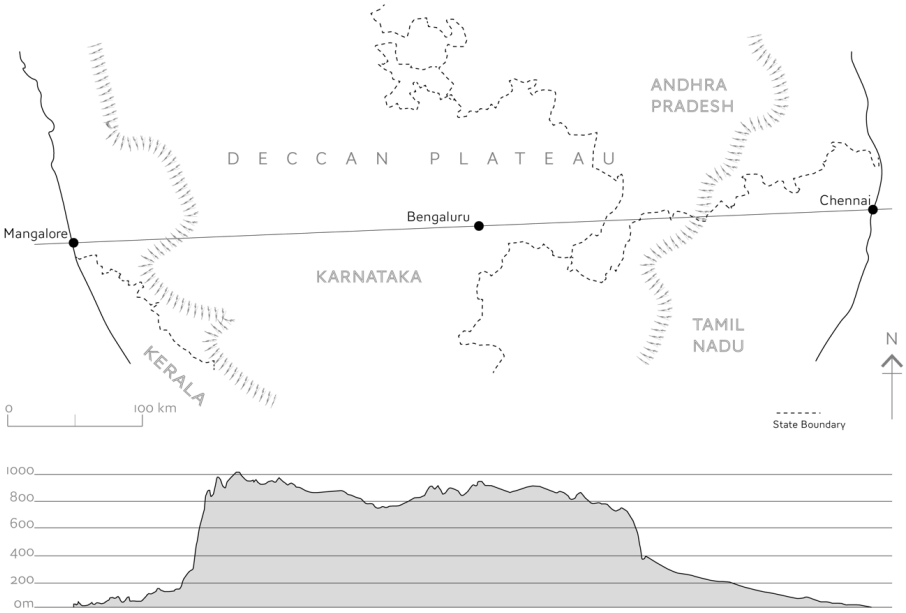

Figure 3. Section of the Indian peninsula (exaggerated Y scale). Drawing by the author.

The region is a (monsoonal) delta, which determines a spatially-shifting landscape. That is to say, large amounts of sediment, carried and deposited by seasonal rivers, continually reshape the land, as it sways between states of liquidity and solidity. The majority of the modern city of Chennai is covered by the recent (Pleistocene) alluvium, deposited by the three main rivers, the Kortalaiyar, the Adyar, and the Cooum. The Kortalaiyar, to the north of the city, empties into Ennore Creek, whilst the Adyar and the Cooum, in the centre of the city, flow directly into the Bay of Bengal. The Palar, further to the south, is the largest of the region's deltas, running continuously from the Nandi Hills in Karnataka to the Bay of Bengal, 45km south of the Chennai Metropolitan Area.

In the immediate area of the Chennai region, the predominant alluvium (sandy, clayey) is underlain by crystallines (Charnockite, Gneiss, and Migmattite) in the southern and western zones, and by Gondwanas (conglomerate and sandstone) in the north and west.[16] Laterites and Ferricretes also occur in the marine plains especially, giving name to areas such as Red Hills, because these strata are rich in iron, and harder than the clayey soils.[17]

[16] Geological Survey of India, 'Survey of India: Madras Quadrangle' (Calcutta: Geological Survey of India, 1999); P. N. Ballukraya and R. Ravi, 'Hydrogeology of Madras City Aquifers', *Journal of the Geological Society of India*, 45 (1995), 87–96.
[17] Hema Achyuthan and N. Fedoroff, 'Ferricretes in Tamil Nadu, Chennai, South-Eastern India: From Landscape to Micromorphology, Genesis, and Paleoenvironmental Significance', in *New Trends in Soil Micromorphology* (Berlin, Heidelberg, 2008), pp. 111–36.

The city is gently sloping, with an average elevation of about 6m, and more or less plain apart from the small hillocks—'little metamorphic plateaus […] scattered over the low country of the Carnatic'—of St Thomas Mount (c.25m) and Little Mount, to the South of the Adyar, and another near Mangadu, on the eastern side of Chembarrambakkam Lake.[18] These small Charnokite hills, reaching to around 150m, form a necklace running parallel with the airport highway between Chengalpattu and St Thomas Mount via Vandalur, Tambaram, and Pallavaram. At St Thomas Mount, the Charnockite rocks are exposed, whereas the Gondwanas—sedimentary rocks containing marine animals and plant remains[19]—are not exposed anywhere in the city. A defining geographical feature is the beach, one of the widest in India, up to 300m in places, and backed by dunes of up to 6m height.

The Kortalaiyar, Cooum and Adyar river basins

> The most important element geographically of the Carnatic is the delta land.[20]

The name 'Cooum' appears to be derived from the Tamil word 'Coovalan', meaning someone specialist in groundwater.[21] For much of the year, the Adyar carries only saline backwater from the Bay of Bengal, which is flushed back out to sea during rainfall.[22] At other times, it is a 'sewer', carrying only a flow of domestic waste. The city lacks any perennial river, and all three are seasonal: dry during the summer, and flowing only during the monsoon, for approximately two months a year, as shallow torrents. The three deltaic rivers are still the primary source of water for the city of Chennai, though this is less likely to be accessed as surface water than groundwater, and so it may be helpful to understand them not just in terms of a one-dimensional flow, but as a broad condition of 'ubiquitous wetness'.[23] The 'drainage basin unit' is a means of understanding a river not as (even bifurcating) lines, but as a spatial, geomorphic whole: 'Ordinarily treated, the river is like the veins of a leaf; broadly viewed, it is like the entire leaf.'[24]

The metropolitain area of Chennai is broadly contiguous with the downstream area of the watershed area of these three rivers, of which two trisect the main centre. The Cooum is a total 72km in length with a macro drainage area of 502 km^2. It's bankfull discharge—the rate of flow

[18] Geological Survey of India.
[19] Krishnan, p. 281.
[20] Cushing, p. 90.
[21] P Sudhakar, 'Ecological Heritage Sites of Chennai', *International Educational Scientific Research Journal*, 2.9 (2016), 15–17 (p. 15).
[22] S. Sathish and L. Elango, 'Groundwater Quality and Vulnerability Mapping of an Unconfined Coastal Aquifer', *Journal of Spatial Hydrology*, 11.1 (2011).
[23] Dilip da Cunha, *The Invention of Rivers: Alexander's Eye and Ganga's Descent* (Philadelphia, PA: University of Pennsylvania Press, 2019), p. 272.
[24] W.M. Davis quoted in Richard J. Chorley, 'The Drainage Basin as the Fundamental Geomorphic Unit', in *Introduction to Physical Hydrology*, ed. by Richard J. Chorley (London: Methuen & Co Ltd, 1969), pp. 37–59 (p. 38).

when the river channel is full—is 991 m^3/s. Though shorter, at 42km, the Adyar has a larger catchment of 720 km^2, and bankfull discharge of 2038m^3/s, almost twice that of the Cooum. Furthermore, the Adyar carries surplus from about 450 tanks, compared to 75 accommodated by the Cooum.[25]

Figure 4. Chennai Sub-River Basin, watershed areas and primary reservoir network. Drawing by the author.

The drainage basin area is studded with wells, and interrupted by an interconnected network of tanks.[26] Though these tanks are increasingly disappearing as they are infilled to create land for development, or lost to lack of maintenance, the landscape is still 'pockmarked with tiny water bodies'.[27] Monsoon waters flow across the region from west to east and drain into the ocean. To capture these waters for agricultural uses, 'local people built bunds in low-lying areas, forming

[25] Pushpa Arabindoo, 'Unprecedented Natures?', *City*, 20.6 (2016), 800–821 (p. 14); Balaji Narasimhan and others, *Chennai Floods 2015: A Rapid Assessment* (Bangalore, 2016), pp. 12–14.
[26] Karen Coelho, 'Lines in the Mud: Tank Eco-Restoration and Boundary Contestations in Chennai', *Urbanisation*, 5.2 (2020), 121–39.
[27] Karen Coelho and Nithya V. Raman, 'From The Frying-Pan to the Floodplain: Negotiating Land, Water And Fire In Chennai's Development', in *Ecologies of Urbanism in India: Metropolitan Civility and Sustainability*, ed. by Anne Rademacher and K Sivaramakrishnan (Hong Kong: Hong Kong University Press, 2013), pp. 145–68 (p. 148).

what are now identified as lakes or *eris*' designed to halt the westward flow of water towards the bay and primarily utilised for irrigation of farmland.[28] There are perhaps 200 small ponds still in the urban region, many of which are temple tanks. This system of rainwater catchment through bunded lakes/eris is uniquely suited to the gently sloping topography of the Chennai region, and serves the dual purpose of flood management and groundwater recharge.[29]

Despite this, and due to the occurrence of rain in sudden, heavy spells, 'large amounts of the rainwater from the monsoon ends up in the sea', rather than percolating into the ground.[30] At times, such as in 2015, the volume is so great as to cause significant flooding. The harnessing of flows within the city is therefore always in balance between storage and release, with either extreme posing a deadly threat to the most vulnerable city dwellers. The movements of rivers have, over time, added geological complexity to the plains, alongside gradual erosion and sedimentation, decay and compression, transmission and settlement:

> Fluctuations in the Holocene climate resulted in variations of the hydric and mineral fluxes passing through the alluvial plains. The streams reacted by adjusting their geometry, and this led to complex metamorphoses or changes in the channel patterns […] Thus, the alluvial infills are internally highly complex, despite the apparent homogeneity of the floodplains.[31]

The typical groundwater movement is seawards, with a gentle slope approximately correlating to that of the terrain above. The aquifers have continuity with the sea, meaning seawater intrusion is possible, but the seaward flow maintains the freshwater-sea interface, and generally prevents sea water from intruding inland (this is discussed in more detail in chapter 1). The crystalline ridge—at some 5 km inland from the shoreline, and at a depth varying from 15 m in the south to about 60 m in the north—and above it, a natural fresh-water ridge, also prevent the intrusion of sea water to the aquifer. Thanks to the maintenance of these subterranean interfaces, the near-surface aquifer, when tapped by shallow wells along the coast, has often been found to be relatively fresh despite the proximity to salt water, and despite groundwater levels being significantly below sea levels.[32]

The level of the groundwater varies with the degree of exploitation, and its quality is heavily affected by surface pollution, as well as the increased seawater intrusion that occurs when the

[28] Coelho and Raman, p. 148.
[29] Arabindoo.
[30] P. Oppili, 'Heavy Rainfall Last Monsoon Cleaned up Groundwater', *Times of India*, 2016 <http://timesofindia.indiatimes.com/city/chennai/Heavy-rainfall-last-monsoon-cleanedup-groundwater/articleshow/51786030.cms> [accessed 15 February 2017].
[31] Janine Gibert, Dan L. Danielopol, and Jack A. Stanford, *Groundwater Ecology* (London: Academic Press, 1994).
[32] P. N. Ballukraya and R. Ravi, 'Natural Fresh-Water Ridge as Barrier Against Sea-Water Intrusion in Chennai City', *Journal of the Geological Society of India*, 52.3 (1998), 279–86 (p. 279).

water level is reduced. The monsoon season significantly increases groundwater levels, and monsoon rains serve both to recharge, and 'flush' the aquifers, improving groundwater quality. [33]

A maxim in groundwater studies is that 'ground water is always in motion'.[34] Liquid flows from an area of high pressure (a recharge area, such as river delta), to one of low pressure (a drainage area, such as the ocean). Velocities vary according to this pressure differential, as well as the permeability of the host material, but are much lower than those of surface streams. In this case, we know that the clayey sand/sandy clay is quite restrictive, it is also clear that the deep concrete foundations of recent high-rise developments interfere with these sub-surface flows, by altering the material composition of the subsurface.[35] We cannot see the water move through the ground, and so quite little is known about its behaviour, but technologies such as remote sensing and GIS have increased researchers' abilities to accurately record shifts in groundwater levels over time.[36] It remains to be understood, for instance, how groundwater occurs at great depths in what is apparently impermeable bedrock, and so (significantly) how (and how quickly) this is replenished.[37]

Forces, magnitudes, and durations

In a recent paper outlining their 'Atlas of the Underworld', van der Meer, van Hinsbergen, and Spakman describe the continual and ongoing subtension of buried slabs, 'sinking histories' of past earths, reincorporated by long-term geologic flows into the molten core of the earth.[38] The atlas evokes forces, magnitudes and durations unfamiliar and uncomfortable to read. By giving the individual slabs names redolent of our contemporary continental formations, the atlas provokes and brings into view our planetary future. These 'sinking histories' of plate tectonics also leave their imprint on groundwater.[39] There is a strong correlation between active faults and lines of high yield in hard rock.[40] Groundwater levels in Chennai, and Tamil Nadu more widely,

[33] Vutla and Ravichandran.
[34] J. P. Waltz, 'Ground Water', in *Introduction to Physical Hydrology*, ed. by Richard J. Chorley (London: Methuen & Co Ltd, 1969), pp. 122–30 (p. 128).
[35] S. Sathish and L. Elango, 'An Integrated Study on the Characterization of Freshwater Lens in a Coastal Aquifer of Southern India', *Arabian Journal of Geosciences*, 9.14 (2016).
[36] S Suganthi, L. Elango, and S K Subramanian, 'Groundwater Potential Zonation by Remote Sensing and GIS Techniques and Its Relation to the Groundwater Level in the Coastal Part of the Arani and Koratalai River Basin, Southern India', *Earth Sciences Research Journal*, 17.2 (2013), 87–95.
[37] B. P. Radhakrishna, 'Man-Made Drought and the Looming Water Crisis', *Geological Society of India*, 63.5 (2004), 477–81.
[38] Douwe G. van der Meer, Douwe J.J. van Hinsbergen, and Wim Spakman, 'Atlas of the Underworld: Slab Remnants in the Mantle, Their Sinking History, and a New Outlook on Lower Mantle Viscosity', *Tectonophysics*, 2017.
[39] J. Saravanavel and S. M. Ramasamy, 'Active Tectonics and Its Impacts over Groundwater Systems in the Parts of Tamil Nadu, India', *Arabian Journal of Geosciences*, 9.6 (2016), 429.
[40] S. M. Ramasamy, 'Remote Sensing and Active Tectonics of South India', *International Journal of Remote Sensing*, 27.20 (2006), 4397–4431.

rise and fall with east–west linear ridges and valleys, resembling 'a series of waves', which are aligned with and reflect the ongoing north–south oriented compressive forces following tectonic collision.[41]

The formation of these geological substrata is an unfinished process spanning hundreds of millions of years. The alluvial deposits were lain down over the last million years, including many during the last 10,000 years, and continue to be reshaped. Contaminant leaching from waste sites is a slow process that might continue for thousands of years. The formal city is 400 years old, and its rapid expansions only a few decades. The flushing and recharge of groundwater is an annual cycle but which is dependent upon the vagaries of the monsoon, determined in multi-year cycles of sea temperature elsewhere, and by the reshaping of the surface by human activity. Differing well techniques access groundwater with differing temporalities, from the rapid dewatering and recharge of near-surface sandy grounds to the timescale of deep 'fossil water' deposits in fractured charnockite rock, whose timespans surpass that of human life itself.

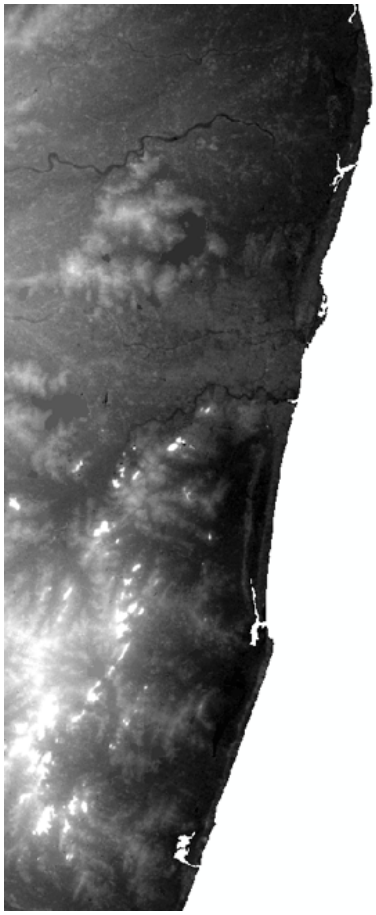

Figure 5. Volatile topography. Drawing by the author from NASA SRTM data.

[41] Saravanavel and Ramasamy.

Figure 6. Chennai situated as run-off of the plateau (exaggerated topography). Drawing by the author from NASA SRTM data.

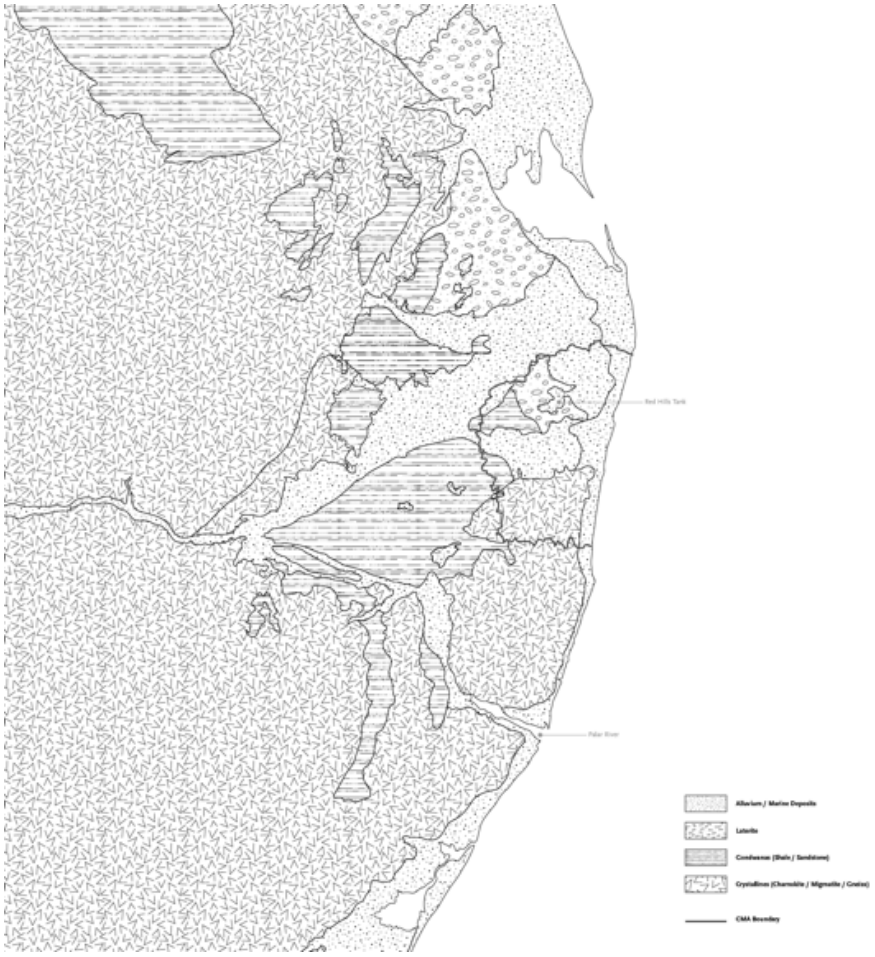

Figure 7. Outline map of Chennai region geology. Drawing by the author from multiple Geological Survey of India maps.

The systematic study of geology of India started in 1851, with the establishment of the Geological Survey of India (GSI) by the East India Company, in the years preceding direct colonial rule. A process of detailed geological mapping across four presidencies was undertaken by the GSI on behalf of the colonial administration. During this work, in 1863, at Atirampakkam, 50km north-west of Chennai near Poondi Lake, Robert Bruce Foote unearthed a

stone tool, which became the first Palaeolithic tool to be identified in the subcontinent. Tools found on this site have since been dated to up to 1.5 million years ago. That is older than any human settlement found in Europe and predates the alluvial deposits that produced Chennai's landscape. It was the location and distribution of these artefacts that supported Foote's thesis that 'great changes in the physical geography of the Indian peninsula have taken place since the time when the implement-makers first inhabited the country'.[42] Recent excavations around Atirampakkam vividly capture the entanglement of human and earth systems over time, as the strata—laminated clay beds—conceal tools and other human-made objects.[43] Here, then, a relatively 'young' geological landscape, and an especially deep history of human inhabitation, combine to offer a remarkable parallel between the scales of material histories of the landscape itself, and of its human occupation.

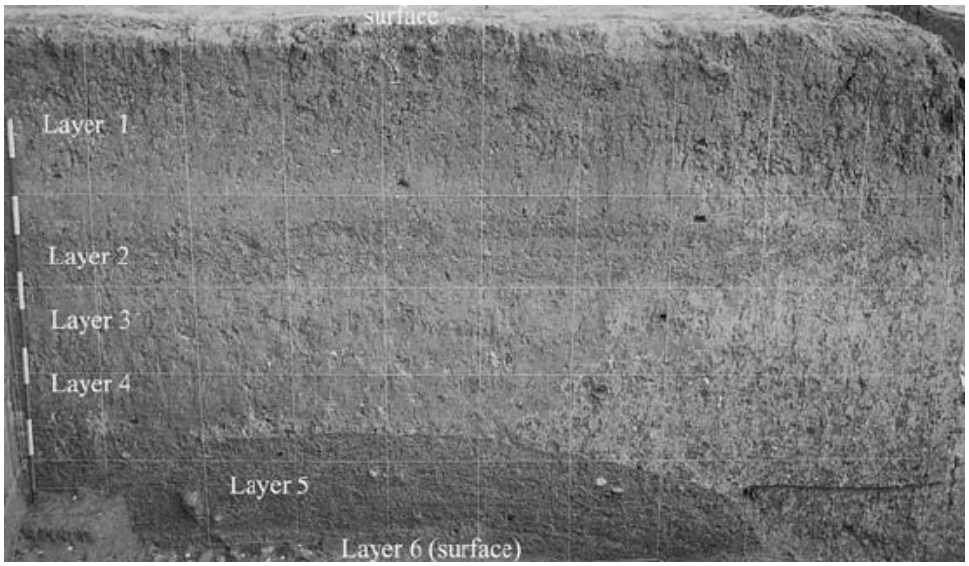

Figure 8. Stratigraphic Sequence observed during investigations at Atirampakkam.[44]

In the ways I have described here, it can be seen that both the landforms, and groundwater of the Carnatic are a result of fluvial processes. These west–east movements meet the bay of Bengal, at an ever-shifting point both above and below ground, and so the plains are also 'the result of a vacillating coast line, and what may be accomplished by the sea, destructively and constructively, under varying conditions of elevation and depress'.[45] Furthermore, noting that many of these processes played out in such recent history that they have been contemporaneous

[42] R. B. Foote, 'On the Distribution of Stone Implements in Southern India', *Quarterly Journal of the Geological Society*, 24.1–2 (1868), 484–95.
[43] Shanti Pappu, 'Changing Trends in the Study of a Paleolithic Site in India: A Century of Research at Attirampakkam', in *The Evolution and History of Human Populations in South Asia*, ed. by Michael D. Petraglia and Bridget Allchin (Dordrecht: Springer, 2007), pp. 121–35.
[44] Pappu, p. 130.
[45] Cushing, p. 92.

with histories of human inhabitation helps to remind us, as Philip Steinberg and Kimberley Peters stress, that we must resist the tendency to view (sub)terranean matter as 'fixed and grounded', finished, complete.[46]

[46] Philip Steinberg and Kimberley Peters, 'Wet Ontologies, Fluid Spaces: Giving Depth to Volume through Oceanic Thinking', *Environment and Planning D: Society and Space*, 33.2 (2015), 247–64.

Ways of Thinking with Groundwater

I have so far given a brief orientation that is intended to situate thinking with groundwater at the centre of my scholarly engagement with the city of Chennai. This necessitates both a broad understanding of the spatially- and temporally-distributed nature of urban settlement, and a resistance to framing hydrogeologic emergence in terms of specific categorisations. In this thesis, I intend to cast groundwater as something elusive, multivalent, and ineffable—offering both an alternative set of concepts for thinking about urban life as more-than-human, and demanding a new set of methodologies with which to approach it. In the following section, I outline an argument for thinking with groundwater, first in terms of its relationship to the monsoon as a climatic system within which Chennai is situated, and subsequently in relation to a review of relevant literature.

The Underground Monsoon

This thesis emerges not only from multiple engagements with the city of Chennai but within the context of a wider project of the monsoon.[47] Here, I understand the monsoon as a climatic system which emerges out of, as much as arrives into, the materiality of Chennai. As a colleague has repeatedly pointed out, 'monsoon' as a singular concept and particular term for a multitude of phenomena does not exist in most South Asian language.[48] Such unification of the many divergent, and emergent processes that comprise multiple monsoons is an abstraction, and our collective work aims to trouble and question such constructions.

I will not, therefore, give a generalised account of the monsoon in conventional terms, but instead allow particular monsoonal understandings to emerge from thinking with groundwater from Chennai. The approach here is in contrast to a framework that functions as 'discursive apparatus that renders climate change legible in a narrow and constrained fashion'.[49] Agricultural proverbs of Tamil Nadu suggest that 'the traditional Indian concept of the monsoon does not involve a relationship between the outburst of the seasonal rains and changes in wind direction', and that the 'cosmological, spatial, and temporal concepts that make nature intelligible and coherent' are specific to individual phenomena, rather than linking different weather effects.[50] That is, there is a willingness to let the monsoon be manifold and heterogenous, rather than

[47] Lindsay Bremner and others, *Monsoon as Method* (Barcelona: Actar, 2021).
[48] Harshavardhan Bhat, 'Stickiness in a Monsoon Air Methodology', in *Rubber Boots Methods for the Anthropocene*, ed. by Nils Bubandt, Astrid Anderson, and Rachel Cypher (Minneapolis, MN: University of Minnesota Press).
[49] Marcus Taylor, *The Political Ecology of Climate Change Adaptation: Livelihoods, Agrarian Change and the Conflicts of Development*, *Routledge Explorations in Development Studies* (Abingdon: Routledge, 2015), pp. 2–3.
[50] Brian J. Murton, 'Monsoons in Agricultural Proverbs in Tamil Nadu', in *Monsoons*, ed. by J.S. Fein and P.L. Stephens (New York: John Wiley & Sons, 1987), pp. 77–102.

amalgamate it into terms unrelated to its specific manifestations in particular places. As well, 'there appears to be no attempt [..] to deny that uncertainty exists'.[51]

Throughout the development of this thesis, I have dwelled on the questions of what groundwater is, and why it is part of a monsoonal assemblage. This has been not only because I asked them of myself, but because others asked them of me, repeatedly. I was told by critical friends that 'groundwater has nothing to do with the monsoon!', that there is a science and a sociology of groundwater and this is an interesting topic, but that they 'do not see how this is connected with the monsoon'.[52] Such categorical denials were often immediately contradicted by commonplace understandings, dropped into the same conversations, of how groundwater is a register of the changing relationship between urban development and the monsoon climate: the importance and failure of storm drain networks, or alternatives of rainwater harvesting, the annual waves of nearly-flooded conditions, frequent droughts, and what happens to groundwater quality during the monsoon. All of these spoke to the ongoing acts of maintenance through which urban development mediates relationships between (sub)surface and atmospheric water cycles.

Very early, I was told—insightfully—by an engineering professor that in Chennai, there are different narratives of different waters such as ground-, surface-, rain-, and river-water. But what makes these waters distinct? What is the purpose of such categorisation? Certainly, all these discrete species of water are attended to in great detail in both conversations and local press reports, where technical terminology of volume, flow, and quality is both common and commonly understood. Each form of water seemingly has its own terms. At the same time, we talked about how the monsoon is a magnet for all kinds of social processes and vagaries associated with these and other waters, and has a psychological impact on thinking about infrastructural processes which bridges between categories. The acknowledgement of the material connection, then, whilst vehemently excluding groundwater from the conceptual space of the monsoon, is redolent of broad social-scientific conceptualisations as well as groundwater's relative invisibility (in contrast to other waters). The same professor spoke about how groundwater is measured, but not managed, due to the difficulty in isolating it as one distinct part of the water cycle. What I will describe throughout this thesis is how what groundwater does in every sense is to leak through such conceptual boundaries, its material properties troubling acts of bordering, making those borders into sites of exchange.

[51] Murton.
[52] Personal communications.

Groundwater is a persistent presence in narratives of the city, firstly in its everyday extraction, or 'abstraction'—a usefully duplicitous term, referring both to the physical practice of removing water from the ground, separating it from its holding structure, and the representational practice of considering certain aspects over others, selecting just a part of it. What is drawn up both is and is not groundwater: it is a product of the material relationships I write about when I write about groundwater. It might contain minerals absorbed from geological strata, dispersed anthropogenic contaminants, or increased salinity due to rising inland seawater. It is a part of this complex material dynamic, abstracted from the rest. Groundwater in this sense is relied upon for around one third of the city's water supply.[53] It is a volumetric resource, 'the river flowing just below the surface', which needs to be cared for and replenished. [54] It is also a stratified zone through which basements and tunnels are built, a three-dimensional structure which is mapped by means of boreholes, core sampling, and the geological section—freezing itinerant hydrogeologic strata in time. And it is a diverse ecology of minerals and microorganisms: the 'groundwater network arises from a complex interaction of morphodynamic processes linked to the water cycle', and 'variations in porosity and permeability create discontinuities and connections between aquifers and river channels and lead to complex distribution patterns of biota'.[55] Matters flow as minerals, in water, as aerosols, and through human bodies. And it is not just minerals but 'organisms that traverse this geologic continuum in association with fluxes of energy and matter'.[56] Bacterial metabolic processes work in tandem with geologic forces.

Groundwater appears in narratives of both drought and flooding as waves of the underground monsoon. In the context of my research, it was everywhere: it appeared, and was something through which I could begin to get to know this place. The connection between groundwater and the monsoon, as mediated by urban infrastructures, was at first something I could see from the street as I stood beneath the canopy of my rented room in Besant Nagar and watched the heavy July rain flow in and between the gaps in storm drains, or pool in the spongiform sands of the city's few remaining unpaved grounds, swelling as the rainwater saturated pore spaces. This literal, material, and sequential relationship between monsoon rains and groundwater is just one aspect of a connection that is far more than linear. The further into that journey one goes, the more it becomes confused and muddled, out of sequence: accessed via a kind of turbulent

[53] An estimated 350 million litres per day (mld) of a total consumption in excess of 1000 mld. A. Graft et al., *Chennai: State of Water*, Chennai, Tamil Nadu State Land Use Board, 2019, p. 41.
[54] Santha Sheela Nair, Besant Nagar, Chennai, 7 July 2018. Interview by the author.
[55] M. Creuzé des Châtelliers, D. Poinsart, and J. -P. Bravard, 'Geomorphology of Alluvial Groundwater Systems', in *Groundwater Ecology*, ed. by Janine Gilbert, Dan L. Danielopol, and Jack A. Stanford (London: Academic Press, 1994), pp. 157–85.
[56] Gibert, Danielopol, and Stanford, p. 1.

material archive left by groundwater drawing together aspects of urban development and the monsoon climate in provisional assemblages. Scientists are quick to point out the connection: 'monsoon plays a major role in groundwater quality',[57] and press articles frequently refer to the effects of the monsoon in relation to groundwater, its pre- and post-monsoon levels, the variance in saturation of different contaminants caused by increased flow rates.[58] Even some scientific papers, albeit few, are organised around the seasonal variation in groundwater brought on by the monsoon cycle.[59]

And whilst making this connection is different from saying that groundwater is (part of) the monsoon, by studying ways in which groundwater is known, and how it troubles them, we might—in the words of Karen Barad—'seek some way of trying to understand the nature of the interplay of the material and the cultural in the crafting of an ontology'.[60] That is, to use the materiality of groundwater as a medium which explicitly evades binaries (social/natural or material/representational), and rather asks: how do they trouble or leak into one another? Groundwater is physically remade through ways of thinking it, just as Barad writes that **'**our knowledge-making practices are social-material enactments that contribute to, and are part of, the phenomena we describe'.[61] The one must be read through the other: neither the object of investigation nor the 'agencies of observation' can be subtracted out, or absolutely determined independent of provisional assemblage through which they both come to be in a way that is both contingent and emergent, and through which both are remade.[62] Barad calls this 'intra-action', indicating the co-production of knowledge and object. The science (hydrology) and the material (groundwater) are co-constituent parts of the same story: 'the very nature of matter and the very matter of nature [are] (iteratively re-)constituted through a(n iteratively reconfigured) multiplicity of force relations'.[63]

[57] L. Elango, Department of Geology, Anna University, Chennai, 25 January 2018. Interview by the author.
[58] U Tejonmayam, 'Monsoon Replenishes Groundwater, but Renders It Unfit for Consumption', *Times of India*, 6 March 2018 <https://timesofindia.indiatimes.com/city/chennai/monsoon-replenishes-groundwater-but-renders-it-unfit-for-consumption/articleshow/63177305.cms> [accessed 23 July 2020].
[59] Vutla and Ravichandran.
[60] Karen Barad, 'Meeting the Universe Halfway: Realism and Social Constructivism without Contradiction', in *Feminism, Science, and the Philosophy of Science*, ed. by Lynn Hankinson Nelson and Jack Nelson (Dordrecht: Kluwer Academic Publishers, 1996), pp. 161–94 (p. 164).
[61] Karen Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (Durham, NC: Duke University Press, 2007), p. 26, emphasis added.
[62] Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, p. 31.
[63] Karen Barad, 'No Small Matter: Mushroom Clouds, Ecologies of Nothingness, and Strange Topologies of Spacetimemattering', in *Arts of Living on a Damaged Planet*, ed. by Anna Lowenhaupt Tsing and others (Minnesota: University of Minnesota Press, 2017), pp. G103–20 (p. 110).

A majority of the primary literatures, and related studies in this area, are concerned with the social aspect of access to potable water, i.e. water as resource. In particular, works by Erik Swyngedouw, Matthew Gandy, and Maria Kaika, as well as Colin MacFarlane, and Lisa Bjorkman emphasises the political and governmental aspect of water, its transmission and circulation above ground, its economy and relationship to capital and modernisation.[64] This thesis is about how *both* earth systems, and processes of urbanisation, performed by manifold actors, have intra-acted to transform a low-lying marshland into a 'global city', of successive imaginaries—a complex web of urban governance structures, plans, municipal authorities, corruption, finance, and politics, which attempts to reshape the city's resources through a conception of earth systems as malleable components in urban landscape production. In seeking to give some definition of groundwater as an assemblage of intra-active material phenomena, I looked to works such as Richard White's *The Organic Machine* which engaged with the hybridity of the Columbia river through the hydrological, atmospheric, subterranean, infrastructural, scientific, and social processes which it generates and is in turn reproduced by.[65] White's approach to the river basin, captured in his composite title, draws together its supposedly natural and supposedly man-made aspects, troubling and blurring the distinctions between them, albeit whilst holding on to some of this polarity in the idea of an absolute 'actual world of plants and animals' beyond 'human heads'.[66] White also critiqued the established, enlightened hierarchy of ways in which the river is known and represented, contrasting engineering science with 'bodily' knowledge. Attempts by scientific practices to order the fluvial environment–both representationally and physically–are routinely exceeded by 'a tangible physical world that sometimes affirmed but often mocked the representations designed to constrain it'.[67]

Away from White's particular concern with energy transfer as a mechanism which dissolves categorisations, Jamie Linton's work on the hydrological cycle further problematises canonical conceptions of environmental systems.[68] Linton shows how the hydrologic cycle, rather than being something 'immanent in nature' to be 'revealed' by scientific practices, is in fact the

[64] Erik Swyngedouw, 'Modernity and Hybridity: Nature, Regeneracionismo, and the Production of the Spanish Waterscape, 1890–1930', *Annals of the Association of American Geographers*, 89.3 (1999), 443–65; Matthew Gandy, 'Liquid City', 2007 <https://www.youtube.com/watch?v=u2UPPjlgb9k> [accessed 18 October 2016]; Maria Kaika, *City of Flows: Modernity, Nature, and the City* (London: Routledge, 2005); Colin McFarlane, 'Sanitation in Mumbai's Informal Settlements: State, `slum', and Infrastructure', *Environment and Planning A*, 40 (2008), 88–107; Lisa Björkman, *Pipe Politics, Contested Waters: Embedded Infrastructures of Millennial Mumbai* (Durham, NC: Duke University Press, 2015).
[65] R. White, The Organic Machine: The Remaking of the Columbia River, New York, Hill and Wang, 1995.
[66] R. White, 'Discovering Nature in North America', The Journal of American History, vol. 79, no. 3, 1992, p. 877.
[67] White, 'Discovering Nature in North America', pp. 874–875.
[68] J. Linton, 'Is the hydrologic cycle sustainable? A historical-geographical critique of a modern concept', Annals of the Association of American Geographers, vol. 98, no.3, 2008.

opposite: something constructed by scientific practices which nature exceeds, resisting the bordering off of one water from another.

> At the same time that the modern hydrologic cycle has structured our understanding of water's nature, these various waters have had to adjust themselves to a single hydraulic paradigm that regards all water (and all people insofar as the way they relate to water) as fundamentally the same. [69]

Why then, if the modernist hydraulic paradigm argues that all water is fundamentally the same, am I arguing the usefulness of thinking with *groundwater* from Chennai? Precisely because it is the locus of so many and frequent intra-actions, because of the variety of professions, agencies and disciplines engaged with(in) it, and the manifold knowledge practices through which groundwater is known and intervened in. Whilst I began by trying to read the city through groundwater, my focus became the onto-epistemological mechanisms of knowing groundwater itself: tools that people use, and how groundwater makes itself known. As such, the focus of my research is not groundwater-as-such but the always hybrid, multiple, specific, and contradictory ways in which different people get at it: scientific abstractions, research methods, instruments of measure, policy, and legal frameworks; the relational assemblage which includes the representational and knowledge practices of different bodies and disciplines. In this way, it is impossible to think with groundwater other than as part of monsoonal assemblages.

Andrea Ballestero describes groundwater as a 'dynamic architecture sucking and seeping, swelling and shrinking, absorbing and oozing'.[70] Groundwater is not a simple substance but a thick and complex three-dimensional environment, an intra-active relationality between water and ground: one upon which we rely for many aspects of our own lives, but which is not there purely for our ends. We come to know it through established scientific practices as well as the immediate, embodied, and everyday use. I was told how people 'use their bodies as a monitor', asking, 'how do we translate scientific experiences of people into science?'.[71]

So, what then does it mean to think with groundwater from Chennai? Throughout these different points of view, it is impossible to say quite what groundwater *is*, other than a set of relations that move in and between urban climates: a socionatural, hybrid condition, neither separable into constituent parts, nor cognisable as a singular whole. Groundwater appears and is drawn into focus as a register which can bring together accounts of such diverse phenomena as alluvial geomorphology, social inequality, municipal engineering, and more. The closer I look at it, the less it appears as a discernible, material thing: instead I begin to make sense of

[69] Linton, 'Is the hydrologic cycle sustainable?', p. 632.
[70] Andrea Ballestero, *A Future History of Water* (Durham, NC: Duke University Press, 2019).
[71] Pooja Kumar, Urur Kuppam, Chennai, 5 July 2018. Interview by the author.

groundwater as a relational substance, one which is not a background to the city's ongoing reproduction, but is both substantially altered by and co-constitutive of lively urban assemblages. Groundwater moves through the city both literally and conceptually as a changing set of relations which shift and need to be followed. Different positions will yield different sets of characters, as certain conceptual frames and knowledge practices bring different aspects of it into view. Through the focus on ways on knowing groundwater, what emerge are provisional glimpses into urban processes that are highly charged and highly political: struggles of liveability, which like groundwater itself can't be rigidified into formal structures. There is not one single thing called ground, but multiple grounds, variously saturated, seeping, sinking, and subtended by others. Living with these grounds is living in conditions of unstable hydrogeological emergence.

Vital-Materialist Enquiry

The opening section established the reciprocity between the city of Chennai and its wider hydrogeologic landscape. The question subsequently posed was of what groundwater is, and why it is part of a monsoonal assemblage. The remainder of this introduction considers how to study groundwater as a dynamic materiality, how to bring it into the realm of research as an active participant. This section, then, offers a substructure for developing a methodology for engaging with groundwater. Through a critical literature review, the aim is scope and outline a theoretical framework that will, like groundwaters, creep and flow through many and varied materials. I will look at a variety of existing secondary literature which seeks to give voice to 'things' and 'materials', before sinking into some philosophical bases for these methodologies, which might help to develop from their limitations. The following sections reflect an initial difficulty in framing the object of enquiry, and an attempt to establish ways in.

> Things-in-themselves? But they're fine, thank you very much. […] Things in themselves lack nothing […] Once things are reduced to nothing, they beg you to be conscious of them and ask you to colonize them. […] Who told you that man was the shepherd of being? […] there is no shepherd. There are too many of us, and we are too indecisive to join together into a single consciousness strong enough to silence all the other actors. Since you silence the things that you speak of, why don't you let them talk by themselves about whatever is on their minds, like grown-ups? Why are you so frightened? What are you hoping to save? [72]

'Our concepts have been formed on the model of solids', wrote Henri Bergson in the 1907 introduction to *Creative Evolution*.[73] Predominant modernist or Western ontologies are predicated on the inanimate nature of objects, and the primacy of human subjects, who bring those objects

[72] Bruno Latour, *The Pasteurization of France*, trans. by Alan Sheridan and John Law (Cambridge, MA: Harvard University Press, 1988), pp. 193–94.
[73] Henri Bergson, *Creative Evolution*, trans. by Arthur Mitchell (New York: Henry Holt, 1911), p. xix.

into being. In contrast to a philosophy in which we are the sole agents of being, a growing field of enquiry loosely-termed 'vital materialism' has—in the past few decades—sought to give materials a 'voice' in the way we understand the material world in which we live. Jane Bennett's *Vibrant Matter* contests the schema by which the world is divided into living things, on the one hand, and inert 'mere matter', on the other.[74] Bennett instead proposes a broad continuum, in which such matter—including things not directly observable—can be made not only visible, but 'thinkable' within 'cultural ensembles' sensitive to their effects.[75] The aim is to bring material actors into an understanding of morality, ethics, and politics, in order to 'cultivate a broader definition of self-interest'.[76]

This is a materialism built on the primacy of anthropocentric knowledge systems, and criticism of it includes Tim Ingold's response to 'the ever-growing literature in anthropology and archaeology that deals explicitly with the subjects of *materiality* and *material culture* [but which] seems to have hardly anything to say about materials'. [77] Ingold's suggestion is that, despite the salutations given to the importance of 'materialism' (loosely termed), existing work in this field very rarely mentions actual 'materials or their properties'.

I would argue that this is what happens in Bennett's account: things become a vehicle to discuss *ideas about things*, specifically the ideas of the observing subject. Discoveries are apparently reached 'after only the lightest possible contact with experience.[78] The thinker remains in the same outside position exactly where they were before. It is the location of thought—its extension beyond the bounded self—that becomes crucial in bringing materials into the work in a meaningful way, and in order to work with this notion we need to be concerned less with things *as they are* and more with things *as they behave*.

It is easy to make things appear as metaphors, not properties—but the point is to strip back the metaphorical content, to let materials in on their own terms.[79] Martin Holbraad describes this difficulty of 'thinking through things' by discussing contrasting approaches to a more distributed attribution of agency.[80] Firstly, Holbraad describes an approach of 'anthropological ventriloquism', whereby things 'speak' only *by association*—with people, culture, ethnography—'i.e. by letting some of the light of what it is to be human shine on them too'. That is, as

[74] Jane Bennett, *Vibrant Matter: A Political Ecology Of Things* (Durham, N.C.: Duke University Press, 2010).
[75] Bennett, p. xii.
[76] Bennett, p. 13.
[77] Tim Ingold, 'Materials Against Materiality', *Archeological Dialogues*, 14.1 (2007), 1–16.
[78] Bergson, p. xx.
[79] Manuel DeLanda, *A Thousand Years of Nonlinear History* (New York: Zone Books, 1997), p. 16.
[80] Martin Holbraad, *Can the Thing Speak?*, *OAC Press Working Papers Series*, 2011.

reflectors or embodiments of human intentions. The non-human things exist and are thought only in relation to their roles in the lives of humans.

But 'things deserve better'.[81] Groundwater does not care that I am writing about it. It is not meaningful to simply include it in this conversation. The humanist approaches to the agency of things 'leave the ontological distinction between things and people unmodified'—they leave the dividing point in place, and simply redistribute certain properties and capacities across the given spectrum.[82] Here, 'agency' gets wrapped up with 'intentionality' in a peculiar way, because we have not addressed the question of what it is to act. It is clear that the landscapes I describe are formed in and through the agency of groundwater, but this need not be confused with 'intentionality' (a human concept, in any case).

In contrast, *posthumanism* seeks to redefine the properties of persons and things, away from the given divide. Sarah Whatmore suggests that the terminology of 'post-human(ism)' implies a temporal axis, an 'after' and so therefore a 'before'—a moment when we were more completely and neatly ourselves, before becoming technologically-infused cyborgs at some point in history.[83] She advocates instead the term 'more-than-human', as an argument for a politics of hybridity, whereby:

> The rhythms and motions of these inter-corporeal practices configure spaces of connectivity between more-than-human life worlds; topologies of intimacy and affectivity that confound conventional cartographies of distance and proximity, and local and global scales.[84]

The temporality of human-geologic relations demands this effort to 'push hybridity back in time' to work through the 'long practised intimacies': 'one never arrives at a time when the human was not a work in progress'.[85] The purpose of utilising this terminology is to decentre the social in descriptions of cities, to unpick an understanding of groundwater as a citizen in the 'community dynamics' of place-making. Using the rubric of non-(x) is profoundly ontological, and restrictive, since the definition of non-human, non-living, etc., ascribes perceived limits to things. The point

[81] Thóra Pétursdóttir, 'Small Things Forgotten Now Included, or What Else Do Things Deserve?', *International Journal of Historical Archaeology*, 16.3 (2012), 577–603; Frank Trentmann, 'Materiality in the Future of History: Things, Practices, and Politics', *The Journal of British Studies*, 48.02 (2009), 283–307.
[82] Martin Holbraad and Morten Axel Pedersen, *The Ontological Turn: An Anthropological Exposition* (Cambridge: Cambridge University Press, 2017), p. 7.
[83] Sarah Whatmore, *Hybrid Geographies: Natures, Cultures, Spaces* (London: SAGE, 2002), p. 4; Sarah Whatmore, 'Earthly Powers and Affective Environments: An Ontological Politics of Flood Risk', *Theory, Culture & Society*, 30.7–8 (2013), 33–50 (p. 35).
[84] Whatmore, 'Earthly Powers and Affective Environments: An Ontological Politics of Flood Risk', p. 162.
[85] Whatmore, 'Earthly Powers and Affective Environments: An Ontological Politics of Flood Risk'.

of this work must at the very least be to *allow* forces, materials, and strata to share in the potentialities of situation.

In the following survey, I make an attempt to work through the question of how non-correlational vital materialism—the proposition that 'value and sense are intrinsic to all entities'—can inform an ontological approach to research, which seeks to describe entangled things, away from configurations of sense and effect, human subjectivity, and operations of knowledge—even within necessarily human-centric formats.[86]

Dynamics and vibrancy: 'to exist is to change'

This conception speaks to long-running architectural debates about the city, as being composed of processes rather than forms. In this thesis I consider the city through an investigation of knowledge practices, which are operationalised in its ongoing reproduction. Architecture is full of static and non-relational imaginations of ground, as well as literature which seeks to engage more fully with the proposition of Bergson, that 'for a conscious being, to exist is to change, to change is to mature, to mature is to go on creating oneself endlessly'.[87] This study will emphasise a new interpretation of groundwater as a counterpoint to such apparent solidity, following examples such as Robert Beauregard's *Planning Matter*.[88] One that has been particularly influential on my work has been an essay written by Bruno Latour and Albena Yaneva. In it, they sketch an understanding of and a methodology for architectural practice beyond static representations: 'every new project modifies all the elements that try to contextualise it […] In this sense, a building project resembles much more a complex ecology than it does a static object in Euclidean space'.[89] In this, they develop from Actor-Network Theory and the proposition that:

> For too long, objects have been portrayed as matters-of-fact [but] they are much more interesting, variegated, uncertain, complicated, far-reaching, heterogeneous, risky, historical, local, material and networky.[90]

Clare Colebrook challenges us to 'imagine a mode of reading the world, and its anthropogenic scars, that frees itself from folding the earth's surface around human survival', asking 'How

[86] Steven Shaviro, *The Universe of Things: On Speculative Realism* (Minnesota: University of Minnesota Press, 2014), p. 77.
[87] Bergson, p. 7.
[88] Robert A Beauregard, *Planning Matter: Acting with Things* (Chicago: The University of Chicago Press, 2015).
[89] Bruno Latour and Albena Yaneva, '"Give Me a Gun and I Will Make All Buildings Move": An ANT's View of Architecture', in *Explorations in Architecture: Teaching, Design, Research*, ed. by Reto Geiser (Basel: Birkhäuser, 2008), pp. 80–89 (p. 88).
[90] Bruno Latour, 'From Realpolitik to Dingpolitik or How to Make Things Public', in *Making Things Public: Atmospheres of Democracy*, ed. by Bruno Latour and Peter Weibel (Cambridge, MA: MIT Press, 2005), pp. 2–34 (p. 11).

might we read or perceive other timelines, other points of view and other rhythms?'.[91] Manuel Tironi and Nerea Calvillo, following Beauregard, have responded to Jane Bennett's call to open up to 'a fuller range of the nonhuman powers circulating around and within human bodies' [92] by insisting that we work with water and air as 'inventive elements', taken 'attentively in their full capacities, specificities, affordances'.[93] Thinking of planning policy not as way of bringing these untameable entities into being as 'risks' to control, which 'marginalizes the material world both theoretically and practically',[94] but instead as a means to 'let [vital non-human elements] speak'.[95] This raises the possibility of extending the concept of participation—which has such a hold on urban planning methodologies—to non-human others, as a means of generating planning policy that is more inventive and speculative.[96]

Material Anthropology: Rocks, Mushrooms, and Rivers

To think groundwater as a participant, we need to open up the multispecies and more-than-human, to think about 'geologic conviviality': the specific and complex ways in which geologic existences intersect with humans. Despite the truism that 'material space is, for us humans, quite simply the world of tactile and sensual interaction with matter, it is the space of experience',[97] feminist studies have destabilised the neat, distant, and binary relation between bodies and the environment, showing them instead as entangled. Elizabeth Grosz describes the human body as being 'incomplete', 'a series of uncoordinated potentialities', which is (re)produced, ordered, and codified—*organised*—in and through relations with others in the urban environment.[98] We can therefore understand both landscape and climate as the 'processual, material and perceptual engagement between body and world'.[99] Ingold reiterates this through his conception of atmosphere as material in motion, a space of flows, and 'textility' between lively things: 'An environment […] can exist only in relation to the forms of life that inhabit it.' [100]

[91] Claire Colebrook, *Death of the PostHuman: Essays on Extinction, Vol. 1* (Ann Arbor: Open Humanities Press, 2014), p. 23.
[92] Bennett, p. ix.
[93] Manuel Tironi and Nerea Calvillo, 'Water and Air: Territories, Tactics and the Elemental Textility of Urban Cosmopolitics', in *Urban Cosmopolitics: Agencements, Assemblies, Atmospheres*, ed. by Anders Blok and Ignacio Farias (Abingdon: Routledge, 2016), pp. 207–24 (p. 210).
[94] Beauregard, p. 225.
[95] Tironi and Calvillo.
[96] *Participatory Research in More-than-Human Worlds*, ed. by Michelle Bastian and others (London: Routledge, 2016).
[97] David Harvey, 'Space as a Key Word', in *Marx and Philosophy Conference*, 2004.
[98] Elizabeth Grosz, 'Bodies-Cities', in *Sexuality and Space*, ed. by Beatriz Colomina (New York: Princeton Architectural Press, 1992), pp. 241–54.
[99] Jonathan Miles-Watson, Hugo Reinert, and Helen Sooväli-Sepping, 'Introduction—Ruptured Landscapes', in *Ruptured Landscapes: Landscape, Identity and Social Change*, ed. by Jonathan Miles-Watson, Hugo Reinert, and Helen Sooväli-Sepping (Dordrecht: Springer Netherlands, 2015), pp. 1–7 (p. 3).
[100] Tim Ingold, 'Earth, Sky, Wind, and Weather', *Journal of the Royal Anthropological Institute*, 13.S1 (2007), S19–38 (p. 25).

Phillipe Descola attempts to deal with the problem of the fundamental configuration of anthropology towards describing 'adaptations' between human (culture) and environment—that is, the tension between a post-cartesian/post-humanist theory and a methodology based upon that dualism. There is an inherent contradiction in the study of adaption to nature, when nature is understood as entangled-with as well as only-visible-through culture:

> Distinguishing among the objects of the world those that are a matter of human intentionality and those that stem from universal laws of matter and of life is an ontological operation, a hypothesis and a choice with regard to the relations that beings maintain with one another as a result of the qualities which are ascribed to them. [101]

For Anna Tsing, going beyond this hypothesis means working with an expanded definition of the 'social' as a means to explore and narrate multispecies networks. The social is a relevant concept if we accept that 'social relations […] do not come into being because of humans':

> I cannot think of a good reason to argues that non-vital things are not social. […] There is no reason not to extend social theory to rocks and rivers.

Colebrook also reminds us of the importance of thinking a world after, or outside of, human life—envisioning a more-than-human world of things, whose 'social relations do not need to be authorised by humans to count'.[102] This doesn't mean avoiding our positionality, since 'our humanness is also a starting point, an opening for getting involved in multispecies worlds. […] Our doings are a way to trace the doings of others'.[103] Several authors in anthropology, archaeology, and the social sciences have applied such approaches to address 'the divide between living and nonliving', illuminating 'a more-than-human polity'—an expanded ethnography including rocks, mushrooms, and rivers.

In Eliabeth Povinelli's *Geontologies*, things speak through their co-habitants, and the knowledge and belief systems developed over millennia of living in the landscape.[104] In this way, rocks, fossils, and creeks become characters in the book, which are named, and which act. Povinelli's concept of 'geontology' is a term which in itself fuses non-life (*geo*—the earthly) and being (*onto*). Povinelli considers how power ('geontopower') operates through classifications of vitality: 'as the previously stable ordering divisions of Life and Nonlife shake, new figures, tactics, and discourses of power are displacing the biopolitical'.[105] Similarly—though from a different starting

[101] Phillipe Descola, *The Ecology of Others*, trans. by Geneviève Godbout and Benjamin P. Luley (Chicago: Prickly Paradigm Press, 2013).
[102] Anna Lowenhaupt Tsing, 'More-than-Human Sociality: A Call for Critical Description', in *Anthropology and Nature*, ed. by Kirsten Hastrup (New York: Routledge, 2013), pp. 27–42 (p. 33).
[103] Tsing, 'More-than-Human Sociality: A Call for Critical Description', p. 34.
[104] Elizabeth Povinelli, *Geontologies: A Requiem to Late Liberalism* (Durham, NC: Duke University Press, 2016).
[105] Elizabeth Povinelli, 'Geontologies: The Figures and the Tactics', *E-Flux*, 2016 <http://www.e-flux.com/journal/78/81514/geontologies-the-figures-and-the-tactics/> [accessed 10 May 2017].

point—for Jefferey Jerome Cohen, history is a story that exceeds human conception, and needs to be told through the experience of geological matter.[106]

In an extensive discussion, Veronica Strang has proposed that water is 'good to think with' because it functions at every level of human and non-human engagement: 'the materiality of water and its particular properties enables us to bring human and non-human scales together coherently'.[107] Reiterating a concept of agency and materiality as relational and distributed, emerging neither from people nor things but their combination, she reminds us that these relations and combinations are themselves formed—at least in part—by the physical properties of things. In developing an 'anthropology of water', Strang writes of 'the permeability of the person as an assemblage of both internal and external matter'. This co-constitution, furthermore, extends notions of mind and cognition—as well as agency, intentionality, and identity. Both body and water are spaces of exchange, entanglements that are 'emergent, dynamically integrating material and human processes of 'becoming''. There is no privileging of the human voice, here: water, rivers, etc., retain their non-human position even when 'wrested with' by humans.[108] This requires an attention to the *molecular* in materiality. As Heather Davis writes, 'there is no possibility of barricading, containing, or sealing ourselves off. We are radically open, inherently constituted by the molecular outside'.[109]

Through a discussion of the relationships and ongoing dialogues between industrial mining processes and traditions of sacrifice stones in arctic Norway, Hugo Reinert gives the reverence of these *sieidl* as an example of 'a more-than-human polity, a shared or convivial space defined by an ethos of pragmatic co-existence':

> human and nonhuman organisms share a range of basic affinities, affordances, and constraints. They interact with their environments, grow and starve, thrive and suffer; ultimately, they die. Some form of empathy is not so hard to establish [110]

This foregrounding of *co-existence with* rather than *concern for* departs significantly from much of existing environmental discourse in that it (counter-intuitively) allows things in themselves to exist and be social, without humans—or without considering the environment as a thing in our care, where the primary motivation for that care is retaining the capacity of the environment to

[106] Jeffrey Jerome Cohen, *Stone: An Ecology of the Inhuman* (Minneapolis: University of Minnesota Press, 2015).
[107] Veronica Strang, 'Fluid Consistencies. Material Relationality in Human Engagements with Water', *Archaeological Dialogues*, 21.2 (2014), 133–50.
[108] Matt Edgeworth, 'On the Agency of Rivers', *Archaeological Dialogues*, 21.2 (2014), 157–59.
[109] Heather Davis, 'Molecular Intimacy', in *Climates : Architecture and the Planetary Imaginary*, ed. by James Graham (Zurich: Lars Müller Publishers, 2016), pp. 205–11.
[110] Hugo Reinert, 'About a Stone: Some Notes on Geological Conviviality', *Environmental Humanities*, 8.1 (2016), 95–117 (p. 106).

be useful to *us*. And yet, groundwater is almost exclusively thought of in relation to its use (to humans), as a substance to be extracted and utilised. This understanding negates a huge amount of its capacity as a thing. As Tsing says, 'We think we already know how to study nature […] We study it in relation to human goals and needs'.[111]

The question of how to bring materials into the conversation is ontological, rather than epistemological. It concerns what is given status, where we understand the line to be drawn (or not drawn) between forms of existence, and how we reject or acknowledge the presence of uncertain energies we can't control. The fact that strata is a concept derived from material behaviours is a step towards a meaningful place for materials in a research methodology, but it requires further questioning of our conception of reality and action, of why things exist and change.

Creative Ontology: Bergson, Whitehead, and Deleuze

> 'Let us take the most stable of internal states [...] The truth is that we change without ceasing, and that the state itself is nothing but change. [...] there is no essential difference between passing from one state to another and persisting in the same state.' [112]

This section will thread the speculative and creative philosophies of Alfred North Whitehead (1861-1947), Henri Bergson (1859-1941), and Gilles Deleuze (1925-1995, who acknowledges great debts to both Bergson and Whitehead, and whose work has helped bring about their renewal)—utilising their work to develop an approach to 'knowledge' and 'thought' in relation to the central tenet of rejecting correlationism: or that the world is not limited to what we know about it.

Conversations between these thinkers are not imaginary. Bergson and Whitehead both read and commented on each other's work,[113] and Deleuze has been largely responsible for bringing both back into contemporary philosophical debate.[114] And yet this is not intended as a comparison. To compare their philosophies, as if static positions to be appraised by the reader from the outside, would miss the point. This is thought that has to be taken in, experimented with, and

[111] Tsing, 'More-than-Human Sociality: A Call for Critical Description', p. 33.
[112] Bergson.
[113] Keith Robinson, 'Introduction', in *Deleuze, Whitehead, Bergson: Rhizomatic Connections*, ed. by Keith Robinson (Basingstoke: Palgrave Macmillan, 2009), pp. 1–27 (p. 2).
[114] Gilles Deleuze, *Bergsonism* (New York: Zone Books, 1991).

put into action.[115] As Deleuze argues, Bergson's philosophical intentions are *methodological*: that is, they refer to ways of thinking rather than forms of absolute knowing.[116]

This section will also rely heavily on interlocutors, in particular Steven Shaviro, and Isabelle Stengers.[117] In doing this, my intention is to develop both an argument and a methodology of non-correlational thought, or how this thesis will employ terms such as 'knowledge' and 'cognition'. None of these philosophers' outputs can be simplified, labelled, or coded, but all offer ways in to working and thinking with vital materiality. They do not offer a ready-made schema, but a new way of understanding problems, and therefore the possibility of developing new methodologies alongside those problems, and with those materials.

This is clearly an enormous terrain of thought, and I will focus on creativity, process, and 'becoming'—being an ontological argument for how and why things happen. Fundamental to the proposition, following directly from Bergson through Whitehead to Deleuze, is that there are no static objects: 'there is no essential difference between passing from one state to another and persisting in the same state'.[118] Therefore, the question of ontology is not the question simply of existence but of change, of fluidity, of *things in motion*. This is one central tenet shared by Bergson, Whitehead, and Deleuze: understanding reality as 'perpetual becoming'.[119]

Correlationism

The key term of this section, *correlationism*, is now associated with the work of Quentin Meillasoux, since the French philosopher is the one who—in his first book, *After Finitude*—has made the greatest efforts in untangling it.[120] Meillasoux defines correlationism as 'the idea according to which we only ever have access to the correlation between thinking and being, and never to either term considered apart from the other'.[121] That is, thoughts are predicated on the subject-object relationship, and we (the subject) only have access to that relationship, not to the object itself.

115 Isabelle Stengers, 'Thinking with Deleuze and Whitehead: A Double Test', in *Deleuze, Whitehead, Bergson: Rhizomatic Connections*, ed. by Keith Robinson (Basingstoke: Palgrave Macmillan, 2009), pp. 28–44.
116 Deleuze, *Bergsonism*.
117 Steven Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics* (Cambridge, MA: MIT Press, 2009); Isabelle Stengers, *Thinking with Whitehead: A Free and Wild Creation of Concepts*, trans. by Michael Chase (Cambridge, MA: Harvard University Press, 2014).
118 Bergson, p. 105.
119 Keith Robinson, 'Glossary of 25 Key Terms', in *Deleuze, Whitehead, Bergson: Rhizomatic Connections*, ed. by Keith Robinson (Basingstoke: Palgrave Macmillan, 2009), pp. 220–34.
120 Quentin Meillassoux, *After Finitude: An Essay on the Necessity of Contingency*, trans. by Ray Brassier (London: Continuum, 2008).
121 Meillassoux, p. 5.

Correlationism, then, is a term for the Kantian idea that thought is both something that happens outside of matter, and as an act of perception: we only have access to the *correlation* between thought and thing, and not to the thing itself. The subject and object are tied, and co-dependent. Objects/things exist to us only by being apprehended or 'thought', and they exist to us as-thought, rather than in-themselves.

This is an ontological problem, concerning the nature of being, but for Meillasoux the question is of (our) *access* to being, or epistemology. Rather than explore being *per se*, Meillasoux reduces the question to one of *our* ontology, not an ontology of all things.[122] So Meillasoux is attempting to find a way of us thinking outside of this correlationist 'circle'. Meillassoux's notion is that the way to overcome correlationism is to strip away all thought from matter. He suggests that 'life is radically discontinuous with mere matter and that thought is radically discontinuous with mere life'.[123] In this, he follows twentieth-century psychologists such as James Gibson, who separated perception (as a conceptual experience) from the 'objective' physical space or phenomena itself, its materiality, and texture.[124] But this schema's assumption is that matter is inert, and outside of meaning-making. This stripping away of being from thought deprives matter of its liveliness and agency: the capacity for experience and creativity.

If Meillasoux's approach to thinking outside of the correlational 'circle is to remove thought entirely from matter, there is an alternative. Shaviro, reading Whitehead, proposes a dramatic inversion: the idea that thought is an immanent property of *every-thing*.[125] Or, that 'thought […] is everywhere rather than nowhere'; 'thought is always there already'.[126] Shaviro shows that the will to decouple objects from concepts—as portrayed by Meillasoux—is totally human-centric, and unnecessary. It is still based on the idea that human perception and cognition are somehow special. It refuses to ascribe these possibilities to other matter that is non-human. What if, instead, we allow human perception and cognition to take its place alongside the many ways in which actual entities 'prehend' other entities, as ontologically equal. It is not a problem that thought and matter are entangled, but an opportunity.

[122] Levi R Bryant, *The Democracy of Objects*, ed. by Graham Harman and Bruno Latour, *New Metaphysics* (Ann Arbor: Open Humanities Press, 2011), pp. 34–35.
[123] Shaviro, *The Universe of Things: On Speculative Realism*, p. 75.
[124] James J. Gibson, *The Ecological Approach to Visual Perception* (Boston: Houghton Mifflin, 1979).
[125] Shaviro, *The Universe of Things: On Speculative Realism*.
[126] Shaviro, *The Universe of Things: On Speculative Realism*, p. 82.

Conjecture and dream

The correlationist argument separates thought and material: 'what is thought is thereby converted entirely into thought, and what lies outside thought must always remain unthinkable'.[127] In contrast, Whitehead's philosophy is founded on a contestation of what he called the 'bifurcation of nature': the separation of reality 'into two divisions, namely into the nature apprehended in awareness and the nature which is the cause of awareness'.[128] In the bifurcated schema, the latter part (nature itself) remains mere conjecture—we have no way of actually accessing of knowing it—whilst the former (the apprehension) is a dream, far removed from the actual entities it represents.

The idea presented by Shaviro, then, is to utilise Whitehead's process- and relation- based metaphysics, not to 'break' thought out of this correlationist circle, but as a way of shifting our understanding of thought altogether. Whitehead attributes to all things a real and immanent property of thought, which he calls the capacity for *experience*. Nothing is given in advance: that is, there is no perception outside of matter—instead, for Whitehead, 'being is constituted by becoming'. In this proposition, consciousness is fictitious, but thoughts are *real*, and *reasons* are *actual entities*. This serves to weaken the former emphasis on anthropocentric 'intentionality'—a stubborn gatekeeper between thoughts and things.[129] Instead, 'actual occasions' always consist of both the physical and the 'mental'. 'Thought is an immanent attribute of being itself and of each individual entity that exists'—rather than something which 'floats into the world from nowhere'.[130]

This relies on the idea, shared by Bergson, Whitehead, and Deleuze alike, that reality is not composed of static objects, but of processes of perpetual becoming. This is what Shaviro takes as his starting point for developing ways of thinking a world before, after, and outside of human perception—ways of making the non-human world thinkable. Because we are not talking about access to static objects, but of our position within ongoing processes of change. Shaviro argues that we *do* directly encounter things, that 'things move us, or force us to feel them, and by this very fact they elude the correlational schema'.[131] This is because Whitehead endeavours to think

[127] Graham Harman, 'I Am Also of the Opinion That Materialism Must Be Destroyed', *Environment and Planning D: Society and Space*, 28.5 (2010), 772–90.
[128] Alfred North Whitehead, *The Concept of Nature* (Cambridge: Cambridge University Press, 1920), pp. 30–31.
[129] Although for Whitehead, objects' very *persistence* (as 'enduring objects') through time describes a kind of 'self-valuing'.
[130] Shaviro, *The Universe of Things: On Speculative Realism.*
[131] Shaviro, *The Universe of Things: On Speculative Realism*, p. 8.

through the creativity, originality, and *experience* of things beyond the human—a metaphysics which immediately decentres the human mind as the locus of all thought:

> 'an alternative image of thought that is nonintentional, nonreflexive, and most often nonconscious: a kind of 'autistic' thought that is not correlative to being but immanently intrinsic within it' [132]

Relation and process / Thought and mind

It might be helpful to approach this question from the other side, thinking about an *excess* of thought. Where does the non-correlated part of thought, the 'out there', go? Stengers reminds us that an important step in Whitehead's method is accepting the thing as an unknown.[133] This is crucial in understanding, and utilizing both Whitehead's theory of *process* and Bergson's theory of *duration*: 'the continuous progress of the past which gnaws into the future and which swells as it advances'.[134]

Bergson's contribution to the development of his own process-based philosophy was acknowledged by Whitehead in the preface to *Process and Reality*, alongside William James and John Dewey.[135] Maria Puig de la Bellacasa notes that Dewey uses the word 'mind' not only to describe the human brain but to describe 'every mode and variety of interest in and concern for things'.[136] In response to Bergson's reputation as a spiritualist and pantheist, and in symmetry with Shaviro's advocation of panphsychism, Whitehead hoped 'to rescue their type of thought from the charge of anti-intellectualism, which rightly or wrongly has been associated with it'.[137] This refers to Bergson's embrace of 'a consciousness as wide as life', which was received as mystic and anti-science.[138]

Shaviro compares Whitehead's ontology of relation and process to Graham Harman's isolation of 'things', in his so-called 'object orientated ontology'. Contact between things, 'need not have anything to do with knowledge at all': the world is not limited to what we know about it.[139] Shaviro proposes a democracy of psyche whereby 'thought' is divorced from knowledge and sentience, becoming instead a distributed property common to all things, denoting an active

[132] Shaviro, *The Universe of Things: On Speculative Realism*, p. 12.
[133] Stengers, *Thinking with Whitehead: A Free and Wild Creation of Concepts*, p. 17.
[134] Bergson, p. 3.
[135] Alfred North Whitehead, *Process and Reality: An Essay in Cosmology* (Cambridge: Cambridge University Press, 1929), p. xii; see also Didier Debaise, 'The Emergence of a Speculative Empiricism: Whitehead Reading Bergson', in *Deleuze, Whitehead, Bergson: Rhizomatic Connections*, ed. by Keith Robinson (Basingstoke: Palgrave Macmillan, 2009), pp. 77–88.
[136] Maria Puig de la Bellacasa, *Matters of Care: Speculative Ethics in More Than Human Worlds* (Minneapolis: University of Minnesota Press, 2017), p. 13.
[137] Whitehead, *Process and Reality: An Essay in Cosmology*, p. xii.
[138] Bergson, p. xxiii.
[139] Shaviro, *The Universe of Things: On Speculative Realism*, p. 137.

capacity and potential for attachment For Povinelli, thinking historically, it is also important to remember that differential understandings of the earth should not be thought of as mere variations or cultural differences from typical Western ontologies, but as distinct ontologies in their own right.[140]

Access, aesthetics

> How can [our thought] embrace life, of which it is only an emanation or an aspect? [141]

What does this mean for a research methodology of groundwater and the monsoon? The question, then, is: if we are unable to think of something outside the reciprocal exercise of us *thinking it*, then how am I to write about groundwater? Can I only write about the way I—and others—perceive groundwater and bring it into existence? What about the greater part of existence outside of our gaze? There is a clear epistemological dimension to this ontological question, and to this study, since it is through systems of knowledge that we access the world:

> Theory of knowledge and theory of life seem to us inseparable. A theory of life that is not accompanied by a criticism of knowledge is obliged to accept, as they stand, the concepts which the understanding puts at our disposal'.[142]

Understanding is itself is a process of internalisation: things become changed into representations. But Shaviro prefers to think of our continual engagement with the universe of things not as a process of representation (i.e. construction of our own pictures), but of 'prehension' (in Whitehead's terminology) as an ongoing process of *adjustment*, of *contact-at-a-distance*. This 'feeling' is ontological, and irreducible to knowledge, discourse, or cognition—which is not to say that it is without thought, but that it does not require privilege (tools, knowledge) to access: it is a property of thought before knowledge. Thought as an immanent property of matter within a world composed of processes, not things: thought itself as a kind of continual feeling and adjusting.

Consciousness is only a narrow part of thought, in this view. And thought, whether conscious or not, is common to all things. Shaviro here goes on to champion *aesthetics* here as an alternative to cognition, and as a way of remembering that 'more things are *felt* than can be known'. [143] Or to put it another way, that 'I always feel more of a thing than I actually know of it, and feel it otherwise than I know it'.[144] Shaviro reminds us of Graham Harman's point that we cannot

[140] Povinelli, *Geontologies: A Requiem to Late Liberalism*.
[141] Bergson, p. x.
[142] Bergson, p. xxiii.
[143] Shaviro, *The Universe of Things: On Speculative Realism*, p. 79.
[144] Ibid., p. 55.

equate what we know of a thing with the actual being of the thing itself. No amount of knowledge of a tree, or the moon, or a volcano, will equate to the thing itself. This picturing, or abstraction, always leaves many things out, does not fully grasp the totality of the thing in itself.

For Whitehead this doesn't mean to imagine that we might eliminate representation, but rather to 'affirm coherence' and continuity in and between these realms of thought and abstraction.[145] Abstractions are not 'opposed to concrete experience' but somehow reciprocal with them.

Sensory aesthetics, feeling, imagination

> In every act of experience there are objects for knowledge. [146]

This thesis is quite *physical*, stressing the sensory aspects of materiality. I would like to steer clear of any suggestion that groundwater is innately 'unknowable' because it is *unmeasurable*, by resisting to conflate these two terms, knowing and measuring: there are ways of knowing, or feeling groundwater which do not depend on a totalising vision, cognition, of 'knowledge' of it.

In beginning to approach a description of the hybrid materiality of groundwater, as lived and represented in Chennai, I find the concept of *aesthetics* to be a useful summary of the problem. Aesthetic relations are just that: relational, 'outside of cognition and affective interest'—they precisely not about 'knowing' the other, and rely on 'somethings separation from me, it's exemption from the categories that I would normally apply to it'.[147] 'Aesthetic judgements have nothing to do with determinations of truth and falsehood […] it is a feeling entirely divorced from objective knowledge'.[148] An aesthetic relation is something loosely held in common, without uniting the those who experience it, maintaining their (in)difference.

This seems to me a useful way about thinking possible relations with groundwater where knowledge-as-fact is secondary to the ongoing and relational processes of knowledge-production, for which sense and intuition, or feeling in the dark, are foremost. Following Shaviro's account of Alfred North Whitehead's aesthetics, I would like to differentiate between 'concepts of understating' as 'presentations referred to an object' and 'cognition of an object'.[149] Aesthetic ideas are intuitions ('unexpoundable presentations'), which no concept can ever fully capture. On the contrary, rational ideas are concepts 'for which no adequate intuition can ever be

[145] Stengers, 'Thinking with Deleuze and Whitehead: A Double Test', p. 36.
[146] Whitehead, *Process and Reality: An Essay in Cosmology*, p. 156.
[147] Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics.*
[148] Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics*, p. 4.
[149] Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics.*

given'.[150] So, this chapter explores the gaps, overlaps, and intra-actions between such 'unexpoundable presentations'—sensorial and direct engagements with materials, which do not need to know—and 'indemonstrable concepts'—which occupy a realm distinct from physical action.

Aesthetic engagements with groundwater are not limited to professional practices but include everyday adjustment of living with / on / in. Intimate, mutual relations between material things (including people) are different from relations with a representational understanding of (specific aspects of) a thing. The first relation is ontological, irreducible to knowledge, discourse, or cognition. This mutual relating is crucial to understanding groundwater as a material: one which can be pictured in part, and in situ, but not abstracted in order to give an understanding of the whole-at-once (and out of time). There is no external world 'as is'. Consciousness is negligible.[151] Experience is 'in our physical feelings' which precede the subject. 'Affect precedes cognition'.[152]

This is also a model for a distributed understanding of agency (referring back to the opening quote), by distributing the capacity for 'thought', not as 'cognition' but as a capacity for reflexivity in an encounter:

> what is at stake is a different model of what thinking is, one that extends reflexivity to all manner of actors, that recognises reflexivity as not just a property of cognition and which realises the essentially patchy and material nature of what counts as thought. [153]

Aesthetics helps to remove the locus of thought from one side of the relation, the place where the 'knowing' subject is. As Deleuze also reminds us, famously: 'Something in the world forces us to think. [..] It may be grasped in a range of affective tones: wonder, love, hatred, suffering. In which tone, its primary characteristic is that it can only be sensed.'

> There are only practices, or positivities, which are constitutive of knowledge: the discursive practices of statements, or the non-discursive practices of visibilities. But these practices still exist beneath archaeological thresholds whose shifting points of demarcation constitute the historical differences between strata. [154]

[150] C.f. John-David Dewsbury, 'Witnessing Space: "Knowledge without Contemplation"', *Environment and Planning A*, 35 (2003), 1907–32..
[151] Whitehead, *Process and Reality: An Essay in Cosmology*.
[152] Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics*, p. 15.
[153] Nigel Thrift, 'Intensities of Feeling: Towards a Spatial Politics of Affect', *Geografiska Annaler, Series B: Human Geography*, 86.1 (2004), 57–78 (p. 59).
[154] Gilles Deleuze, *Foucault*, trans. by Seán Hand (Minneapolis, MN: University of Minnesota Press, 1988).

This is a methodological statement, since we are to 'remember we are producing an understanding of the world because the world is not already out there as such'.[155] To push research into resolute experimentalism means to apprehend the present as practice. To paraphrase Elizabeth Povinelli, it's not that this and that are tied together—it's that the condition of being something is to be through something else. 'In aesthetic contemplation, I don't have particular feelings, so much as my very existence is suspended upon those feelings.' [156] Povinelli invokes the notion of 'twilight' to describe the sense of being offered something you can't fully grasp. This is crucial for dealing with emergent materials: 'Aesthetics precede cognition because we are dealing with practices that can only be comprehended through the new categories that they themselves create'.[157]

> In an aesthetic judgement, I am not asserting anything about what is, nor am I legislating as to what ought to be. Rather, I am being lured, allured, repulsed, incited, or dissuaded […] this is part of the process by which I *become* what I am.
>
> […] the object lures the subject while maintaining indifferent to it; and the subject feels the object, without knowing It or possessing it or even caring about it. The object touches me, but for my part I cannot grasp or lay hold of it, or make it last. [158]

My contention is that despite only perhaps having access to certain forms of *evidence* of groundwater, *writing groundwater* is more than writing *about* it. Groundwater is a force which shapes concepts and can be instructive. Tuning in to this force requires a degree of speculation, as practiced for instance by Ursula K Le Guin, who imagines our future kinship with 'creatures without nervous systems, and to non-living beings: fellowship of things to other things' as 'reciprocal […] always at least two way, back and forth'.

> I guess I'm trying to subjectify the universe, because look where objectifying it has gotten us. To subjectify is not necessarily to co-opt, colonize, exploit. Rather it may involve a great reach outward of the mind and imagination. [159]

Allowing things to be subjects requires mental leaps, beyond what we know we know. But whilst Le Guin imagines future generations of 'geo-linguists', and lichen-fluent students actually *reading* the language of these materials, this project about finding a way of working with and through vital materialities that makes peace with the idea that they do not speak for us to hear them

[155] John-David Dewsbury, 'Performative, Non-Representational, and Affect-Based Research: Seven Injunctions', in *The SAGE Handbook of Qualitative Geography*, ed. by Dydia DeLyser and others (London: SAGE Publications Ltd, 2010), pp. 321–34.
[156] Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics*, p. 13.
[157] Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics*, p. 16.
[158] Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics*, p. 5.
[159] Ursula K. Le Guin, 'Keynote (Arts of Living on a Damaged Planet)', 2014 <https://vimeo.com/97364872> [accessed 6 September 2018].

Indeed, Bergson takes aim at the idea that 'we are brought to a stand before the Unknowable' as 'an excess of humility' and abdication: 'Action cannot move in the unreal'.[160] That is, limiting ourselves to a form of apparently verifiable understanding of things—i.e. science— and saying that this, however limited, is all that we can know, 'gives up' the depths and 'total activity' of life in favour of a mechanistic view. Just because this is our access, does not mean it must be our understanding. It is about the frame with which we think: 'these difficulties and contradictions all arise from trying to apply the usual forms of our thought to objects with which our industry has nothing to do, and for which, therefore, our molds [sic] are not made'. [161]

I see here an opportunity here to get beyond anxiety over how we might relate to the inhuman, relating to the idea that we are not only always, already entangled with those non-human and non-living entities and forces, but that they do not exist outside of 'us', rather only as potentialities to be activated, reshaped and contained by and within each other. It is not to say that things are to be measured in their relation to 'us', nor an attempt to anthropomorphise geology—merely to say that the geologic is here and now. Povinelli describes this in terms of both continuity and difference:

> there is nothing less true about claiming we are also rocks and sediment before and even after we settled into this mode of existence than claiming that the fossil and the hand are in different geological tenses [162]

To be clear, this is not to claim that we are automatically able to see things in themselves simply by being part of a continuum of matter with them. 'It will be said that, even so, we do not transcend our intellect, for it is still without intellect, and through our intellect, that we see the other forms of consciousness'.[163] I am suggesting a form of openness to the unknown, of being critical of representational processes without dismissing them, and of placing ourselves as 'nodes of relation' rather than centres of correlation.

Deleuze and Guattari observed that 'thought lags behind nature'.[164] The theoretical framework I have started to describe here, by extending the concept of thought outwards, aims to develop a form of thinking through things that works with and through vital materialities, and the concepts they produce, rather than projecting onto them.

[160] Bergson, p. xi.
[161] Bergson, p. xi.
[162] Elizabeth Povinelli, Mathew Coleman, and Kathryn Yusoff, 'An Interview with Elizabeth Povinelli: Geontopower, Biopolitics and the Anthropocene', *Theory, Culture & Society*, 34.2–3 (2017), 169–85 (p. 178).
[163] Bergson, p. xii.
[164] Gilles Deleuze and Félix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. by Brian Massumi (Minneapolis, MN: University of Minnesota Press, 1987), p. 3.

Materiality and Method

This section develops the theoretical concerns of the previous section into a methodology of engagement with groundwater, not as an independent substance distinct from anything else, but as a 'continuum of difference'. I understood groundwater as a relational substance, a hybrid condition of both 'ground' and 'water' (and other things and beings), and inseparable into its constituent parts.

Materials and Affect

> Things are not active because they are imbued with agency but because of the ways in they are caught up in the currents of the lifeworld. [165]

In telling particular stories about the utilisation and conceptualisation of groundwater in Chennai, I wish to engage with the provocation given by Tim Ingold that a large part of the literature purporting to be concerned with *materiality* has little to say about material *properties*, and so misses out on what might be gleaned from such an attention.[166] That is, that an understanding of materials as fixed and compliant *objects* reduces matter to a figure of projection, an inanimate *register* of human activity, instead of a dynamic actor within a continuum of difference that composes the lifeworld.

Ingold's argument centres on a distinction between 'materiality' and 'materials': the former being used to refer to studies of material culture which focus on the consumption of 'a world of objects that has, as it were, already crystallized out from the fluxes of materials and their transformations'. In this 'materiality' the 'materials' in question remains at arm's (or eye's) length, discontinuous with the space of conceptualisation, and finished, complete, distinct. 'At this point materials appear to vanish, swallowed up by the very objects to which they have given birth.' [167] The latter term—'materials'—for which Ingold is arguing a greater importance, means considering ways in which matter, always in flux and never complete, composes and animates the world *in* which we live (or, as Ingold would put, the 'environment').

It is important not to read Ingold's provocation as an argument for eliminating the 'social' of the 'material' from the discussion, as if to arrive at some understanding of nature without influence: the same essentialist conception of 'materiality' as a distinct realm outside of human influence, and merely 'reflected' in social forms and representations, that he is arguing against. Donna

[165] Ingold, 'Materials Against Materiality'.
[166] Ingold, 'Materials Against Materiality'; Tim Ingold, 'Toward an Ecology of Materials', *Annual Review of Anthropology*, 41.1 (2012), 427–42.
[167] Ingold, 'Materials Against Materiality', p. 9.

Haraway already raised many crucial problems with the metaphor of 'reflection', noting its requirements of both fixed, external positionality, and sameness (mirroring).[168] This has little to do with how we live *within* and *through* material natures. The risky analogy supports a view of an observing subject outside of the world of objects it is observing:

> Efforts to travel into 'nature' become tourist excursions that remind the voyager of the price of such displacements—one pays to see fun-house reflections of oneself. [169]

So immediately we have a double bind: following from the discussion of correlation in the previous section, we want to focus on materials *in themselves*, and to avoid them merely being co-opted as inanimate reverberators for human uses and ideas. We are aware that they have agency, will surprise, and make worlds outside of and beyond us.[170] But we also know we can only get at materials from a fixed position, sensorially, technologically, visually, and that positionality—that we don't see things-in-themselves but merely our relations with them—is as much a part of our conceptualisations as matter.

In his later discussion of the problems of 'materiality' discourse in anthropology, Ingold notes the ways in which an established conception of the material world as 'non-human' shuts down possibilities for other forms of life to be considered agential beings.[171] I would extend this to include the manifold material agencies with which humans live, regardless of any supposed distinctions between 'life' and 'non-life'.[172] Ingold hits on the problem here: that materials being understood as 'artefacts' or 'objects', and therefore as 'finished', 'stops up the flows of energy and circulations of materials on which life depends.' Materials are not only what we are made of but that which sustain life. They are 'enrol[ed] in form-making processes'.[173]

But I disagree with Ingold's fall back to James Gibson's separation of materials into categories of *medium*, *substance*, and *surface*, despite the aim of the rhetorical device being to talk of *properties* of materials rather than materials-as-objects. My concern is that the categories themselves are surely another case of perception, and groundwater is at least all three, if not none of these things. For example, as Ingold notes, for humans the *medium* through which we move, see, and breathe,

168 Echoing Haraway, the character of Patricia Westerford in Richard Powers' *The Overstory* (New York: W. W. Norton & Company, 2018), reminds us that to *speculate* means to guess, to hypothesise, but also to *mirror*: to show the world back to itself, as if from a static position, outside of and discontinuous with it.
169 Donna Haraway, 'The Promises of Monsters: A Regenerative Politics for Inappropriate/d Others', in *Cultural Studies*, ed. by Lawrence Grossberg, Cary Nelson, and Paula A. Treichler (New York: Routledge, 1992), pp. 295–336 (p. 296).
170 Nigel Clark, *Inhuman Nature: Sociable Life on a Dynamic Planet* (London: Sage, 2011).
171 Ingold, 'Toward an Ecology of Materials'.
172 See also Povinelli, *Geontologies: A Requiem to Late Liberalism*; Reinert, 'About a Stone: Some Notes on Geological Conviviality'.
173 Ingold, 'Toward an Ecology of Materials'.

might be air, but not for a mole, mite, or earthworm, or for a plume of saline water. Similarly, groundwater might be more easily considered as *substance*—implying resistant 'stuff' that is just there, affording support and awaiting utilisation—but this suggests both uniformity and passivity. Groundwater is yet still not a *surface*, as I have argued in the introduction, but it is a volume interspersed with thresholds and surfaces of different kinds: stratigraphic, hydrological, chemical, etc..

In Ingold's writing, there can be this tendency to invoke classificatory schema: attempts to resolve, at a discursive level, these messy 'materials' which are all about mixture, inseparability, ambiguity, and adjustment. Such an ordering would limit the scope of possibility of what might be, and which restrict therefore what it might be possible to see. There remain several hints, such as the use of Henry Hodges' *Inventory* at the beginning of the article, of a tendency to read materials as kinds of raw ingredients: 'it is from them that everything is made'.[174]

> Bringing things to life, then, is a matter not of adding to them a sprinkling of agency but of restoring them to the generative fluxes of the world of materials in which they came into being and continue to subsist. [175]

I have in the earlier introduction used the term 'behaviour' to describe what I am looking at, and this is a deliberately durational term through which, in step with the following chapters, I seek to emphasise the *processual* and *relational* nature of the materiality of groundwater.

> Thus the properties of materials, regarded as constituents of an environment, cannot be identified as fixed, essential attributes of things, but are rather processual and relational. They are neither objectively determined nor subjectively imagined but practically experienced. In that sense, every property is a condensed story. To describe the properties of materials is to tell the stories of what happens to them as they flow, mix and mutate. [176]

Living, knowing(, and representing)

It is the emphasis on the processual through which, in this thesis, I hope to approach the materiality of groundwater in Chennai from two sides: that of both *living with* and *conceptualising*. These are not binary opposites, but rather two constantly entangled and co-produced relations with dynamic materiality. Groundwater both produces and is reproduced in representational and visual cultures. Karen Barad's *diffractive* methodology as set out *Meeting the Universe Halfway* starts with physicist Nils Bohr's position that 'neither the subjects nor objects of knowledge practice

[174] Ingold, 'Materials Against Materiality'.
[175] Ibid.
[176] Ibid.

can be taken for granted'.[177] Describing Bohr's crucial commitment that 'we are part of that nature that we seek to understand', Barad summarises:

> Scientific practices must be understood as interactions among component parts of nature and […] our ability to understand the world hinges on our taking account of the fact that **our knowledge-making practices are social-material enactments** that contribute to, and are part of, the phenomena we describe. [178]

That is, the one must be read through the other: neither the object of investigation nor the 'agencies of observation' can be subtracted out, or absolutely determined independent of the intra-action through which they both come to *be* in a way that is both contingent and emergent, specific to a moment of entanglement through which both sides are remade.[179] Barad calls this 'intra-action', indication the co-production of knowledge and object, as opposed to the two being linked by a slender thread, but remaining distant and distinct.

So in the articulation of knowledge-making practices as *enactments*, I am interested in exploring the relations, and gaps, between different knowledge(-production) practices and the materials that they involve. I wish to engage, following Barad, with: 'epistemological and ontological issues […] such as the conditions for the possibility of objectivity, the nature of measurement, the nature of nature and meaning making, and the relationship between discursive practices and the material world'.[180]

Barad's work doesn't seek to separate such representational practices from the 'material world' but rather to relate, for example, modelling to experience: not setting them up in opposition to one another, as binaries, but relationally. 'To read our best understanding of social and natural phenomena through one another in a way that clarifies the relationship between them.' How do they trouble or leak into one another? What do representational practices leave out?

This is also not to say that representational practices are hopeless and without utility, either: both Bohr, and Whitehead, reiterate the importance of representational practices. The diffractive method, therefore, is apposite to this study, where rather than start with a given methodology, it is necessary to work by 'reading insights through one another in ways that help illuminate differences as they emerge'.[181]

[177] Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, p. 27.
[178] Ibid., p. 26, emphasis added.
[179] Ibid., p. 31.
[180] Ibid., p. 24.
[181] Ibid., p. 30.

Non-representational Ethnography

If this research, then, means to seek things not 'as they are', but instead in fleeting moments, fragile combinations, and partial perspectives, then what is required is a methodology more attuned to matter in motion, of practices rather than things, and of glimpses rather than facts. Following what Nigel Thrift defines as 'non-representational theory' or the 'theories of practice', a growing trend in anthropology and cultural geography attempts precisely this, to 'escape from the established academic habit of striving to uncover meanings and values that apparently await our discovery, interpretation, judgement and ultimate representation', and instead to focus on the positional, performative, and restless.[182] *Non-representational* or *more-than-representational* ethnography withdraws from the traditional or 'realist', 'know-and-tell' approach to ethnographic fieldwork, which claims to represent worlds in a true or accurate account. These methodologies focus upon *practice*, and *performance* over *production*—and crucially outside of and before framing in relation to cognition, knowledge, and representation.

Though part of an ethnographic tradition, these theories are applicable to more-than-human worlds as are calls to resist the reduction of materials to objects, and instead to think 'ecologically, in terms of the processes and conditions' of the intense and constant work of materials,[183] which is understood as never being fully apprehensible to, or made so by (human) subjects.[184] There is no attempt to 'know', to define, to hold in one's mind or in a text the completeness of a thing but instead a concern with the multiple showings, presentations, manifestations. This work is aware of the positionality and creativity of its makers, and relishes the failures of knowledge (or acknowledges that all research is about failure) in order to challenge the 'restrictions that methodological protocols might impose on what can count as knowledge'.[185] So writing, or drawing, is not 'product' but processual and performative: 'to animate rather than simply mimic, to rupture rather than merely account, to evoke rather than just report, and to reverberate instead of more modestly resonating'.[186] And to dwell on problems, not just accounts or solutions.[187]

[182] Nigel Thrift, *Spatial Formations* (London: SAGE, 1996); Nigel Thrift, *Non-Representational Theory: Space, Politics, Affect* (Abingdon: Routledge, 2008); Hayden Lorimer, 'Cultural Geography: The Busyness of Being "More-than-Representational"', *Progress in Human Geography*, 29.1 (2005), 83–94 (p. 84).
[183] Fernando Domínguez Rubio, 'On the Discrepancy between Objects and Things: An Ecological Approach', *Journal of Material Culture*, 21.1 (2016), 59–86.
[184] Jasmine B. Ulmer, 'Posthumanism as Research Methodology: Inquiry in the Anthropocene', *International Journal of Qualitative Studies in Education*, 30.9 (2017), 832–48.
[185] Dewsbury, 'Performative, Non-Representational, and Affect-Based Research: Seven Injunctions'.
[186] Phillip Vannini, 'Non-Representational Ethnography: New Ways of Animating Lifeworlds', *Cultural Geographies*, 22.2 (2015), 317–27.
[187] Dewsbury, 'Performative, Non-Representational, and Affect-Based Research: Seven Injunctions'.

Research-assemblage

Groundwater might not be something I am able to wander through, as a typical field-site, but it is a condition that is constantly experienced, from the salty taste of the water used for bathing in, to the feel of the soil after rain, and the sediments left on cooking pots and car tyres, to the smell of the ground emerging via vapour migration.[188] Groundwater sustains, cleans, and eventually decomposes our own deliquescent bodies. Our minds function as an extension of elements given to us in groundwater, and their workings are deeply affected and redirected in ways we do not fully understand.

The implication of this is that the focus of my research is not the thing (groundwater) in the sense of what it *is*, but the relational assemblage, following this section's ontological emphasis on processes of becoming over states of being, and on interactions over objects. Drawing on this framework, Nick Fox and Pam Alldred propose the methodological concept of 'research-assemblage', comprising of 'the bodies, things and abstractions […] including the events that are studied, the tools, models and precepts of research, and the researchers'.[189] This framing attempts to account methodologically for the Baradian understanding that both events and knowledges are produced by relational assemblages, and that researchers are material individuals within a world of objects and agencies.[190] This is to say, research assemblages are *productive*, they *do* something, *produce* knowledge. They do not go out and find it. Assemblage does away with subject and object (states), in favour of affect and becoming (change), so neither can come before the other. Fox and Alldred describe this as a shift from agency to affect, i.e. from properties to relations: 'we begin to recognise research as a territorialisation that shapes the knowledge it produces according to the particular flows of affect'.[191]

This project is about developing ways of thinking with groundwater to a world before, after, and outside of human perception—ways of making the non-human world thinkable. This is an inter-disciplinary effort, part of an emerging mode of doing research which includes directly interlocuting with scientists but also with philosophers and sociologists of science, as well as applying both anthropological and design research methods, in hybrid forms and significantly altered through the prism of vital materialism. As researchers, we are not talking about access to static objects, but of our position within ongoing processes of change. This thesis is about

[188] The pleasant smell rising from the ground (such as after rain) is known as petrichor.
[189] Nick J. Fox and Pam Alldred, 'New Materialist Social Inquiry: Designs , Methods and the Research-Assemblage', *International Journal of Social Research Methodology*, 18.4 (2015), 399–414 (p. 400).
[190] Diana Coole and Samantha Frost, 'Introducing the New Materialisms', in *New Materialisms: Ontology, Agency, and Politics*, ed. by Diana Coole and Samantha Frost (Durham, NC: Duke University Press, 2010), pp. 1–43 (p. 27).
[191] Fox and Alldred, p. 403.

attempts to think through the creativity, originality, and *experience* of things beyond the human—a metaphysics which immediately decentres the human mind as the locus of all thought. Feeling and being are not something that only humans do. This also means that thinking is not something humans have exclusive access to, either. Attending to the research-assemblage, therefore—not only the subject of research but the whole bundle of affective, historical, disciplinary and other relations within the process of knowledge-production—is critical.

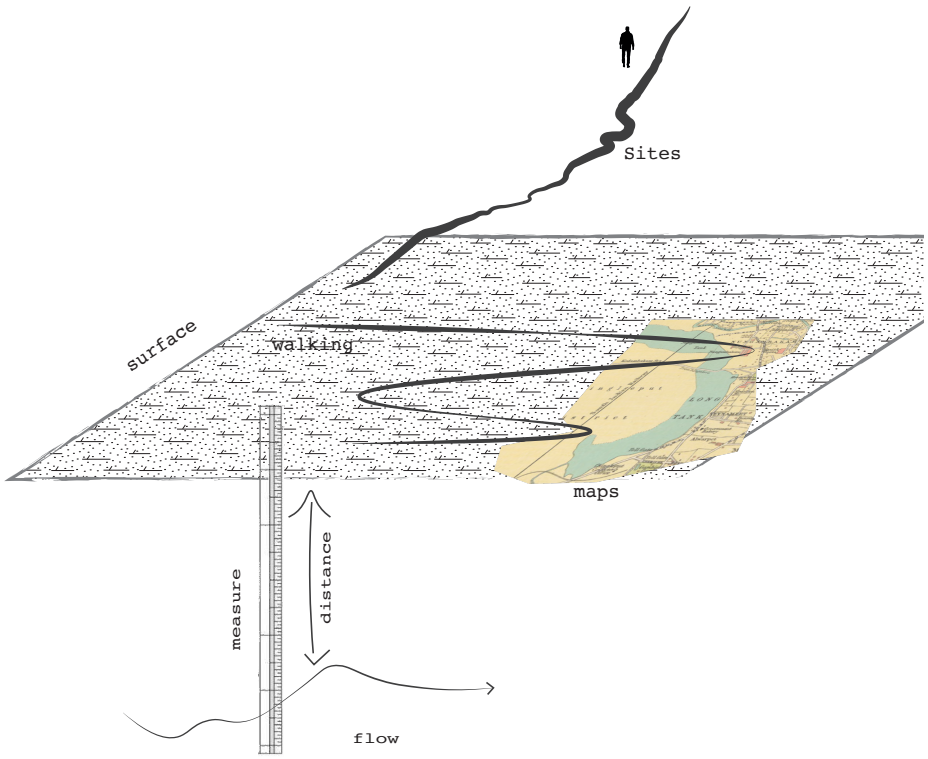

Figure 9. Partial research-assemblage diagram: materials, methods, and movements. Drawing by the author.

Design of the Research: Erratic Methods

This thesis will not attempt, in an objectivist fashion, to get at 'groundwater-as-such'. I am only able to get at groundwater through anthropocentric methods, concepts, and subjectivities. This means utilising a range of research techniques, hoarding and connecting material, and following leads in an open-ended way. I examine the sources, the (constructed) knowledge traditions in which they were produced, and the technologies by which data has been collected. I will re-present, in both descriptive and analytical manners, the available data to give an account of groundwater in a way sufficient to draw connections across material. The matter at hand, the methodology with which I approach it, and the erratic availability of resources, does not warrant

fixed methods leading to clear findings but 'messy description' through which emerges a methodological framework *of* groundwater itself.[192]

Following this unfolding process, and in keeping with the concept of research-assemblage, it is important to note that I understand my own representational practices in producing this work as being no less removed from the various kinds of relations involved in producing knowledge than those I study, and I will treat then as such. My drawings, for example, are not posed as a solution to the problem of representation but in conversation with other forms. A key purpose of the diversity of methods described in the following section is in order to consider, in a Baradian sense, how different operations produce different knowledges, and draw groundwater into view in different ways. As source material is patchy and incomplete, the research design must be flexible and allowed to respond, unfold, and change according to what is found, utilising a mixture of sources and methods.

Distance

This research relies heavily on the work, data, and participation of others—particularly scientists, engineers and others working in/on groundwater. I do not intend to drill, pump, scan, test, or indeed employ any of the field techniques usually associated with hydrogeological study. I might pick up soil, squeeze and sniff it, smell water, even taste it, but the key data collection process involves working with and through other scientists, activists, academics, and professionals. Those are the ones who, within various networks, are doing the surveys, chemical tests, electrical resistivity scans, and modelling. In this way, the data I utilise is always secondary, distorted, textured and coloured by the places through which it has moved. That this data is mediated, touched by many hands, and partial (being from a certain perspective) forms an important part of the work: 'specificities are themselves specific, and contextual'.[193]

These movements will themselves become an object of examination, but *I do not position myself outside of the relay*. Nor do I draw a veil between myself and the other practitioners with whom I will work during this process. My data-collection and -production is also partial. Though I consider these processes essential to a multi-disciplinary methodology: 'The distinction between qualitative research and quantitative research occurs at the level of methods'.[194] That is to say, it is possible for me to enter this field as an architect-researcher and to pursue groundwater in

[192] 'if this is an awful mess […] then would something less messy make a mess of describing it?'. John Law, *After Method: Mess in Social Science Research* (Abingdon: Routledge, 2004).
[193] Hugo Reinert, 'Entanglements: Intimacy and Nonhuman Ethics', *Society & Animals*, 2 (2014), 42–56 (p. 42).
[194] Michael Crotty, *The Foundations of Social Research: Meaning and Merspective in the Research Process* (London: SAGE, 1998), p. 14.

conversation with others pursuing the same material using a different process. Indeed, this is the core of this project: how groundwater is remade (physically, conceptually) in different ways depending on the methods of access.

> 'Attention must be paid to the *work* involved in material determinations; and specifically; to how that work delineates what comes to matter, ontologically and epistemologically.' [195]

This is not a project of straightforward data collection; a central thesis is that groundwater *itself* challenges the ways in which it is known. Interlocutors, and their relationship to groundwater therefore are an important part of the writing. Though this is a project which emphasises more-than-human material agency, people and their perspectives are so much a part of what I am writing about. For myself, impressions, feelings, and reactions are recorded in field notes and process notes, and will be woven in amongst the following text.

My research process is based on short periods of field work, between 2 and 6 weeks. Otherwise, I will be working at considerable physical and cultural distance from the primary object of study. Though there is considerable entanglement both historically and at present, in the intellectual and professional structures and traditions of the United Kingdom and India, I am working from a very different context.

Case studies

My research process is organised around three case studies: knowledge practices and means of accessing groundwater more conceptually, though its properties, rather than particular sites. Each of these begins with an event or events, from which highly complex and protracted assemblages emerge, and become removed from their places of origin, since groundwater is a process that is constanly in motion. Through these practices—the 'human-nonhuman working group[s]' through which I access groundwater [196]—concepts are generated. These are 'deep' as opposed 'surface' concepts: a set of *relational* concepts from groundwater which are also methodologies: e.g. *depth*, *porosity*, *measure*, or *modelling*. This reversal therefore emphasises dynamic states which are common to human and other forms of life.

A first week-long visit to Chennai in August 2017 helped to identify three themes from which I would develop the three case-study chapters and form the core of the written and drawn work, enabling me to explore groundwater through them. These emerged in turn, through studying news reports to establish sites of contestation which revolved around groundwater (the Metro

[195] Myra J. Hird and Kathryn Yusoff, 'Subtending Relations : Bacteria , Geology , and the Possible', in *Geneaologies of Speculation*, ed. by Suhail Malik and Armen Avanessian (Continuum Press, 2014).
[196] Bennett.

Rail construction project), in studying academic papers and activist reports relating to groundwater in Chennai (the industrial contamination problem), and in conversation with contacts in Chennai and the wider project team and board (the rainwater harvesting project).

Each chapter in this thesis is an *experiment* in accessing groundwater through different practices. Exploratory research builds gradually, and contingently—both by steady progress, and in sudden bursts. Case studies become prompts for thinking about how the materials of research are co-producers of knowledge: how research emerges not only from a network of collaborators, interviewees, sites, chance encounters, and missed opportunities, but also through a material assemblage of instruments, ions, standards, bodies. Such accounts are examples of the ways in which my research approaches groundwater through interlocutors of many kinds. In some cases, I use secondary data sourced from scientists, in others I follow them around and record my impressions of their work, methods, and results. At other times, I rely on newspaper reports, official documents, and whatever I can access. Researching groundwater is working with something which I have no direct access to (being invisible, physically out of my reach, and always in movement). So, groundwater is drawn into visibility through a variety of descriptive and representational practices—both my own and those of the people I have been working with.

Recounting these stories offers a different picture of groundwater than one that would emerge out of any one singular form of representation. Episodes are *excess*ive in that they are full of mixed and contradictory impressions that do not fit the format of question-and-answer research, and which might often be edited out from its reported results. One question I am asking myself here is of how to 'write up' such fieldwork in a way that pays attention to the networked and contingent nature of scientific knowledge production. That science is far from exceptional to these kinds of fortuities a view which has been well established by feminist science studies, particularly in the work of Haraway,[197] Stengers,[198] and Barad. Barad's elaboration of 'performativity' as a critique of representationalism—the idea that representational forms of knowledge are independent of the physical world they represent—is a particularly useful starting point here.[199] It prefigures the problem of correlationism.

[197] Donna Haraway, 'Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective', *Feminist Studies*, 14.3 (1988), 575–99.
[198] Isabelle Stengers, *The Invention of Modern Science* (Minneapolis, MN: University of Minnesota Press, 2000).
[199] Karen Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter', *Signs: Journal of Women in Culture and Society*, 28.3 (2003), 801–31.

Existing Visual Data and Reports

I initially make use of the visual data of satellite images, maps, and large-scale drawings. Visual data forms a key basis of this project both in its primary and secondary sources, sensory engagements, and techniques of analysis and representation. Atkinson and Delamont write that 'we should pay serious attention to visual data insofar as culture and action have significant visual aspects that cannot be expressed and analysed except by reference to visual materials'.[200]

This 'baseline' data includes google earth and maps, as well as the British Library map collections, government of India geological and hydro-geological mapping, state-level water resource monitoring, and local-level information produced by NGO and activist groups. Even in the years since Roy wrote about Calcutta, the accessibility of digital and mapping technologies has decentralised the production of geographical information, and so I am also able to make use of crowd-sourced maps such as those initiated by Transparent Chennai during the 2015 floods.[201]

As far as any of this data can be considered 'primary' (e.g. satellite photography is already heavily mediated), there is also a great deal of secondary visual data from other researchers, professional, activists, and officials—drawings which have been produced for specific purposes, and hold specific intentions. I have so far made use of background hydro-geologic literature not specific to my project context, as well as broad and historical literature relating to the Indian peninsula, much of which was produced during British colonialism. There is some rich material relating to Chennai's hydro-geology,[202] as well as the formal and in-formal urban water networks.[203] I also developed contacts currently working in the field of groundwater studies, such as with an ongoing project at Anna University, in order to source further background and contemporary data.

Discourse

Essential to my understanding of events are the knowledges, and accounts, shared by others—both institutions, and individuals (academics, researchers, activists, professionals—often linked to the former). A primary means of both developing these connections, as well as gaining

[200] Paul Atkinson and Sara Delamont, 'Analytic Perspectives', in *The SAGE Handbook of Qualitative Research*, ed. by Norman K. Denizen and Yvonna S. Lincoln, Third Edit (Thousand Oaks, CA: SAGE, 2005).
[201] Though website is no longer live, Transparent Chennai produced a platform for crowd-sourced information gathering based on google maps, hosted at <http://www.transparentchennai.com/>.
[202] Ballukraya and Ravi, 'Hydrogeology of Madras City Aquifers'; K. Parameswari and B. V. Mudgal, 'Assessment of Contaminant Migration in an Unconfined Aquifer around an Open Dumping Yard: Perungudi a Case Study', *Environmental Earth Sciences*, 74.7 (2015), 6111–22; K. Brindha and L. Elango, 'Impact of Tanning Industries on Groundwater Quality near a Metropolitan City in India', *Water Resources Management*, 26.6 (2012), 1747–61.
[203] Veena Srinivasan, 'An Integrated Framework for Analysis of Water Supply Strategies in a Developing City: Chennai, India' (Stanford University, 2008); Geeta Lakshmi and S. Janakarajan, *Intricacies of Chennai Metropolitan Water Laws*, 2005.

insight, access, and partnership, is the use of unstructured and semi-structured interviews. These interviews vary in length according to the availability of the interviewee but are typically from half an hour up to an hour and a half long. I note a range of questions based upon the interviewee's available work but allow the conversation to develop freely, using open-ended questions, and probes (silence, repetition), in order for the participant to lead the direction of the interview, potentially opening up unknown sources, or areas of possible research. I do not speak Tamil, and on occasion I have relied on translators, as in the case of speaking with residents of certain communities.

With the permission of the interviewee, conversations are recorded in order to enable verbatim transcription, by me, as soon as possible after the interview. I am able to pay attention in the interview, to ask better questions, and as I re-read these transcripts, as texts in their own right, I am able to extract key points and make connections, paying attention to language and argument, reflecting on the conversation. I treat these transcripts like written texts: key topics and any references are noted for further investigation; I recall what the key points made by the interviewee are, and on what assumptions these are based; I note what terms and concepts are used and referred to; and I question the form of argument, or discourse, including uses of evidence and rhetoric. Follow-up questions are given by email, or in person if a second meeting is possible.

Interviews are a core method, around which other processes such as site visits and drawings revolve. A reciprocal and reflexive practice will be employed to test, explore, and add depth to interview conversations, by using visual materials (maps, drawings, photographs) in additional to questions. This process, then, of being open with visual information, begins to generate crossovers between different materials, and professional contexts. It also radically contrasts the protective practices around data, and—by making drawings using information from interviews and site visits, and returning them to participants—has the potential to offer something back to those who collaborate with me on the project. Participatory drawing/mapping is also a possibility, though this hasn't yet been used.

Shadowing, Site Visits, Field Notes

I have said that this is not a field study in the sense that I am collecting my own data. Even, the 'being there' which is crucial to environmental anthropology is precluded by the buried nature of groundwater. The ways in which I can 'probe' during ground-level exploration are limited.[204]

[204] Karen Lutsky and Sean Burkholder, 'Curious Methods', *Places Journal*, 2017.

Some primary observation will be possible, such as looking for 'registers' of contamination as sediments in pots, encrustation of pipes (salinity), yellow colour (iron salts)—but this is not possible for most forms of contamination which are undetectable sensibly.

Figure 10. Lending a hand in others' research: on site near Pulicat with V. K. Haritha and G. Gowrisanka (Anna University), 8 July 2018. Photograph by the author.

Groundwater complicates geographically-bounded notions of site, as introduced at the beginning of this chapter. Despite this, site exploration is also a way of assessing the ways in which different people access groundwater in particular places. 'Shadowing', or visiting sites as a guest of scientists, researcher, and activists, is a method for exploring both impressions of the sites themselves, and of the way work is done in them. I have used sketches, notes, audio, video, and photography, both as means of recording and of ways of having a conversation around a particular place. Further to this, I register prompts both from the environment and from my colleagues, in the form of a daily field notes journal. These accounts contribute to the ways in which I write up the case studies.

Also important is to consider the methods and tools used by the researchers I am shadowing. 'Measurements Matter'.[205] But in this case the material and political histories of physical instruments are less important than their usage.

[205] Barad, 'Meeting the Universe Halfway: Realism and Social Constructivism without Contradiction'.

I have also made use of unaccompanied walks and wanderings to explore possible sites and case studies, and to continually help re-shape the research plan. In both means of visiting sites, though not 'visiting' groundwater, the live and repeated immersion, on foot, is a means of access which offers a different view to a drawn map, or satellite photograph, not only in the angle of view but also in the temporal dimension: observations take place over a period of time, sites are revisited as they transition from one state to another. Spontaneity and contingency are allowed to shape what happens.

Access, Self-presentation, Ethics

Though I have access to specific archival material in the British Library and the India Office, protective attitudes and policies of government and academic departments in Chennai restrict access to certain local material. Methods will therefore be led by availability of resources. This is not unique to me as a foreign researcher: Ananya Roy, writing about her home town of Calcutta, describes the difficulties of navigating 'the politics of an unmapped city', where information is so often either inaccessible or simply non-existent.[206] Participants in Chennai have told me of their own difficulties in obtaining data even from different departments in their own university. In any case, access is only part of the problem—it's also about process. Even publicly-available data is only useful-to and useable-by those who have the facilities, knowledge, and software to process it.

Access to this data is partial and complex. In some instances, access has been simple, particularly in speaking with and receiving data from academics, and activists. In other cases, particularly in relation to public works, the sensitivity of data, and inaccessibility of the people working on the project, has meant barriers to progress and made it necessary to re-work the research plan based on what has been available publicly. One strategy I found for dealing with potential hostility and therefore opening some additional conversations, has been to try and reassure that I am not interested in the data *per se* (for example, groundwater level monitoring data during construction, which could be used by neighbouring property owners in court claims against the contractor), but rather that I am interested in talking to people about their experiences with/of groundwater. Key contacts were easily developed for the first and third chapters. The nature of the second chapter has been more opaque and required a shift to examining publicly avaliable documentation over a reliance on interviews and site visits.

[206] Ananya Roy, *City Requiem, Calcutta : Gender and the Politics of Poverty* (University of Minnesota Press, 2003), p. 137.

It is important in all contexts where participants are involved in the research, to introduce myself, and make clear my affiliations and motivations. I developed a participant information sheet and consent form to describe the nature of the project, how information would be used, and to offer the option of anon-/pseudo-nimity.

This research has had the potential to enter awkward, if not dangerous, situations—although the emphasis here is on the ethical implications of my making certain things visible through my research, rather than concern about safety. In the attention given to illegal, contentious, and corrupt practices, however well-established—such as photographing peri-urban water trade, and chemical effluents from leather tanning, or discussing construction's impact on urban groundwater levels—I am dealing with sensitive information. I am aware also that I will rarely fully understand a situation without translation or interpretation.

Media-making as a Research Method

I conclude this section on methods with an extended reflection on the role of media-making (especially various kinds of drawings) in the development of this thesis, and the relationship of this as a method to the analysis of other forms of representation.

I do not set out to duplicate, or indeed to somehow do better—to go beyond the limits of certain practices. They are all ways of drawing groundwater into visibility.

The impetus behind making my own 'working drawings' is the lack of clear or available documentation on specific aspects crucial to my research, such as lithography, or drainage infrastructure. I therefore make drawings based on what I know, acknowledging their partiality and incompleteness, and use these as means to have further conversations with participants—people who would be able to correct and offer additional information for them. These methods are intended to collect and examine material, representational, and discursive data—and to represent these both textually and visually in ways which are explicitly self-conscious.

Drawing as synthesis

> Make a map, not a tracing. […] What distinguishes the map from the tracing is that it is entirely oriented towards an experimentation in contact with the real. The map does not reproduce an unconscious closed in upon itself; it constructs the unconscious. [207]

One method I use to bring together disparate information is drawing. Ilpo Koskinen suggests that creative researchers should take their practice seriously by not only using visual practice as a

[207] Deleuze and Guattari, p. 12.

research method but by interrogating *how* they make their work.[208] This 'starting where you are' need not be 'edited out' of the enquiry in search of some form of objective account.[209] The 'practice-based' element of this enquiry is both in the background (in terms of the output being a predominantly written thesis, and entirely unavoidable and intrinsic to the way I approach the study as a trained professional architect, in a school of architecture, in a former polytechnic college, and as part of a grant-funded applied research programme.

Though a great deal of scholarly attention is given to the use of visual media tools in ethnographic study (e.g. photography, film) and the use of participatory research methods (mapping, model making)—the use of one's own creative practice as a research tool might be considered limited to artistic practices and 'design research' understood as a process of prototyping/testing or 'active research'. This may be something of a simplification, but there is a point here to be made: that the narrow scope of 'design research' is suggestive of a logic which restricts anything with the word 'design' in it to an iterative process of practical problem-solving.

I want to consider also the 'behind the scenes' creative processes of research. The 'exegesis'—a critical reflection on one's own creative output—is typical of practice-based research, but has a narrow status in humanities, and especially in science. But this reflexivity and conscious positionality is crucial to the methodology I have laid out. As Karen Barad writes of Niels Bohr:

> Bohr's style is atypical of most science writing. His writing reflects a self-conscious regard of his own descriptive process, which is consistent with his thorough-going examination of the role of description in scientific knowledge production, fundamental to his approach to understanding quantum physics. In like manner, I have tried to remain attentive to my own descriptive/interpretative process in my reading of Bohr. [210]

A critical approach to drawing-making should focus on the 'why' I make drawings, as well as the how, but not in the sense of specific technologies and packages used. It's about the choices I make, what and how I draw, the means of representation used. 'These introspective aspects of thought that are self-critical and self-consciously analytical.' The kinds of drawings I have made throughout this project have changed. The drawing below, for instance, is an early drawing made to bring together certain aspects of systems of recharge and storage, extraction and dispersal—

[208] Ilpo Koskinen, 'Throwing the Baby Out or Taking Practice Seriously', in *Reflections and Connections: On the Relationship between Production and Academic Research*, ed. by Nithikul Nimkulrat and Tim O'Riley (Helsinki: University of Art and Design Helsinki, 2009), pp. 11–17.
[209] Colin Robson, *Real World Research: A Resource for Social Scientists and Practitioner-Researchers*, Second Edi (Oxford: Blackwell, 2002), p. 49.
[210] Barad, 'Meeting the Universe Halfway: Realism and Social Constructivism without Contradiction', p. 174.

earth systems, highly engineered interventions, as well informal and expedient systems of water management.

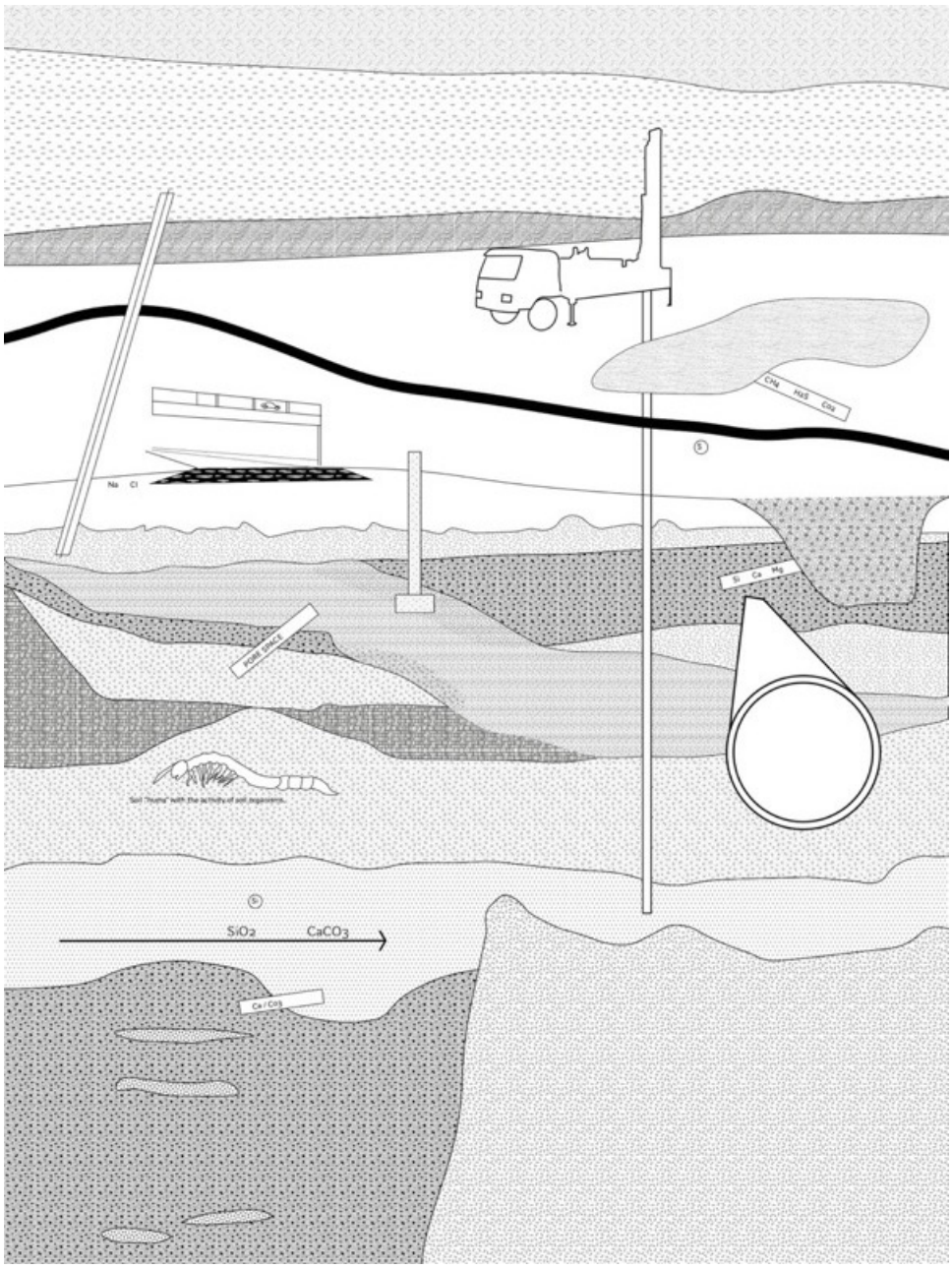

Figure 11. The groundwater assemblage (v1), 2017. Drawing by the author.

This drawing is an imaginative non-scalar catalogue of how tanks, channels, deltas, pipes, hand pumps, valves, wells, aquifers, factories, domestic sewerage, industrial effluent, tankers, plastic containers, and bore holes all come together in groundwater's cycles of depletion and renewal, contamination, and remediation. At other times, I might begin with sketches, a collection of photographs, and some fading memories: making large map-like drawings on my laptop, in my room in the Kalakshetra Colony of Besant Nagar, which are added to as I walk up and down the beach each evening. I use data bought from a website offering 'High Resolution World City

Maps' with 'closed polyline layers for buildings, streets, highways, city limits, and geographical data—all ready for use in CAD programs like Autocad, Rhino, BricsCad and SketchUp'. I try and match these files to stitched-together satellite photographs screenshot from Google Earth and Bing, which offer remarkable images although in greatly lower resolutions than for London. Not everything matches, but I repair some inconsistencies with observations on foot, or I just make it up, since the drawing at 1:5000 won't show the misalignment of the pavement. I have to decide whether to show the fish market on the map, since it only operates in the evenings.

I have diligently photographed the entire elevation between an apartment complex I have been shown around, and the beach, imagining a meticulous line drawing, and trying to eliminate the perspective created by the camera lens by standing as far away from the buildings as I can when taking the pictures, which means standing in the sun and it is a hot afternoon so I rush more than I should. When making the section I refer to the closest thing I can find which is a 20-year old geological section, hand-drawn. I find myself looking for ways to bring my own partiality onto the drawing in a more deliberate way. I project an outline onto my drawing board and the angle of the projection distorts the image, just as the angle of a satellite photo shows the façade of a building we think we are viewing from directly above, or the form of cartographic language used to flatten a sphere.

> Science explicates, poetry implicates. [211]

Our modes of representation are fundamental to our understanding, but also to our construction of things as bounded objects, separate from ourselves. As Mary Jacobus has explored in relation to poetry, a representation always holds multiple histories of production, multiple interests and politics, multiple (perhaps contradictory) understandings. [212] 'Geographical knowledges […] are fragmentary, multiple, contradictory, inconsistent and, often, downright hypocritical'.[213] We might embrace this, seeking to make it explicit—'insofar as conceptual-empirical relations are *in any case* recreated on an ongoing basis, they might as well be actively engaged, challenged, and transformed'.[214] 'Deep mapping', for instance, is a methodology that engages with the subjectivity and partiality of image-making.[215]

[211] Le Guin.
[212] Mary Jacobus, *Romantic Things* (Chicago: University of Chicago Press, 2012).
[213] Ian Cook, 'Follow the Thing: Papaya', *Antipode*, 36.4 (2004), 642–64 (p. 642).
[214] Casper Bruun Jensen, 'Continuous Variations: The Conceptual and the Empirical in STS', *Science, Technology & Human Values*, 39.2 (2013), 192–213 (p. 208).
[215] Iain Biggs, 'Deep Mapping: A Partial View', 2014 <http://www.iainbiggs.co.uk/2014/10/deep-mapping-a-partial-view/> [accessed 23 April 2018].

The impetus to make data 'objective' is certainly less helpful. Matthew W. Wilson notes how the transition to Geographical Information Systems (GIS) enabled 'a particular and limiting narrative' devoid of critical concepts around the use of such technologies.[216] This has been evident in some of the literature from the natural sciences on Chennai: around the mid-nineties, representation no longer factored as a question, it had been taken care of by others, by computer systems. But there 'is no unmediated access to the facts of the matter' and no objective means of representing them if there were. [217]

Drawing as method versus drawing as representation

> They used to be called *physical* appearances because they belonged to solid bodies. Now appearances are volatile [218]

Drawing-as-method is a form of dialogue, and distinct from drawing as a form of representation. It is an example of the 'reciprocal […] always at least two way, back and forth' engagement with things below the level of consciousness, as suggested by Le Guin in the earlier quote. Latour and Yaneva describe the dialogue between designer and drawing as being that drawings can be surprising and stimulating.[219] As we have seen, drawings are an example of conceptual-empirical hybridisation, and the two aspects are inseparable.[220] Drawing allows for something akin to a letting go of point of view—describing something *through* a relation with us, not outside of it. This is different, therefore, to saying that 'the drawing is an argument about the world': more like saying (the process of) drawing is an argument *with* a world. [221]

My attitude to drawing follows Barad's argument that the subjects and objects of knowledge practices are deeply entangled, and transformed by one another, but also, as articulated by John Berger, that making images, specifically drawings, potentially opens up worlds beyond the immediately apparent. Can drawing be used to illuminate things unseen? I returned to Berger's writing in this project on groundwater because of his comment that 'images were first made to conjure up the appearances of something that was absent', and the recognition that those images outlasted what they sought to represent.[222] Berger wasn't thinking about groundwater, but this felt a lot like a problem with which I was confronted in my work: that groundwater research, and

[216] Matthew W. Wilson, 'New Lines? Enacting a Social History of GIS', *Canadian Geographer*, 59.1 (2015), 29–34.
[217] Latour, 'From Realpolitik to Dingpolitik or How to Make Things Public', p. 12.
[218] John Berger, 'Steps towards a Small Theory of the Visible', in *The Shape of a Pocket* (London: Bloomsbury, 2001).
[219] Latour and Yaneva, p. 84.
[220] Jensen.
[221] Rania Ghosn and El Hadi Jazairy, *Geostories: Another Architecture for the Environment* (ACTAR, 2018).
[222] John Berger, *Ways of Seeing* (London: Penguin, 1972), p. 3.

its dissemination, is often described as 'making the invisible visible'.[223] It chases after something which is both unseen and always in motion. This dual problem of the 'invisible and capricious nature of groundwater' presents immediate challenges for any form of research into groundwater, particularly that which makes use of visual representations.[224]

In Berger's *Ways of Seeing*, the multiple layers of image, representation, and reality suddenly delaminated from one another and stretched apart, became distant, and never went back together. Berger, as others have done since, reminded us again and again that images are not the things they depict, and that representations of things are both made and read depending on habit and convention.[225] They communicate an attitude to something, an idea and condition how we are to read the world. This is one interpretation: that images represent a narrow part of reality, conditioned by specific intentions and assumptions.

I have suggested that drawing is a practice of expressing ideas about objects, rather than representing objects themselves. The drawing is not once removed (i.e. a record of a thing) but twice removed. It is a description of an idea about a thing. Drawing is a method with which to understand something, but a drawing describes a theoretical idea, not a reality, albeit usually through engagement with some form of material evidence. Drawing is not simply about 'reflecting and mirroring' in the sense of making a so-called accurate description, but must instead 'transgress its limits a little'.[226] To speculate is partly to show the world back to itself, but also to hypothesise, 'to contemplate; to theorize upon'.[227] It is to enact matter, rather than simply mirror as if from a fixed position, outside of and discontinuous with the world. In this process of grasping things and ideas at a distance, drawings are thinking tools and tools for making contact. One way of expressing this is to say that drawings help us to see: they are processes which the anthropologist Andrew Causey describes as 'seeing-drawing'.[228] Causey defines looking as being about what we already know, but seeing is about perception, a kind of feeling towards something and bringing it into being.[229] Drawing is a process which 'envisions', one of 'illumination' after a period of incubation.

[223] Rohini Nilekani, 'Rohini Nilekani Dreams of Making Invisible Water Visible', *Livemint*, 10 August 2018 <https://www.livemint.com/Leisure/7ztndZVQNjFd9HVtfn9vnI/Rohini-Nilekani--Making-invisible-water-visible.html> [accessed 6 September 2018].
[224] Nilekani.
[225] See e.g. Kester Rattenbury, *This Is Not Architecture: Media Constructions* (Abingdon: Routledge, 2002).
[226] Henri Lefebvre, *Rhythmanalysis: Space, Time and Everyday Life*, trans. by Stuart Elden and Gerald Moore (London: Continuum, 2004), p. 80.
[227] 'speculate, v.', in *The Oxford English Dictionary* [online], <https://www.oed.com/view/Entry/186112>.
[228] Andrew Causey, *Drawn to See* (North York, Onatario: University of Toronto Press, 2017), p. 11.
[229] Causey, p. 12.

Causey also suggests that ideas committed in drawings have generally been formed through visual experiences. However, drawing groundwater never derives from visual experience for it is impossible to have a visual experience of groundwater. Instead, to draw groundwater involves feeling in the dark, inferring a visual record from a non-visual experience. In this instance, drawing is a process by which I, as well as and alongside others such as scientists and activists, make information into images. In order to do this, such as when making a geological section from borehole logs, requires me to infer and fill in the blanks until I have a comprehensible picture that I can interpret in relation to things that I have had visual experience of (including other drawings). Disciplinary conventions use analogy and metaphor to comprehend via seeing that which one cannot see. This is similar to the problem in Susanne Keller's account of the evolution of the geological section: their function is precisely to make visual something which is otherwise unseen and unviewable.[230] This applies to well-established forms of representation, but also to emerging ones like numerically-based models which generate many thousands of textual and graphic images based upon a mixture of observation, assumption, and improvisation.

Tania Kovats calls this mode of visualisation-by-analogy 'a positive act of displacement' by which one thing is used to describe another.[231] Thinking through the double meaning of the verb to draw, Kovats reminds us that making a drawing, like drawing water from a well, is an act of making something appear in the world, of taking something from a hidden place and bringing it to our attention. Drawing on and drawing up are also dependent upon selection: isolating a part from the whole, or carving out a piece of it, is a necessary condition of making something visible. This describes an always dual process of both observation and projection, which for Kovats means that 'acts of drawing occur all the time'.[232]

In the sense that drawing is about making contact, perhaps drawing isn't a visual (in the sense of optical) process at all. It is only ever about relating certain observations, which are to some degree mediated (whether by sense, prejudice, and/or instrumentation) to prior knowledge, in order to generate a speculative image of an intra-active encounter between multiple, indistinct matters. Such observations will almost always include haptic, audial, olfactory, and other impressions. If we think again of drawing water from a well, we realise that the drawing is not at either end (top or bottom), but that most of this process takes place in the space between the

[230] Susanne B. Keller, 'Sections and Views: Visual Representation in Eighteenth-Century Earthquake Studies', *BJHS*, 31, 1998, 129–59.
[231] Tania Kovats, *The Drawing Book—a Survey of Drawing: The Primary Means of Expression* (London: Black Dog, 2005), p. 8.
[232] Kovats, p. 7.

first contact of the bucket with the base of the well, and its coming to the surface. This long gestation of what it is to draw focusses on the process, the work of drawing, not the product: the time spent between drawing and drawn where the thing not yet at the surface is being brought into view by the act of drawing.

Groundwater, as a hybrid material of both grounds and waters, in rest and unrest, is never experienced or seen directly. So its being drawn is a composition of traces, which are brought together to indicate both a material state and/or its ongoing change. By doing so, each act of drawing necessarily brings to the surface only certain traces, and analogises them with something already visible. In the case of groundwater, the description of the condition is limited by the condition itself: that of inaccessibility (both visually, and physically). But at the same time groundwater is drawing itself, leaving an archaeology of movements in and through sedimentary strata, creating transient records which can be drawn up and thought with.

The point of this, then is not to make the claim that drawing makes for better observation, or closer looking. This isn't about saying we see (visually) better or more clearly when we draw, but that we literally create things when we draw. I find Berger the most appealing when he is seeming to suggest that drawings are not about trying to 'seduce the visible'.[233] Drawing is not pictorial, but starts with making 'notes on paper', and proceeds to become more-than-record: the drawing itself is an act of making something appear. In the page reproduced below, which was made in conversation with researchers at a field site, the sketch is not an attempt at representing what is happening—of documentation—but rather in order to prompt further conversations, corrections, disagreements. Measurements are revised and crossed-out, and notes of related conversations intersect the page as questions are raised.

[233] John Berger, 'Drawing on Paper', in *Keeping a Rendevous* (Granta, 1992), p. 188.

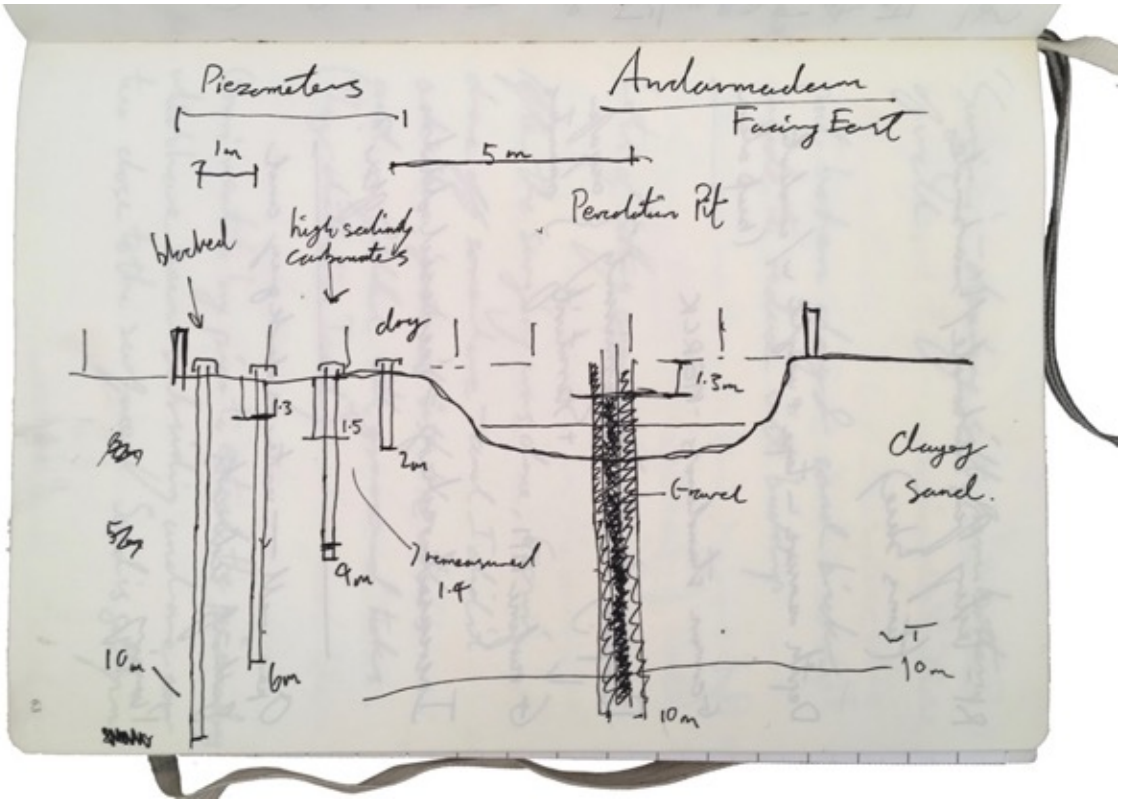

Figure 12. Sketch section made in the field in conversation with researchers. Drawing and photograph by the author.

Indeterminacy

So much for the invisible, but what about the relation of drawing to the dynamic? Groundwater is always registered in movement. Whereas a photograph of a tree, for instance, makes a record of the tree as a thing at a moment in time and despite its constant movement, groundwater is accessed only through measures and traces of its movements, which indirectly describe certain material conditions and relations with other matter. Berger had two important points to make about this.

Firstly, if a drawing is a record of a discovery one has made, rather than received, then the drawing itself is an event which 'contains the time of its own making'.[234] Berger dwells upon this time of the drawing-making process as being the difference between making and receiving, which emphasises that drawing is about an intra-active encounter.

> Isn't the act of drawing, as well as the drawing itself, about becoming rather than being? Isn't a drawing the polar opposite of a photo? The latter stops time, arrests it; whereas a drawing flows with it. [235]

[234] John Berger and Jean Mohr, *Another Way of Telling: A Possible Theory of Photography* (New York: Pantheon Books, 1982), p. 96.
[235] John Berger, 'Lobster and Three Fishes: A Dialogue between John and Yves Berger', in *Berger on Drawing*, ed. by Jim Savage (Aghabullogue, Co. Cork, Ireland: Occasional Press, 2005), pp. 119–45 (p. 124).

The processual nature of drawing, then, makes it absolutely suited to working with the processual nature of matter. Kovats opens her enquiry into drawing by giving primacy to the 'liquid knowledge' which 'floods and informs the work'.[236] This means admitting the liquid processes that are central to drawing with ink or paint, and in the production of paper and canvas (leaking, bleeding, staining, soaking, swelling, etc.) into the 'congress between mark, medium and subject' of drawing itself. [237] The making of a drawing, and what it depicts, are thus bound up with the vagaries of fluid motion, of 'the spill, the drip, or the blob'. This brings 'the emblem of uncertainty' into the process of drawing.

These are forms of disrupted practice which emphasise the drawing as a unique event. Acts of drawing are complex combinations of knowledge, surprise, chance, time, and the unknown. As the Artist Ilana Halperin writes, 'drawing is a study in potential'.[238] It expands, not limits, possibilities, and provides a means of accessing and translating across scales.

> Tectonic plates move at the same rate as your fingernails grow. Glaciers move one to two meters a day. Every moment has an infinite number of possibilities. Drawing provides a framework through which new territories can emerge. [239]

Drawing groundwater requires practical resistance to assumed certainty, or to what Whitehead called 'misplaced concreteness'.[240] There needs to be some acknowledgement in the form of the drawing that what is being drawn has only been lightly experienced. In my own work, this has meant injecting other kinds of artificial disruptions into the drawing process in order to move away from the idea of the act of drawing as being to approach a known outcome. Instead, by expanding the space and time of the drawing process to allow more room for ludic creativity, or non-cognitive intention, drawing becomes an open-ended exploration rather than a pre-planned record.

Secondly, Berger describes the encounter of drawing-making as always unfinished. The act of drawing is forever reaching out at something, as opposed to a recreating or capturing it. 'Real drawing' is not about supplying an answer but instead 'is a constant question, is a clumsiness, which is a form of hospitality towards what is being drawn'.[241] This openness or hospitality generates a kind of 'collaboration': we are not only 'always looking at the relation between things

[236] Kovats, p. 10.
[237] Kovats, p. 10.
[238] Ilana Halperin, 'Integrating Catastrophe: A Talk on Drawing', 2003 <http://www.ilanahalperin.com/new/drawing_talk.html> [accessed 12 January 2020].
[239] Halperin.
[240] Alfred North Whitehead, *Science and the Modern World* (Cambridge: Cambridge University Press, 1925), p. 52.
[241] John Berger, 'Drawing: Correspondence with Leon Kossoff', in *The Shape of a Pocket* (London: Bloomsbury, 2001), p. 75.

and ourselves', we can also say that neither element precedes the encounter.[242] This is a deeply Baradian observation.

In this interdependence of the seen and the seeing, drawing 'approaches something which is eloquent but which we cannot altogether understand'.[243] It is a kind of never-ending catching up, of foregrounding the unfinished, of the remainder through which the drawing never quite corresponds with its subject. Drawing is the opposite of permanence or record, which is not to say it is inaccurate, but that it must combine great attentiveness with an awareness of the limits of perception. My interest in geological and archaeological drawings comes from their ability to reconcile the precise and the ambiguous: whereas many architectural drawings tend to render liquid, mucky things with imagined precision, other forms of drawing leave space for the unfinished. Since they aren't the end of a process, they are situated within a conversation with the material, rather than being observations from outside, from a completely different realm. Berger said in an interview, 'There's not really a point where you realise that there's nothing more to correct—and if you were aware of that, it would probably be very bad'.[244]

The idea of never being fully able to draw something, then, is important when drawing groundwater. Berger's assertion that arriving at a final 'answer' would be a very worrying thing, refers to the impossibility of absolute depiction, and the necessity of ongoing collaboration. There needs to be something left over, some residue, something unresolved in the drawing.

> If something is complete in itself, perfection, nothing is left over, there is an end of it. If there is a remainder there is no end to it. So the remainder is the germ and material cause for what subsists. It is the concrete reality of a thing. [245]

Matter is incomplete, in both formation and degradation, and so drawing matter must be too. Just as Elizabeth Grosz describes the human body as being 'incomplete … a series of uncoordinated potentialities', if a drawing is about resolving the space between the observer and the object, it can never reach resolution because if it did, that would be the end of collaboration.[246]

[242] Berger, *Ways of Seeing*, p. 1.
[243] John Berger, 'Branching Out', in *Berger on Drawing*, ed. by Jim Savage (Aghabullogue, Co. Cork, Ireland: Occasional Press, 2005), pp. 78–83 (p. 80).
[244] BBC Newsnight, 'John Berger on Ways of Seeing, Being an Artist, and Marxism', 2011 <https://www.youtube.com/watch?v=b5y7QRt2bws> [accessed 12 January 2020].
[245] Stella Kramrisch, *The Hindu Temple* (Calcutta: University of Calcutta, 1946), p. 45.
[246] Grosz, p. 243.

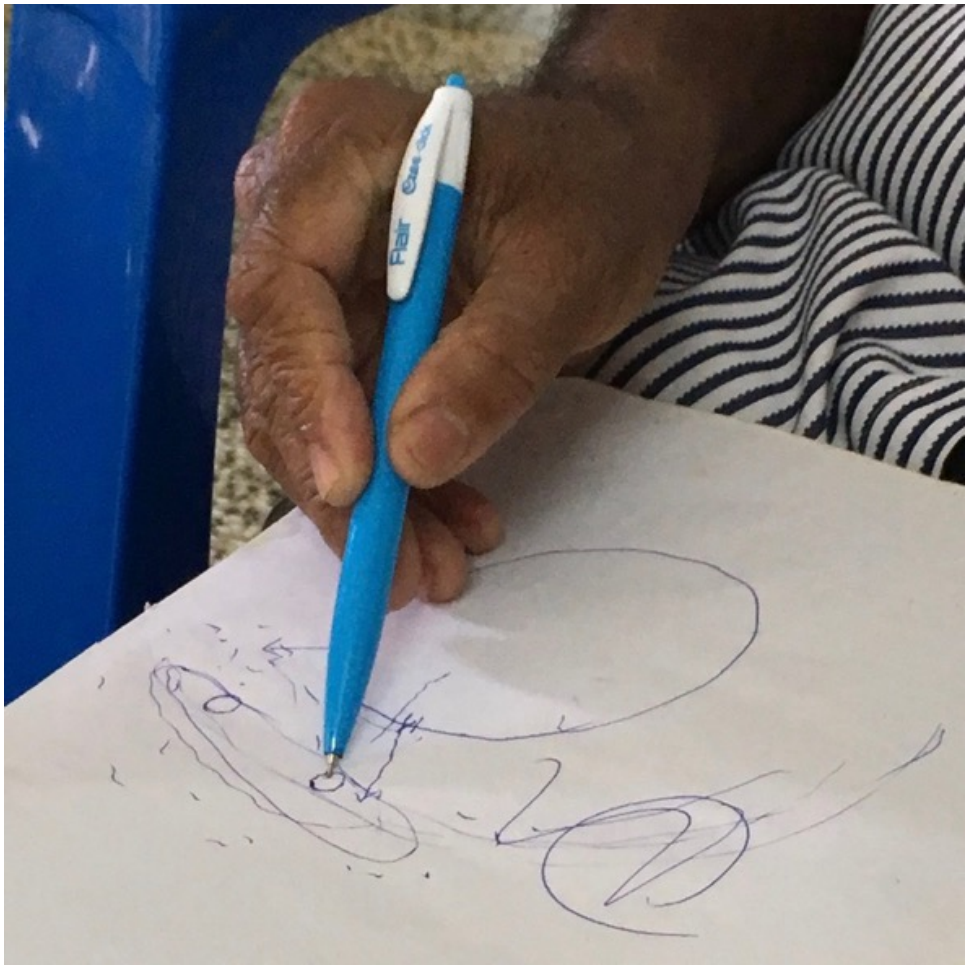

Figure 13. Spontaneous drawing during a fieldwork interview with Sekhar Raghavan, Chennai, August 16, 2017. Photograph by author.

Thinking with Groundwater from Chennai

To conclude this introduction, I will now give a summary of the basis and aims for this research project, and describe how the thesis will unfold through the chapters.

Aims

The purpose of this thesis is to develop implications of thinking with groundwater from an account of the process of knowledge production around and through groundwater in Chennai. The first stage is to unsettle a casual assumption, often held, that (under)ground is static/measurable, whilst (surface)water is turbulent/unknowable.[247] I wish to proceed not only by rejecting these categorisations, but by rejecting entirely the separation of water and land, of surface and (under)ground. Instead, it is only through exploring their manifold entanglements that I might glean from this research a sense of how urban livelihoods are fundamentally bound up with geology and hydrology.

This thesis attempts to bring attention to the ground of the city of Chennai. What is it? A picture emerges of the ground as series of strata, of hybrid formations; a composite; an active, vital component of the city. I will cast groundwater not as an objective fact, always pictured by and relative to a human subject, but as an 'actual being' which we (and other things beyond 'us') perceive, relate to, and come into contact with. This relation is ontological, irreducible to knowledge, discourse, or cognition, and therefore intrinsic.

In order to approach this problem, I will investigate how groundwater is known, how it is engaged with, whether and how these different knowledges diverge and converge, and what the implications of this are for operations and relations. I will describe the (re-)generation of grounds though geologic, architectural, and engineering processes, investigating the dynamics of where groundwater erupts into and is disrupted by human agency—reading the city through its intersections with groundwater (and vice-versa), as well as how these material dynamics are socialised, and approaching the city as a material and social entanglement that is constantly being reordered.

[247] Despite 99% of the Earth's liquid fresh water being *in the ground* (rather than visible on the surface in the form of rivers, lakes, and wetlands), the image of security offered by 'dry land'—reflected in geological representations, which ignored the water—remains pervasive. In Michael Madsen's 2010 film, 'Into Eternity', a manager of the Finnish nuclear waste disposal facility being carved out of the rock repeatedly refers to the stability of the underground, in contrast to the instability of the surface world. Advertising for the Chennai Metro Rail project also taps into the image of the underground as an uninterrupted space of transmission, away from the unpredictable and hazardous surface.

Objectives

In order to pursue these aims, I summarise the objectives of the thesis in terms of the following developed research questions:

Firstly, what are the ways of thinking about materials and materiality arising from vital materialism that are relevant to thinking with groundwater, and how do these inform an ontological approach to research that seeks to describe entangled things, away from configurations of subjectivity, and detached knowing—even within necessarily human-centric formats? I have started to answer this question through the theoretical review, but it will be revisited and developed through the core chapters of the thesis.

Second, and forming the bulk of the empirical research, what different knowledges of groundwater exist, how are these forms of knowledges (co-)produced, and how are these knowledges then enacted as operations in the ground or re-inscribed through scientific, professional, and everyday practices? Here I am concerned with how different audiences know groundwater differently, how groundwater is measured and recorded, and where and with whom these records reside. The question also naturally moves to what the effects of different representational practices are, as operations in the ground, whereby the material dynamics of groundwater meet these social worlds and ways of knowing groundwater. What technologies and machines are produced in order to work with groundwater, and how do differential understandings shape material relations? These questions form the focus of the core chapters.

Thirdly, relating ways of thinking arising from the first question, and the substantive accounts arising from the second, how can this research develop a vocabulary, and a critical approach to representational techniques, that better describe materials, things, and lives in combination (ground-water, water-ground) in their 'work' and in their becoming, maintenance of self, and/or transformation. This analysis is folded into the chapters, as well as forming part of the thesis' conclusions.

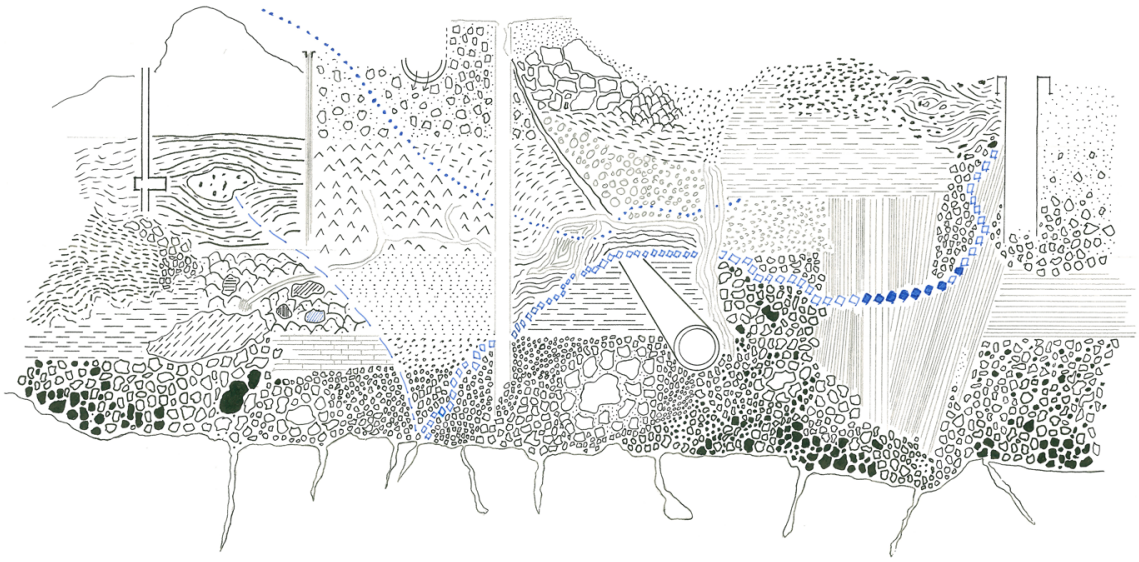

Figure 14. The groundwater assemblage (v2), 2018. Drawing by the author.

The above drawing (figure 14) was produced for a project advisory board meeting in 2018. It was intended to show both the content and structure of the project, as a series of interrelated enquiries into the complex and variegated materiality of groundwater in Chennai. I composed the drawing from fragments of geological drawings (both particular and generic), and graphic conventions (such as hatching), with elements of the project. Although rather than collage, it is drawn by hand on paper and unedited. These fragments therefore are moving through me (my memory, my hand) as they do in this thesis. There are areas of concentration on particular elements, as well as fault, wells, tunnels, and flowing substances that cut across and trouble the division of chapters. It is not intended to mimic, represent, or define, but borrows the analytical language of a geological section in order to reflect the intra-activity of the project itself.

Chapter Structure

I have developed the sequence of chapters in order to describe an escalation of relational concepts, beginning with the abstract, moving through the material, towards the more dynamic. This deliberately avoids a focus on groundwater as a simple commodity, as told through socio-political circulations and networks, although some accounting for this context is included. These specific cases were also chosen based upon the availability of data and contacts (archives of different sorts). It also avoids unfolding groundwater in terms of scale, in favour of a focus upon particular practices, since (as Barad notes) 'anything like some preordained geometrical notion of

scale must have long ago been blown to smithereens, and the tracing of entanglements might well be a better analytical choice than a nested notion of scale'.[248]

Chapter one is a first experiment in ways of knowing groundwater, through knowledge practices concerned with its everyday utility and maintenance. I consider how groundwater is understood and managed in an urban context, as a measurable *resource*, particularly through the Rainwater Harvesting programme of the Tamil Nadu state govenment. Dealing with abstract concepts of level, measure, and depth—as well as approaching the more material, in terms of balance, conductivity, and salinity. This chapter primarily builds from interviews, and site visits, but also refers to newspaper articles, and published reports, and gathered data: multi-year level and quality monitoring data of the Rain Centre, and academic research including aquifer mapping. It concludes around issues of translation between forms of knowledge and how these relate to the politics of knowledge production.

Chapter two develops a relational account of groundwater materiality through an engagement with knowledge practices applied during the construction of tunnels as part the Chennai Metro Rail project. By reading across archival material from the project, and recounting scientific histories of hydrological concepts, I unpack *strata*, *porosity*, and *pressure*—concepts that bring into view the materialities of groundwater and help us think with it, both because they are ideas that groundwater helps to generate, but also that groundwater continually exceeds. I close by drawing from this discussion a possible further set of concepts which groundwater generates—dynamic states which are common to human and material life—suggesting that a relational theory of groundwater materiality, based on leaking as opposed to bordering, might better respond to the ways in which groundwater troubles knowledge. This chapter relies on newspaper reports, (mostly importantly) the tender documents archived by Chennai Metro Rail Limited, as well as interviews and historical material.

In chapter three, I explore groundwater's dynamic and capricious nature through its interrelation with present and historical industrial contamination in the two post-industrial neighbourhoods. Contamination is central to thinking with groundwater in that it is explicitly founded on hybridisation and intra-action. Contamination also refers to processes of neglect and dilapidation: humans move materials, accelerating and distorting contamination processes, transplanting relationships and generating new assemblages. It is not just about what is released into the ground and later brought up, but how the ongoing vibrancy of the substance, saturated

[248] Barad, 'No Small Matter: Mushroom Clouds, Ecologies of Nothingness, and Strange Topologies of Spacetimemattering', p. G108.

within the groundwater environment, produces something different, deleterious—and how this toxicity then comes back into (our) world. The point is not to distinguish between 'natural' and 'anthropogenic' contamination, but to consider how the two are interrelated, and how these processes might be productive for understanding groundwater through the interrelation of different knowledge-producing practices. This chapter relies heavily on existing applied research both within and without Tamil Nadu, and India as a whole, but also utilises field visits, newspaper reports, interviews, central water quality standards, baseline monitoring data of government departments, and policy documents of Tamil Nadu Pollution Control Board—in order to establish a wider picture of the ways in which contamination is registered and understood.

The final chapter concludes by working back across the thesis's internal stratifications, questioning any image as being more-than-partial. I work across the chapters to propose a series of implications of thinking with groundwater, and position my research within an emerging field of study engaged with subterranean environments. I also reflect on this thesis's methodology of studying groundwater and consider this as a form of practice that is suggestive of modes of relational practice in situations where knowledge is (necessarily) incomplete, unfnished, and inconclusive.

Chapter 1: Utility and Conceptualisation

Measuring, Modelling, and Forecasting Groundwater within an Urban Water System

In late March 2019, the Tamil Nadu state government declared seventeen districts, including the capital Chennai, as well as thirty-eight 'blocks' (administrative units) in seven other districts, as being in drought. As the 'water crisis' spreads across international news, as I write this, I notice the frequency of that word, 'crisis', across my interview transcripts from the last two years, and newspaper articles from multiple decades. It seems evident that Chennai is never not in water crises. One report noted that, 'For many in South India, Cape town's [sic] dreaded "zero-day" (no piped supply), is in fact every day'.[249]

Groundwater in an urban water system

As Veena Srinivasan's significant work on the water supply network of Chennai has shown, even at its peak the municipal water system only supplies a portion of potable water required by the city. 'Water available via the utility has varied considerably in the last five years: from over 650 mld in Oct-Dec 2005, to less than 200 mld in Jul-Apr 2004'.[250] This is in contrast with a water demand now over 100 crore, or 1000 million litres per day (mld)—a figure generally used, as being based on WHO guidelines of 80-100 litres per day per person and a population now in excess of 1 crore (10 million). Clearly the rapid expansion of Chennai population, the rate of which has been steadily increasing since independence, compounds this problem—but Chennai's water system has historically always been multiple and distributed, with only a fraction coming from a municipal piped water supply. The basic role of groundwater as the mailable resource, the

[249] Veena Srinivasan, 'Wake up, There's No Water!', *Deccan Herald*, 23 June 2019.
[250] Srinivasan, 'An Integrated Framework for Analysis of Water Supply Strategies in a Developing City: Chennai, India', p. 120.

buried contingency, that can be drawn to meet this shortfall is something deeply ingrained in the urban imagination:

> the pattern has always been that the people of Chennai have not depended much on public water supply: they have depended on their private water supply which is the groundwater source. Any management of water in Chennai has to accept the fact that public water supply need not meet the full requirement: the private resources of the people can meet about 50% of the requirement, and it is good that they do so because then they will take interest to conserve that private water source.[251]

Infiltration during the period of precipitation is the only source of recharge to this water source.[252] In India as a whole, over 60% of agricultural and 85% of domestic water supplies are fed by groundwater, and the country accounts for a quarter of the world's total groundwater use. In monsoonal, coastal cities such as Chennai, which receive the bulk of a year's rain sometimes in a few days, groundwater provides a crucial means of storage, safe from evaporation and surface run off: a secondary storage capacity, but one which has an entirely different regulatory regime governing access.[253] Still, Chennai has the least available fresh water per person of any major city in India, and piped supply may only be available for a few hours per day, also the lowest of any Indian city.[254] The balance of water needs are met by 'abstraction' (extraction) of groundwater, as well as supply by commercial tanker, drawing groundwater from agricultural areas outside of the city.[255]

This chapter is about how groundwater is both utilised, and simultaneously conceptualised, through practices both within and in the margins of this disparate urban water system. My aim is to trace the knowledge-production of different individuals, institutions, and disciplines, and to consider the interrelations and translations between them. A disparate water supply is made up of distinct elements, but is also deeply interconnected. Focussing on the complete suspension of the water supply in 2003-2004, Srinivasan describes the interlinkages of the utility supply and groundwater levels: most simply, as the quantity of water supplied by the utility goes down, the proportion of dry wells goes up (and vice-versa), since 'total groundwater extraction within Chennai was inversely correlated with total utility supply'. When we met in Bangalore during my fieldwork in 2018, we spoke further about the hydrological interconnectivity of ground and

[251] Santha Sheela Nair, Besant Nagar, Chennai, 7 July 2018. Interview by the author.
[252] Ballukraya and Ravi, 'Hydrogeology of Madras City Aquifers'.
[253] Veena Srinivasan and Seema Kulkarni, 'Examining the Emerging Role of Groundwater in Water Inequity in India', *Water International*, 39.2 (2014), 172–86.
[254] Samuel Roumeau and others, *Water Governance and Climate Change Issues in Chennai*, Working Papers Series, 2015, pp. 16–17.
[255] *Terrain Guide of Chennai City* <http://www.rainwaterharvesting.org/downloads/chennai_terrain.pdf> [accessed 17 February 2017].

surface water systems: land, ocean, and rain. Emphasising the importance of the vertical section, Srinivasan describes the ways in which these systems are a continuum, not discrete.

Srinivasan's diagram (figure 15) shows how the groundwater element of the Chennai water system is not independent but interrelated to the other systems of water supply and delivery. These linkages occur in multiple ways, for instance in the significant contribution of pipeline leakages to the recharge of groundwater, such that when the utility supply is decreased, groundwater levels also fall. Outside of nation-wide monsoon periods (July to December), most groundwater recharge is from leaking pipes. This situation determines an annual cycle where the groundwater recharge is proportional to the availability of piped supply (post-rainfall), but groundwater extraction is inversely proportional to the same: demand is highest when supply is lowest. Furthermore, once the levels of the reservoirs fall, loss through evaporation becomes more significant. Groundwater is the piped supply's other, both continual with and opposite.

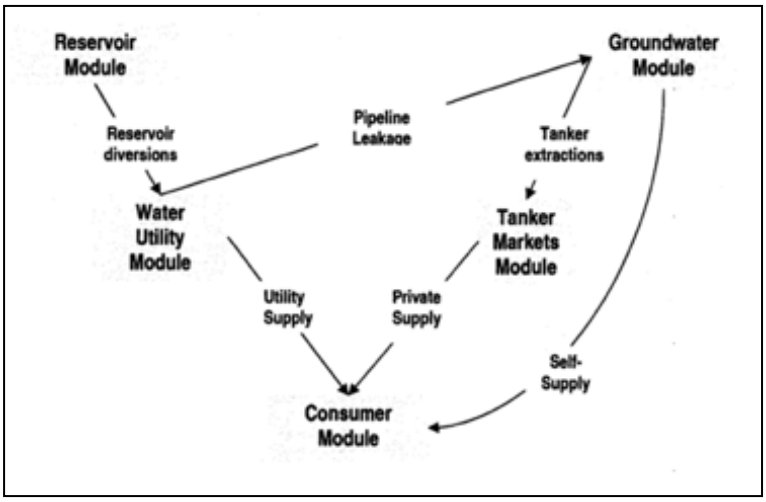

Figure 15. Chennai Water Model linkages. Veena Srinivasan.[256]

Though certain modules can be more easily quantified, Srinivasan points to the first Cauvery water tribunal as an example of the legal ineffability of groundwater.[257] In the context of an inter-state dispute over the sharing of waters from the Cauvery river, the groundwater element was omitted from calculations entirely, since it could not be reliably measured. This is typical of groundwater's anti-objectivity and the difficulty of accounting for it as evidence. Within the city, quantifying groundwater is equally difficult. At all times, 'the maximum quantity extractable from any single well varies spatially across Chennai', and without consistency, since the variation in

[256] Srinivasan, 'An Integrated Framework for Analysis of Water Supply Strategies in a Developing City: Chennai, India'.
[257] Government of India (Ministry of Water Resources), 'Cauvery Water Disputes Tribunal', 2007.

geology and recharge occurs at such a fine scale.[258] Data on groundwater recharge and abstraction is collected and held in piecemeal fashion, without central mandate. Knowledge of the piped water supply itself, as well as the drainage network, is both limited and highly fragmented, relying on the experience of specific departments and officials.[259]

The primary metropolitan drinking water supply is fed from four reservoirs on the western edge of the city—Chembarambakkam, Red Hills, Cholavaram, and Poondi—which are in turn fed by the seasonal rivers. The major challenge of water supply is the storage of monsoon water for use throughout the year. The current storage capacity of the city's reservoirs is insufficient for this, and requires negotiation with other agencies: the city cannot store enough of the monsoon water to supply for the rest of the year. The wet season rainfalls are also highly variable, and so at times the system is not recharged to capacity on an annual basis. Regularly, the piped water system will fail entirely—such as in the years 1992/3, and 2003/4—and residents will depend entirely on groundwater and tanker supplies.[260] Historical data shows that the reservoir system has dried up completely (to <5% capacity) once every five years, on average; there is an equivalent but non-correlating cycle of storm events, where the system is largely replenished.

The municipal system of water delivery is characterised by a modernist predilection for high-tech solutions, based on moving water from one place to another, such as inter-state river-linking network, canals, and reservoirs. At the same time, the government is also seeking to construct 'bypass' channels connecting the lakes directly to the sea: 'urban water utilities continue to plan and build projects to import, treat, and distribute' water as a solution to the supply problem, whilst underestimating the current or potential role of groundwater within the urban water system.[261] Even with highly-engineered solutions, such as the ongoing project to increase capacity via desalination plants, the formal water supply system is highly variable.[262] The reliance upon groundwater constitutes both the problem of a significant, unplanned extraction from aquifers, and a vital water resource, particularly for the urban poor, who have less access to the

[258] Srinivasan, 'An Integrated Framework for Analysis of Water Supply Strategies in a Developing City: Chennai, India'.
[259] Niranjana Ramesh, 'Between Fragments and Ordering: Engineering Water Infrastructures in a Postcolonial City', *Geoforum*, 119 (2021).
[260] Ballukraya and Ravi, 'Natural Fresh-Water Ridge as Barrier Against Sea-Water Intrusion in Chennai City'; Srinivasan, 'An Integrated Framework for Analysis of Water Supply Strategies in a Developing City: Chennai, India', p. 119.
[261] Srinivasan and Kulkarni.
[262] Since it is outside the scope of this project, I will not discuss desalination at any length here, though it comes up in conversations recounted in later chapters. For a fuller account of desalination plants as part of Chennai's water infrastructure see e.g. Ramesh, 'Between Fragments and Ordering: Engineering Water Infrastructures in a Postcolonial City'.

private supply markets. The World Resources Institute's Water Risk Atlas now rates Chennai (and much of India) as 'extremely high' risk.[263]

After the 2005 floods got international attention, it is only now that the daily water crisis of Chennai—drought, or at least lack of supply—is being widely recognised in the same way. This water crisis happens every year, as the storage of rain from the winter monsoon in a small number of surface-water reservoirs to the west of the city falls towards the summer months, and before summer rains or the runoff from the south-west monsoon falling on the Eastern Ghats reaches the city. Management of drought so far involves searching for more and new surface-water sources such as quarry pits, inner-city lakes, and by transporting water from neighbouring districts, as lakes already part of the water system dry up.[264]

Above / Below

The latest drought designation in 2019 came at the same time as Indian Insitute of Technology (IIT) engineer Vimal Mishra, along with a group of other engineers, geographers, and meteorologists, published a paper linking historical droughts in India to a lack of soil moisture, as opposed to a lack of rain.[265] That paper resonated with work coming from meteorological historians and remote-sensing specialists in Australia and elsewhere, which seemed to be re-conceptualising drought as something which comes from below, not from above. In Andrea Ballestero's words, 'Climate change has brought the underground to the surface; the media, government officials, and everyday citizens increasingly discuss the impending underground water crisis along with questions of value and property that new regulations entail'.[266]

Two tropes characterised the images of Chennai that punctuated the international press in 2019. Firstly, time-lapsed satellite photographs of drying lake beds alongside increasing urban sprawl sought to describe in large-scale terms the changes leading to the drought. Second, though, were photographs taken closer to the ground, but also looking downward, into it, at an absence. A much-circulated press photograph from global news agency Agence France-Presse gazed down

[263] World Resources Institute, 'Aqueduct Water Risk Atlas' <https://www.wri.org/applications/aqueduct/water-risk-atlas>.
[264] Express News Service, 'Rs 233 Crore Set aside to Tide over Chennai Water Crisis', *New Indian Express*, 1 June 2019 <https://www.newindianexpress.com/cities/chennai/2019/jun/01/rs-233-crore-set-aside-to-tide-over-chennai-water-crisis-1984457.html>; Julie Mariappan, 'City May Get 25 Million Litres per Day of Water a Day from Vellore via Wagons', *Times of India*, 4 June 2019 <https://timesofindia.indiatimes.com/city/chennai/city-may-get-25mld-of-water-a-day-from-vellore-via-wagons/articleshow/69640925.cms>; B. Jothi Ramalingam, 'A Thirsty Chennai Waits', *The Hindu*, 1 June 2019 <https://www.thehindu.com/news/cities/chennai/a-thirsty-chennai-waits/article27401259.ece>.
[265] Vimal Mishra and others, 'Drought and Famine in India , 1870 – 2016', *Geophysical Research Letters*, 2019.
[266] Andrea Ballestero, 'Andrea Ballestero' <https://andreaballestero.com>.

into an open well with coloured plastic pots (a third trope) dotted around, whilst in Chennai journalists rushed (as did farmers and fishers) to kneel and peer into the cracks and hollows of lakebeds, searching for water. Local media, in particular, seemed to focus on the ground itself rather than technologies of access, suggesting a different culture of knowledge around water and where it comes from.

Figure 16. How global media illustrated the Chennai water shortages in 2019. Getty Images.

Figure 17. Local media reporting 'on site' at dried up Korattur Lake. Mirror Now.

Alongside the long-term trend forecast by government agencies, and a general awareness of groundwater as a dwindling resource, Chennai is looking down at the ground, not up at the sky, for both a register and a solution of the level of crisis.[267] These efforts take on multiple timescales: the Sustainable Water Security Mission (SWSM) of the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB, known as 'MetroWater'), for example, works on both

[267] NITI Aayog, *Composite Water Management Index: A Tool for Water Management*, 2018.

drought-proofing (extreme, long-term) and monsoon-proofing (regular, annual).[268] As reservoirs dry up, MetroWater, and private companies, reach further outside the city to bring groundwater in from agricultural areas.[269] Protests are erupting between residents of peri-urban areas and packaged water companies, whom they say are responsible for significant reduction in groundwater levels and the loss of water in their own domestic wells.[270] The government's initial attempts to restrict withdrawal of water by these companies to 12 hours per day resulted in strikes and was withdrawn, with MetroWater and the state Public Works Departments (PWD) now set to publish a draft report on guidelines for water extraction, intended to lead to new legislation.[271] Domestic users within the city—who can afford the service—drill deeper borewells, in search of 'fossil water' held within in fractured bedrock. [272]

> What until the end of the millennium politicians left quietly underground, today they pull up as critical for the future of the nation. Subterranean water has risen to prominence as a geopolitical token, an object of national security projects, and an irresistible riddle in planetary science. [273]

What follows is a critique of representational practices, from the scientific to the (multi)sensory, not in order to belittle or deride any one in favour of the other, but to draw out and explore the gaps in and between them and their material objects. As information is discovered (during fieldwork), and developed through the text and drawings, I and others are producing something *new* through producing representations, which doesn't necessarily correlate with what's 'out there'. Since this chapter relies heavily on interviews, or rather conversations (as opposed to the following chapter which draws mainly from archive and historical material, and chapter three which utilises published papers and technical research), I also consider the role of discursive analysis as a method of engagement. It becomes immediately clear, when you spend any length of time talking to different people about the same thing, the ways in which these conversations, through manner or terminology, give away their concerns. The sections develop via descriptions of a series of different knowledge(-production) practices, initially from the point of view of

[268] Avilash Roul, 'Who Will Provide Water Security to Chennai?', *Down to Earth*, 2019 <https://www.downtoearth.org.in/blog/water/who-will-provide-water-security-to-chennai--64855>.
[269] S Senthalir, 'As Lakes Dry up, Chennai Will Stop Receiving Water from Its Three Main Sources by June', *Scroll.In*, 2019 <https://scroll.in/article/922884/as-lakes-dry-up-chennai-will-stop-receiving-water-from-its-three-main-sources-by-june>.
[270] 'Chennai Takes to Streets, Demands Water', *Times of India*, 7 June 2019 <https://timesofindia.indiatimes.com/city/chennai/city-takes-to-streets-demands-water/articleshow/69682204.cms>.
[271] Komal Gautham, 'Chennai: Getting Your Bubble-Top Cans May Become Harder', *Times of India*, 16 June 2019 <http://timesofindia.indiatimes.com/articleshow/69808535.cms>.
[272] Carole Dalin and others, 'Groundwater Depletion Embedded in International Food Trade', *Nature*, 543.7647 (2017), 700–704.
[273] Andrea Ballestero, 'Aquifers (or, Hydrolithic Elemental Choreographies)', *Fieldsights*, Theorizing the Contemporary, 2019 <https://culanth.org/fieldsights/aquifers-or-hydrolithic-elemental-choreographies> [accessed 20 August 2019].

municipal and state politics, then proceeding to a more material account of groundwater abstraction and harvesting, and finally to basin-scale modelling.

Groundwater as Urban Infrastructure?

> Before we even start to improve groundwater management, we must better understand and measure it. […] A lot of the problems that we have in groundwater are because we don't have even the basic understanding on some of these systems.[274]

In this first section I will consider how groundwater is *infrastructuralised* within an urban water system in order to make up the shortfall described in the opening. Infrastructuralising groundwater requires specifc ways of knowing it: specifically, means of measure. Ashley Carse suggests thinking with the term 'infrastructure' as 'a useful theoretical tool and empirical topic for analyzing the politics of environmental service provision […] paying attention to the contingent history of engineering decisions and the politics embedded in the changing socio-technical system'.[275] In this way, Andrea Ballestero has traced the ways in which aquifers in Sardinal, Costa Rica, are 'infrastructuralised', but also themselves are 'particularly uncooperative' to that infrastructuralisation, critiquing in particular 'figure/ground separations as means for infrastructural analysis'. To even speak of the transmutations of earth, water, and air casts them as separable substances, pure resources rather than part of material assemblages.[276] We will see in this section how percolation and infiltration, as intra-active physical processes of waters and grounds, complicate infrastructural framings of groundwater which demand separation of elements. Focussing on how certain technical constructs enter into legal and political domains, Ballestero traces and critiques the translation of hydrological environments into representational figures in discourses. The concept of translation will be returned to in the chapter's conclusions.

In this section I am thinking about how geologic strata are instrumentalised as part of a municipal water system, or of how the infrastructural imagination is extended to attempt to take control of the ground. I focus here on Tamil Nadu's Rainwater Harvesting (RWH) programme as a means of understanding groundwater, as an element of monsoon climate, and as a piece of infrastructure. These two things clash in very interesting ways: the programme is an intervention both directly in hydrogeologic processes and in the remaking of subterranean space through systems of measure and representation. It's about conceptualisation as well as physical intervention, and the two are absolutely inseparable.

[274] Craig Simmons quoted in Natalie Parletta, 'The Importance Of Groundwater And Of Predicting Human Impacts On It', *Forbes*, 2019 <https://www.forbes.com/sites/natalieparletta/2019/07/17/the-importance-of-groundwater-and-of-predicting-human-impacts-on-it/>.
[275] Ashley Carse, 'Nature as Infrastructure: Making and Managing the Panama Canal Watershed', *Social Studies of Science*, 42.4 (2012), 539–63 (p. 239).
[276] 'The Underground as Infrastructure? Water, Figure/Ground Reversals, and Dissolution in Sardinal', in *Infrastructure, Environment, and Life in the Anthropocene*, ed. by Kregg Hetherington (Durham, NC: Duke University Press, 2019), pp. 17–44.

Uncertainty, here, 'is something that is both produced and productive'.[277] Governmental frameworks, plans, jurisdictions, models, interventions, and boundaries focusses on the 'mitigation' of risk, and therein distribute risk to create spaces of vulnerability. These attempted neutralisations operate primarily on the level of representation, such as in the Tamil Nadu policy of Coastal Management Zones, which is hard and absolute on paper, soft and malleable in practice, being rarely effective, or enforced. Such promises of security against uncertainty in Chennai re-appear in real estate adverts touting the availability of 'sweet ground water', or in the offer of a 24hr water supply made to potential investors to develop around a planning zone dubbed the 'IT corridor'.

Rainwater Harvesting

Amongst the people who were instrumental in establishing Rainwater Harvesting as a state response to drought is Santha Sheela Nair, then Vice-Chair of the Tamil Nadu State Planning Commission. During an interview in 2018, she begins by recalling the image of young men playing cricket in dried-up temple tanks before the implementation of rainwater harvesting by government mandate in the early 2000s. In the period leading up to the elections of the state assembly in 2000, 'Tamil Nadu was facing a severe drought and the political parties who were vying for power were responding to the drought, each of them saying what they would do to mitigate it'. In response, a state-wide programme of RWH was included in the 2001 manifesto of J.Jayalalithaa's AIADMK party. 'So it became a political statement and not just something that a few concerned bureaucrats and activists'. Shortly after, it was made law, and by August 2003 the Tamil Nadu government had mandated that every plot in the state must harvest rainwater.[278]

This was a rare moment of government policy which focussed directly on the underground, and a political (re-)engagement with soil moisture. Such a policy was an incredible exercise of power: simply making it mandatory for every plot in the state to harvest rainwater. It became an attempt to deal with the 'suddenness' of water, to spread it out, create future groundwaters—kinds of inheritances across future years, the making of future grounds. The law also contained a second part, on recycling of greywater, which was never implemented.[279] Existing laws on the regulation of groundwater abstraction have proved ineffective, to the point that the current draft State Action Plan on Climate Change still proposes to 'control the volume of groundwater abstraction

[277] Austin Zeiderman and others, 'Uncertainty and Urban Life', *Public Culture*, 27.2 (2015), 281–304.
[278] Amendments made to Section 215 (a) of the Tamil Nadu District Municipalities Act, 1920 and Building Rules 1973.
[279] Santha Sheela Nair, Besant Nagar, Chennai, 7 July 2018. Interview by the author.

by strictly enforcing the groundwater regulation acts'.[280] Harvesting rainwater through infiltration is a means to fill up the underground surplus for the rest of the year, a response to rains that are concentrated in very short periods. RWH endeavours to spread the availability of monsoon waters across the year by utilising the storage capacity, in particular of the near-surface sandy strata, by increasing percolation in an urban environment otherwise made impermeable through hard surfacing.

The government established 'rain centres' in cities to communicate and consult on the installation of harvesting structures in people's homes. A wealth of drawings and diagrams on the walls of the Chennai centre describe the construction of different types of structures to increase percolation in from different building types and in different plot sizes, based on available space: via open wells, percolation pits, and interconnected drainage, for example from roof terraces. Alongside, the building itself is an exemplar and test site for technologies both traditional and modern: sand filters, sumps, and floor drains, as well as centrifuges and pumps. The project is oppositional to the construction of storm drains, which is ongoing, where the intention is to remove water as quickly as possible. As much as the city has been urbanised and been paved and concreted and tarred—the roads have been laid all over the city—the natural percolation of rainwater into the ground has been very much compromised. Here, the intent is to keep rainwater in place and to 'inject' water into the ground (in the terms used by one interviewee). Percolation is an important concept because it implies movement, transition, and exchange between above and below: it comes across as a seeking out of the porous fluidity of subterranean strata, in contrast to the anthropogenic crusts of urban structures. Pavement is marked as 'clay' in infiltration models—the closest, geologically, to zero infiltration[281]

Figure 18. Illustrations of RWH, Rain Centre. Photographs by the author.

[280] Government of Tamil Nadu, *State Action Plan on Climate Change of Tamil Nadu State: Towards Balanced Growth and Resilience*, 2014, p. 12.
[281] Anandaruban P., Chennai, 17 July 2018. Interview by the author.

Although an audit found that only 50% of structures were effective post-installation, the scheme was considered a success following heavy rains in 2003, and 2004, after which the rain centre declared a 20ft rise in groundwater levels—which was visible across the city as temple tanks, which were having games of cricket played in them, were filling with water again. A 2011 audit of harvesting structure has now led to further guidance being incorporated into the latest (January 2019) building codes, with the aim of making recharge structures more efficient.

Quantifying Groundwater

Mapping and monitoring is fundamental to the kind of understanding of groundwater required by the RWH project. When speaking with Nair, she shows me some of the news reports describing Chennai's groundwater situation, which is communicated through charts that map groundwater levels against rainfall. These measurements are concerned with quantity and speed of recharge but also wider questions of quality.[282] The rain centre itself keeps a network of 90 monitoring wells, which are checked monthly. The level of the water, and its general quality measured in terms of 'Total Dissolved Solids' (TDS), are recorded in notebooks, and later digital spreadsheets. The data is highly erratic, but confirms an annual trend whereby water is at its most 'pure' after the monsoon rains in October-November:

> There is a quality contamination in terms of brackishness of the groundwater. Especially in summer, it turns brackish. During the monsoon, the quality improves. Then as you draw more and more of it then the slight brackishness comes, then the taste is something that bothers the people. By the taste they imagine that it's a bad quality water.[283]

> Immediately after the monsoon the TDS will be less. In summer, the water level will also go down, the TDS will also increase. Because the dissolved substances stay at the bottom. The inferior water will stay at the bottom. Up to 2000 ppm. It's still potable according to standards.[284]

Quality here is measured in terms of *conductivity*: TDS refers to the content of mostly dissolved ionised solids (salts) as well as very small suspended particles. It is measured by determining the electrical conductivity (EC) of a water sample, since EC is a result of the separation of ions of the dissolved solids, meaning that the level of conductivity is proportional to the concentration of dissolved solids.[285] The solids content is derived by equation and expressed in terms of mg/L or ppm (parts per million), with 500 being the standard ceiling for fresh water. It is integrally

[282] Komal Gautham, 'Concerns Arise over Quality of Tanker Water in Chennai', *Times of India*, 10 June 2019 <https://timesofindia.indiatimes.com/city/chennai/concerns-arise-over-quality-of-tanker-water-in-chennai/articleshow/69718267.cms>.
[283] Santha Sheela Nair, Besant Nagar, Chennai, 7 July 2018. Interview by the author.
[284] Sekhar Raghavan, Chennai, 25 January 2018. Interview by the author.
[285] Hence, this method does not account for things in the water which do not have an electrical charge: pollutants like motor oil, pharmaceuticals, and pesticides, or microorganisms including bacterial contamination.

linked with groundwater levels, as falling levels near the coast increases seawater intrusion as the balance of pressure between freshwater and saltwater change.

Chennai water situation not as dire as made out to be

Former Metrowater chief counters Niti Aayog's doomsday scenario for 2020

T. RAMAKRISHNAN
CHENNAI

Strongly disagreeing with Niti Aayog's recent statement that Chennai would be among 21 cities in the country that would run out of groundwater by 2020, Santha Sheela Nair, a former civil servant, says that the situation is not as alarming as it is made out to be, if one is to go by the groundwater numbers of the city for the past 15 years.

Ms Nair, who handled the subject of water supply in various capacities for many years, points out that even 15 years ago, Chennai set an example for the rest of the country by taking to the idea of rainwater harvesting (RWH) in a big way.

"In 2003, when the city was in the midst of a huge water crisis, the average water level below the ground was around 5.6 metres. But, that was also the year people of the city started implementing RWH, going the whole hog. In three years, the level improved to 3.17 metres," explains Ms. Nair, who promoted RWH during her stint as Chairman and Managing Director of Chennai Metrowater, and as Secretary in the Municipal Administration & Water Supply Department in the State government.

She emphasises that political will demonstrated by former Chief Minister Jayalalithaa in supporting the concept 15 years ago made the RWH programme a "complete success."

Despite the 2016 north-east monsoon (October-December) being scanty, the previous year's level (4.3 metres) did not go down to the 2003 level. "This is precisely because of RWH," Ms. Nair asserts, adding that the quality of groundwater has also improved.

No room for complacency

However, the Niti Aayog's statement should be taken as a "wake-up call" as one cannot remain complacent, she says.

"It is time for all of us - the government, Metrowater and citizens of the city - to continue our efforts in water conservation with the kind of fervour we did then. If we pay sustained attention, the groundwater level can even rise up to one metre, as we are getting enough rain."

To ensure that Chennai does not suffer as it did in the past, a two-pronged strategy needs to be adopted, she says.

One, the concept of reuse and recycling of wastewater should be popularised in a big way. Two, with the limits of the city getting expanded, the authorities should adopt a decentralised method of meeting the drinking water supply requirements of people, apart from redoubling measures for preserving lakes and water bodies, meant for public water supply.

On reuse and recycling of wastewater, Ms. Nair says 80% of wastewater can easily be reused and recycled even at home. She makes it clear that she is suggesting only the reuse and recycling of sullage or grey water and not sewage or black water.

On decentralisation of water supply, local sources in extended areas of the city should be used to supplement and complement the city's water supply system. People in these areas, which have been brought under the control of Chennai Metrowater, should not entertain the thought that they too will get water from high-cost desalination plants or other such sources, she says, recommending that all the water bodies meant for public water supply be declared water sanctuaries and maintained on the lines of reserve forests.

Far from grim scenario

Groundwater levels have not plumbed to the levels seen in 2003-05 though rainfall has been poor

*AS PROVIDED BY CHENNAI METROWATER

'Need to rethink Western water supply standards'

T. RAMAKRISHNAN
CHENNAI

It is important to stop evaluating a city by the level of water provided per capita per day, according to Santha Sheela Nair, a former civil servant. Emphasising that the system of litres per capita per day only marks the average level of supply, without ensuring equity, she says, "We have to see each family, be it a slum family or a well-off family, how much water it gets. We have to decide that there is a basic lifeline supply that is maintained at all times. It can be either free or at minimum cost."

Ms Nair says the present standards of water supply have been "borrowed from the West." These standards promote "abundant use" of water and not conservative use of water, she adds. The focus should be on the use of minimum quantity of water and maximum utilisation. "This thinking does not exist in our policy level, engineering designs or in our curriculum," she says.

Figure 19. A newspaper clipping shared and discussed during an interview, Chennai, 2018. Photograph by the author.

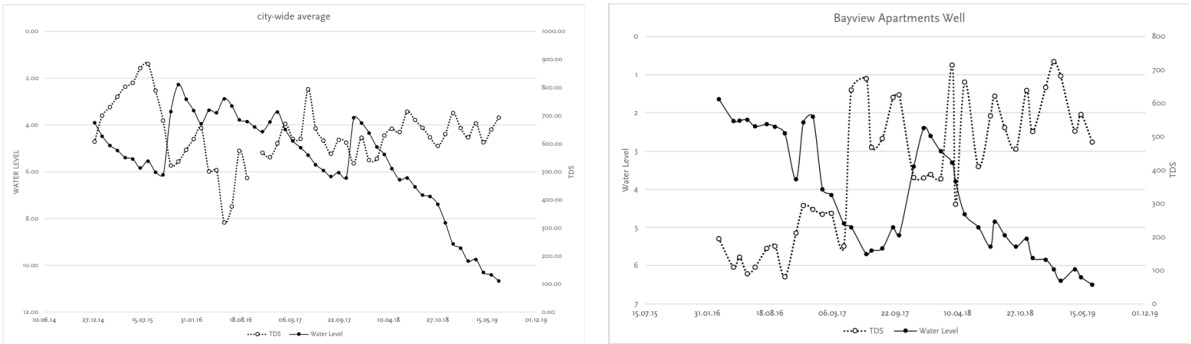

Figure 20. Plotting groundwater level against quality. Charts prepared by the author from Rain Centre well monitoring data.

The RWH programme's view of groundwater is multi-directional: in order to generate these graphs, water levels have to be measured by drawing from wells. To determine the appropriate

structures, an understanding of the ground conditions in a particular place is required, which will be established via ground investigation: the programme is about both extraction and injection. Alongside the general talk of areas of the city as being good for 'sweet' water or those worse off, where the water is 'brackish', 'saline', or just 'bad', there is a range of interpretations of the ground conditions responsible. In my initial conversations with Sekhar Raghavan, a groundwater activist in charge of Chennai's rain centre, he would immediately speak about depth, strata, geology: 'our intention is, the permeability of the soil […] how much of it gets absorbed by these different layers? Clay will absorb less, sand will absorb more, gravel will absorb equally a good amount'.[286] The rain centre, despite its state-backed position, initially utilised borrowed records of construction companies and borewell contractors to try and make sense of geology.[287] Now, the state 'plans to place digital water level recorders for better understanding of deep aquifers'.[288]

We were speaking over a section diagram (figure 24) used to describe how different technologies access groundwater at different depths, from the near-surface sandy strata, down through clayey and rocky formation, to fractured rock and solid rock. Epistemologies of depth pervade groundwater science. With depth, so increases uncertainty, and generally the efficiency of extraction decreases. Deeper groundwater is less mobile, tends to be more salty, and becomes unusable for drinking.[289] Groundwater is most often thought in terms of this level: the vertical distance from the ground we walk, down to the zone of saturation, usually far off. This conception foregrounds the vertical, specifically the holes that are used both to inject and to extract, over the more voluminous and three-dimensional strata that hold water. This is perhaps because in drawings like these geological sections we only really know the holes, from which we infer the rest of the picture.

[286] Sekhar Raghavan, Chennai, 25 January 2018. Interview by the author.
[287] Indukanth S Ragade, Chennai, 24 January 2018. Interview by the author.
[288] The Hindu, 'Chennai Suffers with No Water' <https://www.youtube.com/watch?v=iaG7kRcSxwA>.
[289] Brian F. Thomas, 'How Deep Can the Straw Go?', *Nature Sustainability*, 2.8 (2019), 659–60; Debra Perrone and Scott Jasechko, 'Deeper Well Drilling an Unsustainable Stopgap to Groundwater Depletion', *Nature Sustainability*, 2.8 (2019), 773–82.

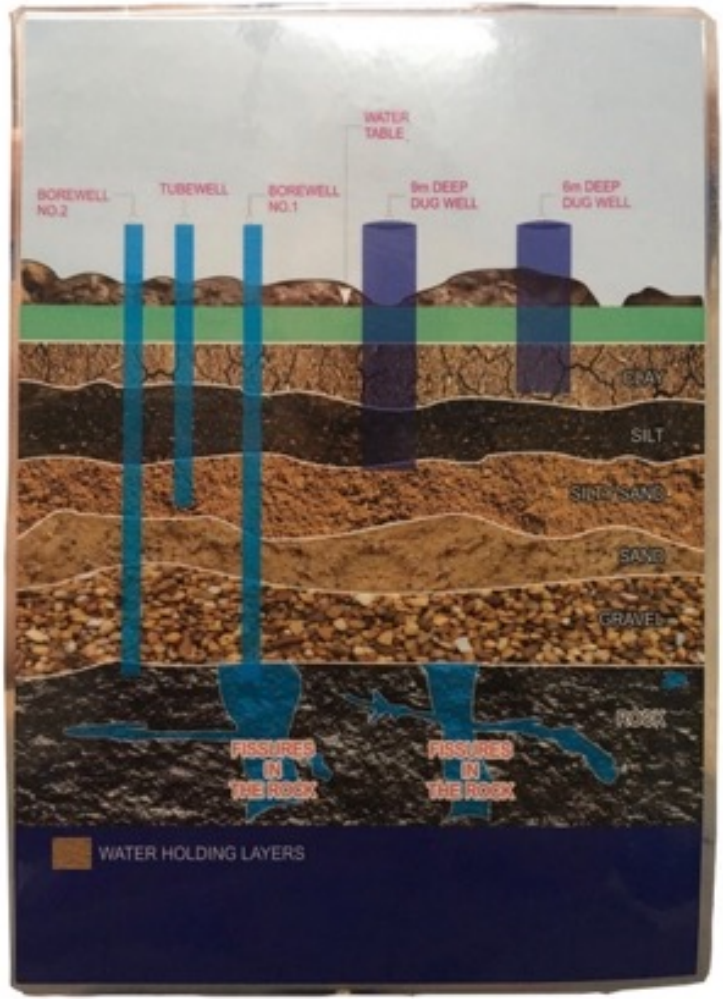

Figure 21. Diagram showing well types and indicative strata. Displayed at the Rain Centre, Chennai. Photograph by the author.

These drawings, produced in order to create awareness, start to describe the various technologies of access, dependent upon the level at which water is sitting. Chennai, even within individual neighbourhoods, has a heterogenous groundwater system, patchy and bounded, where areas of high permeability are separated by material of lower permeability. Groundwater varies at a fine scale according to the geological strata, recharge potential, and the technologies used to access it.

All the groundwater I discuss here is unconfined or 'perched' above a layer of (relatively) impermeable bedrock. The crystalline rocks are of low porosity, but are topped by a layer of weathered and jointed/fractured rock of the same type, up to 12m deep, which is capable of holding water.[290] This type of condition occurs for example in 'Saidapet, Adyar, Kasturba nagar, Gandhi nagar and Ashok nagar […] down to depth of 60 m below ground level'.[291] This source

[290] T Balakrishnan, *District Groundwater Brochure: Chennai District, Tamil Nadu* (Chennai: Central Ground Water Board, 2008).
[291] Balakrishnan.

can be of high yield, up to 4 litres per second (lps), but requires a deep bore well to access, and takes far longer to be recharged. The Gondwanas are also jointed and fractured, and the thickness varies 'from 24 m in Kilpauk area through 20 m in Ashok Nagar area to more than 130 m in Koyambedu area'.[292] They can be deeper than the crystallines (20-60 m below ground level), occurring in the western regions of the city, and offer relatively high yields of 1-3 lps, accessible using a tube well.

The near-surface alluvium offers the easiest access, and covers the major part of the city, including central, coastal and northern areas. Since water generally occurs a few meters below ground level, this is accessible by dug wells, but these offer lower yields, and can only be drawn from for a few hours per day. The aquifers being predominantly clayey sand, they 'do not have any good potential for sustained ground water development', though the sandier alluvium overlaying a crystalline ridge running north-to-south, inland of the coast, is comparatively better.[293] Tube wells in deeper, sandy alluvium offer the city's greatest yields, since the material is of the greatest porosity. This stratum also recharges more quickly after rains: users of high-tech bore wells may often find that their deep wells are dry from over extraction whilst the shallow open wells are filled.

The level of near-surface groundwater is typically only a few metres below ground and oscillates variously by between 0 and 10 m between mean high and low periods (wet and dry season). Relatively modest extraction of groundwater, both deep and shallow, by means of 'ring wells, dug wells, filter point wells, bore wells and tube wells',[294] has a significant effect on the water levels both locally and in surrounding areas, which also vary according to proximity with old tanks and surface reservoirs.[295] Overexploitation accelerated with the introduction of new technologies of sinking wells deeper and pumping water faster, allowing farmers and households to withdraw from the regulated sphere of surface water distribution into the uncharted space of groundwater. [296]

The conversations with groundwater activists, and the kinds of representations they use, produce a very different view of that found in state reports based around plan drawings of aquifers: drawings that can more easily correlate with the kinds of information in municipal plans. Instead,

[292] Balakrishnan.
[293] Ballukraya and Ravi, 'Hydrogeology of Madras City Aquifers'.
[294] Balakrishnan.
[295] Ballukraya and Ravi, 'Hydrogeology of Madras City Aquifers', pp. 95–96.
[296] Anthony Acciavatti, 'Re-Imagining the Indian Underground: A Biography of the Tubewell', in *Places of Nature in Ecologies of Urbanism*, ed. by Anne Rademacher and K. Sivaramakrishnan (Hong Kong: Hong Kong University Press, 2017), pp. 206–37.

Nair and Raghavan convey an understanding of depth and care for an environment that is geologically complex and has to be dealt with in particular, material ways. The definition of an aquifer is subjective, being simply the point at which the accessibility and availability of groundwater becomes useful for a specific purpose, in a specific location.[297] In any ground, at some depth, you will find water.[298] Therefore, and notwithstanding the ever-shifting nature of groundwater levels, a comprehensive mapping of aquifers in the region is a never-ending task. To name and draw aquifer is to suggest a static body of water, whereas we should instead be thinking about points at which to access a flow. Some maps exist (e.g. figure 22), though the often-competing information is unreliable. Important known groundwater sources, such as the coastal aquifer at Thiruvanmiyur, may be referred to by name, but these are typically based on zonal qualities of rock types, not necessarily presence of water.

As I have said, landscape is reproduced through representations, knowledge systems, and selective description in various ways attempts to render the subterranean 'legible', in order to intervene in its construction. One function of such is to divide the 'resource' below—rendered static, dead by the drawing—and the lively world on the surface. Groundwater troubles this neat separation of worlds. Ballestero writes that aquifers, 'while partially sharing some elements with the cave and the mine also exceeds them'.[299]

[297] Waltz.
[298] Liquid fresh water itself is only a small proportion of the water on earth, the majority of which is saline ocean (97%), and glaciers and permafrost (2%). Of the remaining 1%, which is fresh, only 1% is in lakes, rivers and wetlands (0.01% of total), while 99% is groundwater. Igor Shiklomanov, 'World Fresh Water Resources', *Water in Crisis a Guide to the World's Fresh Water Resources*, 1993, pp. 13–24.
[299] Ballestero, 'Aquifers (or, Hydrolithic Elemental Choreographies)'.

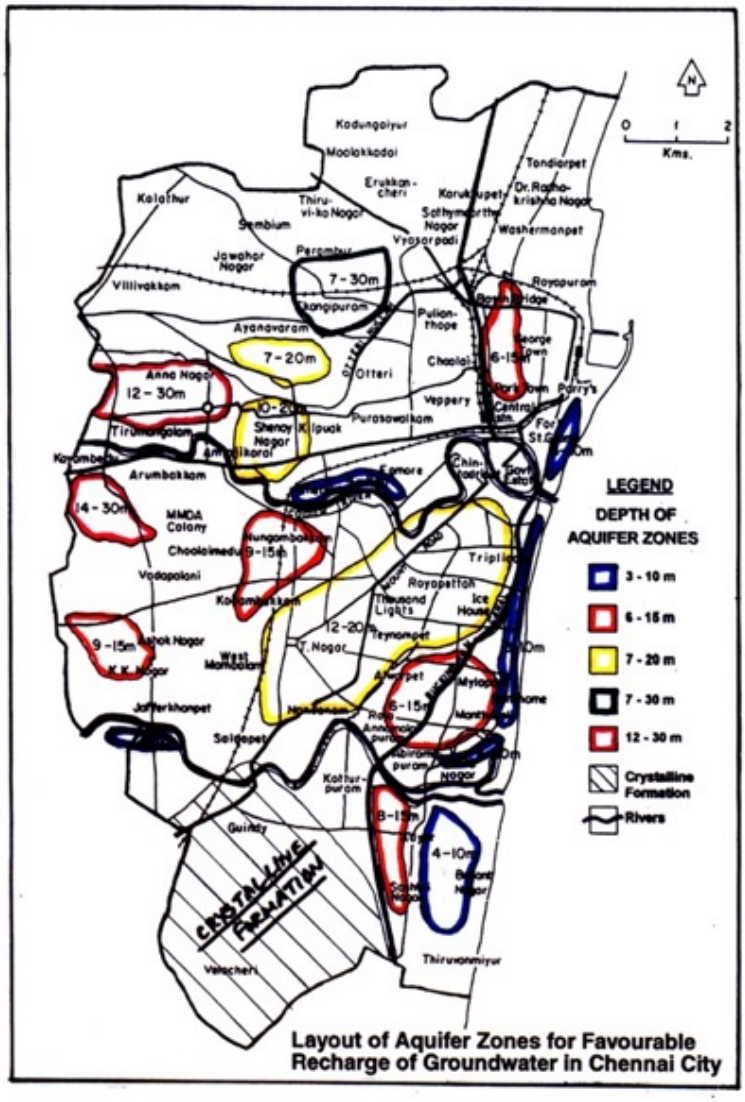

Figure 22. Municipal map of 'aquifer zones' as bounded objects. Tamil Nadu Water Supply and Drainage Board (TWAD).

Percolation and recharge

We need to better understand the role of percolation in groundwater. Water occurs within the ground because of voids, or pore spaces within materials. This gives us both 'storage'—the ratio of free space (pores/voids) to the total volume—and 'permeability'—the facility by which fluids move through the material.[300]

On a Sunday in July 2018, I arrived at 4:30 am to the geology department at Anna University. There was no one there save for the dogs, but by 5:30, after loading equipment into a taxi, we were underway. The objective was Pulilcat, to the north of the city, and a trial project to investigate the efficacy of percolation pits in improving groundwater recharge to raise the water

[300] *Groundwater (Benchmark Papers in Hydrology)*, ed. by Jeffrey J. McDonnell and Mary P. Anderson (Wallingford: International Association of Hydrological Sciences, 2008).

table and reduce salinity. The project referred to another term for Rainwater Harvesting: 'Managed Aquifer Recharge'.[301] I was following a group of researchers who, as part of their regular fieldwork, were undertaking sampling, pumping tests, and recording physical parameters of water from a recharge well. Physical parameters (Ph, electrical conductivity, TDS, Oxidation-Reduction Potential) were to be tested on site, since the properties may change once the water is drawn from the ground, and over the time taken to get it to a lab. So the lab goes to the field.

The site was suffering from high levels of seawater intrusion, with initial TDS recorded at around 4000 ppm. A percolation pit was constructed to increase the recharge rates and reduce the salinity of the shallow groundwater. Field measurements taken that day were messy, involving transport of equipment, and practical constraints of access. There was no road, so we all contributed to carry equipment including a generator across a few fields on the way, after earlier encountering a locked gate on the intended route. The site needed to be cleared of overgrowth, the dust blown out of sensors. There were grapples with electronic devices, batteries to change, calibrations to question. A digital Eureka SUB 2 was used for physical parameter tests, whilst chemical testing kits were used to identify carbonate / bicarbonate in the water. Depth was measured by means of a tape with a weight attached and a conductor which beeps as it reaches the water level. A number of the operations followed on site that day followed standards for water analysis developed by German company Merck.[302]

A pumping test, involving an electric water pump attached to a diesel generator, measured transmissivity and storativity (direct properties of the aquifer rather than the water itself). Water was pumped into buckets until silt is reached, then we rechecked the level. The water coming through at the end was dark grey and full of sediments: the tubes needed to be cleaned or 'surged' to remove silt. Broken clay and bricks, gathered from around the site, were added to the wells to reduce silt build-up. There was a lot of sitting around, and the tests took most of the day. Gowri went off to buy some pipe to extend the piezometers, which were subsiding and sitting too low to the ground, meaning sand was getting in. There wasn't enough water in the tubes to take an accurate level.

> 'the quality of sampling, the way you collect samples really changes the quality of the results' (PK, Coastal Resources Centre)

[301] M. C Raicy and others, 'Mitigation of Seawater Intrusion by Managed Aquifer Recharge', in *Managed Aquifer Recharge: Methods, Hydrogeological Requirements, Pre and Post Treatment Systems*, ed. by L. Elango, V. C. Goyal, and W. Thomas, 2012, pp. 83–99.
[302] Merck KGaA, 'Diluted, Certified Standard Solutions (CRM) for Water and Wastewater Analysis' <https://www.merckmillipore.com/GB/en/analytics-sample-preparation/certified-standard-solutions/4qib.qB.BRMAAAFTnc8fGO_i,nav> [accessed 29 May 2019].

The concept of percolation sets up the idea of ground as a kind of sieve, zone of transmission rather than a surface: a threshold, a 'net which serves as passage and as support' between above and below.[303] I want to engage with Tim Ingold's proposition that we are not *on* the surface of the earth but *inside* it: the ground is constitutive of our living within it, not separate from or on top of it. [304] The importance of movement as a key condition of groundwater here is twofold: since movement is essential to groundwater quality, but also that groundwater can be *seen* when it moves (as in the pump-based testing of aquifer parameters).

The infrastructural view of groundwater treats it as a singular substance, held within a containing vessel. This is the idea presented that the ground is a 'sponge'. As I will argue in the following chapter, this infrastructural analogy is false since it relies on separating the grounds waters from the vessel which contains them. 'We need to think water and stone together, inseparable, but also in constant movement'.[305] It is both physically and conceptually inaccurate to treat these elements of groundwater as separable: groundwater is a complex and variable environment consisting of diverse materialities, flora, and fauna. Water is not 'pure' below ground, but in constant entanglements with other minerals, taking on aspects of things it comes into contact with. Groundwater picks up chemicals from the geological substrate (limestone, and almost all other rocks, sands, and gravels), buried materials (rubble, gravel, and dredged fill, topsoil, buried structures and foundations, dumps, etc.), atmospheric inputs (acid rain, aerosols, industries, and trees), and surface applications (road salt, pesticides, runoff from buildings and roads, and sludge form wastewater treatment).

> Privileging movement, the difficult and never frictionless encounter between water and stone confounds our capacity to distinguish between figure and ground.[306]

Through municipal processes of excavation, survey, monitoring, and mapping, RWH and MAR attempt to reconstructs groundwater as a certain kind of material resource, simple in function and behaviour. In contrast, groundwater escapes its geological holding structure, and representations are only able to account for *either* the ground—the solid (or very slowly moving) part, such as in figure 21—or the *water*—as an abstracted quantity or spatial extents, such as in figures 19, 20, and 22.[307]

[303] Italo Calvino, *Invisible Cities*, 1974; in Zeiderman and others.
[304] Tim Ingold, 'Ground', *Society and Space*, 2019 <http://societyandspace.org/2019/03/03/ground/>.
[305] Ballestero, 'Aquifers (or, Hydrolithic Elemental Choreographies)'.
[306] Ballestero, 'Aquifers (or, Hydrolithic Elemental Choreographies)'.
[307] C.f. Andrea Ballestero, 'Spongiform', *Fieldsights*, Theorizing the Contemporary, 2018 <https://culanth.org/fieldsights/spongiform> [accessed 20 August 2019].

Abstraction and Harvesting Groundwater in a Coastal Neighbourhood

> 'To describe these processes means telling their stories.' [308]

In order to develop an account of the more material dynamics of rainwater harvesting, it is necessary to move to a particular place, from which this account can unfold. I articulate this particular neighbourhood not in order to give an account of an individual site, but as a point of access for engaging with groundwater relations. Matthew Desmond describes the practice of 'relational ethnography' as 'studying fields rather than places, boundaries rather than bounded groups, processes rather than processed people, and cultural conflict rather than group culture'.[309] This neighbourhood is a starting point, not a bounded space of which I will attempt to give a comprehensive account. This is also part of the argument I am making about the nature of cities, since: 'a place, despite its frequently settled appearance, is an essay in experimental living'.[310] Place is an experiment, dynamic, not fixed; tentacular, not bounded.

Besant Nagar is such a place: a suburban residential neighbourhood, in the area also known as 'Adyar' to the south of the Adyar river, developed post-independence initially as a housing colony for government workers, and later with a mix of housing types for middle-income groups, schools, and playgrounds. Being itself a liminal point between the Carnatic plains and the Bay of Bengal, the neighbourhood is characteristic of Chennai's reliance on its extended hydrologic environment. 'One of the reasons Adyar became a place that people wanted to develop was because of the availability of water. [And] in Chennai, if the water is good, that is the first consideration.' [311] Initially there was no metropolitan piped supply, but residents were able to utilise the good groundwater resources of the sandy subsurface. Compounds, typically low- and medium-rise apartment blocks, but also individual houses, will always contain an open well (even if in many cases it is no longer used, supplanted by tanker water, or only used for cleaning). Everybody has stories and experiences of groundwater (as we shall see in this section), news media frequently report even minor fluctuations in groundwater level and quality, which is a regular subject of conversation, and property is even advertised based on having good groundwater. In this way Besant Nagar has always been inextricably knotted with both the ground and the ocean, dependent on and vulnerable to their fluidities and intra-actions.

[308] Ingold, 'Materials Against Materiality'.
[309] Matthew Desmond, 'Relational Ethnography', *Theory and Society*, 43.5 (2014), 547–79.
[310] Edward S. Casey, *Getting Back Into Place: Toward a Renewed Understanding of the Place-World* (Bloomington, IN: Indiana University Press, 1993), p. 31.
[311] Santha Sheela Nair, Besant Nagar, Chennai, 17 August 2017. Interview by Lindsay Bremner.

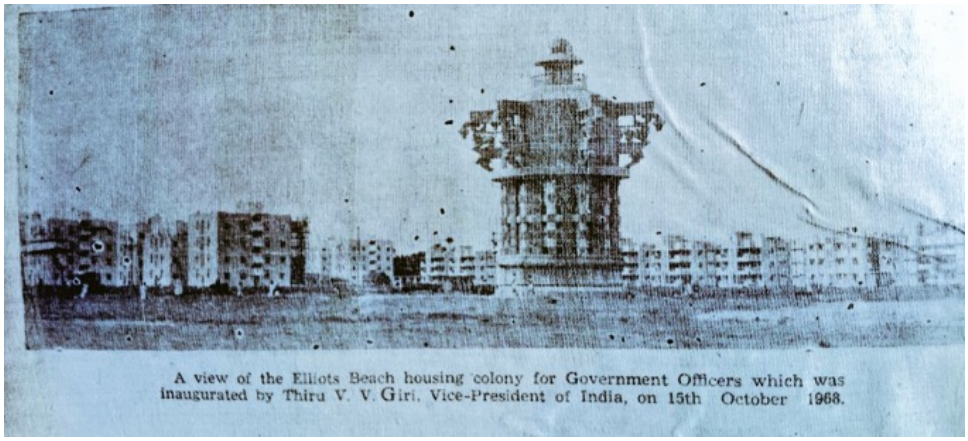

Figure 23. 'A view of the Elliots Beach housing colony for Government Officers which was inaugurated by Thiru V. V. Giri, Vice -President of India, on 15th October 1968'. The tower in the foreground now sits with the Metrowater compound. Madras Corporation Archives via Aditya Ramesh.

Figure 24. Digging in Besant Nagar, July 2018. Photograph by the author.

Besant Nagar is bounded by large green spaces to the north and south, the legacies of two women: The Theosophical Society of Annie Besant, moved to India in 1886, and the Kalakshetra Foundation for arts, established by fellow Theosophist Rukmini Devi Arundale in

1936. But it is also bracketed, closer to the sea, by two fishing hamlets—Urur Kuppam and Odai Kuppam (also known as Odai Nagar). The villages, which pre-date the rest of the area, have shrunk over time as land has been sold (to schools, churches, and residential developments), and now face predominately towards the Bay of Bengal to the east via Elliots Beach. Besant Nagar is also where a number of activists whose voices make up this section live, and where I stayed during fieldwork.

Figure 25. Besant Nagar Map. Drawn by the author including information from 'The Urur Olcott Kuppam Model'.[312]

[312] Urban Design Collective and The Madras Office for Architects and Designers, *Urur Olcott Kuppam Model*, 2017.

Depth, salinity, pressure

Besant Nagar is not next to the ocean, but quite literally floating on top of it, subtended by a wedge of saltwater which rises and falls with the freshwater table. Due to the 'hydraulic continuity with the Bay of Bengal', [313] zones of salt and fresh water are determined by a complex balance of pressures, with a narrow freshwater ridge created by the beach dune complex along the coastline preventing seawater intrusion and affording abstraction of freshwater from below sea-level near the coast.[314] At the same time, groundwater does not stop at the coastline, but low-salinity aquifer systems often extend offshore, as described in a recent study of the US Atlantic coast where electromagnetic imaging has been used to locate areas of 'fossil freshwater' fed by modern subterranean run off from the land. 'As water from rainfall and water bodies percolates through onshore sediments, it is likely pumped seaward by the rising and falling pressure of tides'.[315] The section drawing (or diagram) immediately becomes paramount in thinking about the land-ocean balance in terms of a co-ordination of wedges—of pressure, and materials.

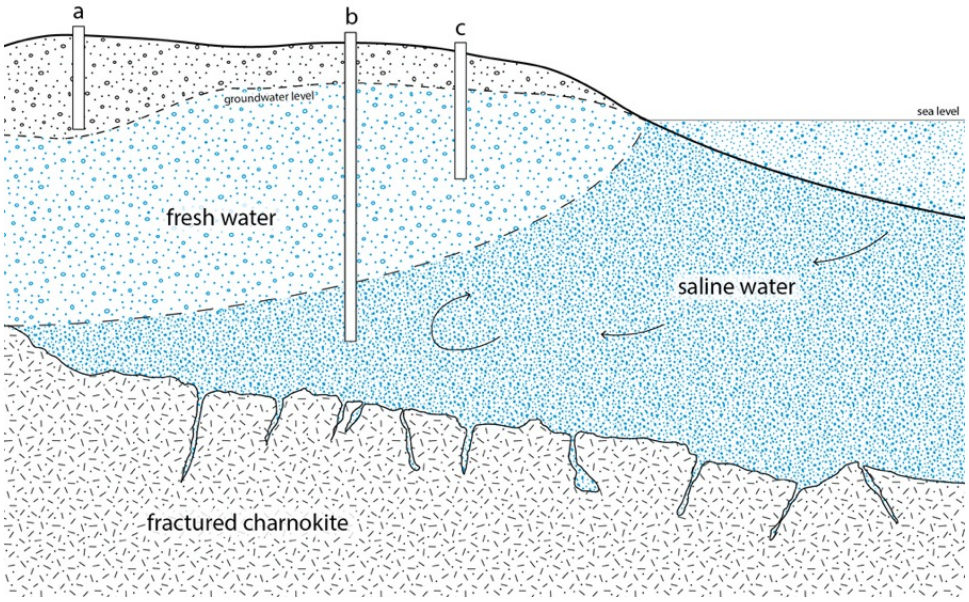

Figure 26. Coastal groundwater section. Well 'a' draws no water as the water table is too low, well 'b' is too deep and draws saline water, well 'c' draws fresh water. Drawing by the author with reference to Ballukraya and Ravi.[316]

Because of this vertical complex of different groundwaters, different material technologies are used to access groundwater in different places, and yield different products. Different depths

[313] Ballukraya and Ravi, 'Hydrogeology of Madras City Aquifers'.
[314] Ballukraya and Ravi, 'Natural Fresh-Water Ridge as Barrier Against Sea-Water Intrusion in Chennai City'.
[315] Chloe Gustafson, Kerry Key, and Rob L. Evans, 'Aquifer Systems Extending Far Offshore on the U.S. Atlantic Margin', *Scientific Reports*, 9.1 (2019), 8709.
[316] Ballukraya and Ravi, 'Natural Fresh-Water Ridge as Barrier Against Sea-Water Intrusion in Chennai City'.

hold different kinds of water, from the sandy near-surface alluvium which offers both the fastest flow and the easiest access, but the lowest yields. Tube wells and bore wells accessing fractures in bedrock offer greater yield but run dry from over-extraction because percolating surface water reaches so slowly, if at all. Physical drawing of groundwater, like the process of drawing to make it visible, is dis-integrated, fractious and multiple—there are multiple ways of making groundwater appear.[317] Water is flowing through these sections. They are static pictures of something that is dynamic. It is notable that they represent the strata and not the water, though we can consider the difficulty of drawing something so elusive and ephemeral as groundwater, which is always in motion. Wells, diagrams, and pumps are all part of 'the techno-political practices through which these flows are secured'.[318]

Because of the subtension of the shallow aquifer by seawater, bore wells in these areas, though illegal according to Coastal Regulation Zone (CRZ) restrictions but still widely used, tap saline water.[319] This coordination of wedges was described to me in fragile terms:

> If you go deeper down, it is likely to lead to saline intrusion. It will suck in the seawater. And also the quality of water deteriorates and you keep on going deeper and deeper and you actually harm the shallow aquifer: the shallow aquifer will be punctured. **The shallow aquifer is like the river flowing just below the surface of the earth and it is flowing into the sea**. So if you harvest the water in the shallow aquifer and recharge the water it will continue to give you a good source of water and a good quality source of water… if you puncture it, not only will you get less water, but you also damage it.[320]

The change in quality of water, of its content of other salts and minerals, is at first sensory, noted by smell, residues left on clothes after washing, scum on pots and pans. The first developments at Besant Nagar were set back from the coastal dunes, leaving the freshwater ridge intact, but as more recent development creeps towards the shoreline, combined with increased groundwater abstraction, the utility of this freshwater ridge has been reduced, and groundwater has become more saline as the level of the water table has fallen and the seawater wedge has risen. At the Coastal Resources Centre, a research and activist group headquartered in Urur Kuppam, Pooja Kumar related stories from residents of the hamlet, of the long-term trend against groundwater use, and how it has been replaced by other, expensive sources from elsewhere:

[317] As Francois Jullien reminds us in his essay *Living off Landscape*, the word 'landscape' was popularised 'as a technical term of painters'—referring not to a material space but to an image: 'a view or prospect of natural inland scenery, such as can be taken in at a glance from one point of view; a piece of country scenery' (OED). This idea of a 'piece' is crucial to the way that representations of landscape are generated, as is the invocation of 'glance'—the (human) eye is always a part of this process, selecting what we see, slicing earth into parts, generating something new and separate. François Jullien, *Living off Landscape: Or the Unthought-of in Reason*, trans. by Pedro Rodriguez (London: Rowman & Littlefield, 2018).
[318] Gavin Bridge, 'The Hole World: Scales and Spaces of Extraction', *New Geographies*, 2 (2009), 43–49.
[319] Pooja Kumar, Chennai, 5 July 2018. Interview by the author.
[320] Santha Sheela Nair, Besant Nagar, Chennai, 7 July 2018. Interview by the author. Emphasis added.

> They don't use groundwater for anything else other than just activities like washing the floor. They don't even use that for washing clothes because it is salty and hardwater effects the clothes. And so groundwater is only used for sprinkling outside the house or mopping or whatever. Everything else they buy water.
>
> [Speaking to an Urur Kuppam resident] He's saying that up till the 80s it was good, that in three feet they had water, but after the 80s as this area started developing and larger buildings, and competition for the groundwater started increasing. He's saying that since then it's been sort of salty. 80s is when he remembers the water as being usable. [321]

The interrelations between atmospheric, surface, and sub-surface flows change the composition of the groundwater environment. Pooja spoke about the ways in which these waves of variation in the groundwater environment are registered, through analogies made with familiar sensory experiences used to describe unfamiliar environmental changes, and the difficulties of translation:

> Because they are the ones … **they use their bodies as a monitor**. How can you convert that science into science which is understood by scientists? […] we've had communities who've approached us and said that: every day at this time we get rotten egg smell from this factory, what is that smell? Or, every day we're getting cooked cabbage smell, what is that? They're all markers of chemicals. You don't need to have a scientific equation or a name for that particular element to say that that chemical is being released. And so all you need to do is then attach a scientific name to what this boiled cabbage smell is, and then you find that it is sulphuric acid, or whatever it is that they are releasing. In that sense, **how do we translate scientific experiences of people into science**—sampling and monitoring is something that we try.[322]

In the traditional systems, water was always boiled for drinking, and it would be boiled with herbs and spices such as jeera (cumin seed), giving the water both a smell, and a colour—registers of quality. 'Even if you went to a restaurant or a wayside eatery, if the water had that slightly yellowish colour then you were assured it was boiled water because it was boiled with the cumin in it.' [323] The freshness of the cumin lasts for about 12 hours or so, after that the cumin starts degrading, a slight smell starts coming, and leftover water would be thrown away in recognition of the time by which bacteria will again start multiplying, 'when the effect of the boiling is over'. 'That was a natural system by which people, by using the cumin, could tell the quality of the water.' [324]

[321] Pooja Kumar, Chennai, 5 July 2018. Interview by the author.
[322] Ibid. Emphasis added.
[323] Santha Sheela Nair, Besant Nagar, Chennai, 7 July 2018. Interview by the author.
[324] Ibid.

Figure 27. 'R U Sure Your Water is Safe?': poster advertising in bottled water in Besant Nagar. Photograph by the author.

So ways of knowing groundwater are at first sensory, both in the water itself and its alteration in domestic processes. The understanding around how water contains different minerals counters a sense in some conversations around perceptions of groundwater in Chennai that there is a purity attributed to the substance that has been just extracted, as if it were unmediated, unhandled, unadulterated: 'The only absolutely trustworthy water is from the ground only'.[325] This extends deep into the surface, though, and is not only limited to water once it is extracted.

Compound

In order to better understand how groundwater is conceptualised in everyday use, in July 2018 I meet Sekhar at his apartment complex in Kalakshetra Colony, at the southern end of Besant Nagar, 500m inland from Elliot's Beach and roughly 5m elevation above mean sea level. The complex consists of 140 apartments across 5 buildings, built in 1989 along with paved external areas used for parking, and 5 open wells. On the day of my visit the water level is 5-6m below ground, though not the same in each well: the level is higher in the wells closer to the sea. As he tells me this, I am drawing the section in my mind, the information corroborating those curved lines in sections I have seen in diagrams of academic papers.

The wells are dug to a depth of 30 ft (~9 m). Sekhar talks of the importance of not 'puncturing' the interface between freshwater and seawater. When they dug a (relatively shallow) new bore well during the drought of 2001–2, the water was tasted every metre the bore drilled deeper into the soft ground. That meant standing next to the drill, watching it sink, and ceasing the operation

[325] Niranjana Ramesh, 'A Tank Half Full: Water in the Socio-Ecological Imagination of Chennai', 2013.

when the taste of the water was deemed salty (at 44 ft/~13 m). The methodology of construction here recalls the earlier use of the phrase, 'they use their bodies as a monitor'. Now the borewell is unused, since it yields only saline water—a compromise for washing and cleaning in times of drought, but otherwise the borewell is only pumped a little, from time to time, to keep the plastic pipes 'alive' by stimulating groundwater flows.

The level of groundwater is typically only a few metres below ground level and oscillates variously by between 0 and 6m between mean high and low periods (wet and dry season). Level of extraction affects users both collectively—'common pool effect'—and individually—'in well drawdown' or 'egg carton effect' (where the aquifer dries up locally despite water levels being high around, due to limited transmissivity). Relatively modest extractions have a significant effect on the water levels. In this context, local groundwater levels also vary according to proximity with old tanks and surface reservoirs, which serve as buffers to recharge the groundwater.[326]

Depletion of the aquifer disproportionately affects poorer residents, since they are more reliant on near-surface wells. Large commercial customers, fed from deep boreholes, are less susceptible to impact from groundwater level change.[327] Methods of extraction vary according so the aquifer material and depth. Private well ownership is correlated with higher household income. Richer households are also more likely to have access to deep bore wells, whilst poorer residents' wells dry up as the water table falls.

We discussed proposals to provide desalinated water within the next 2 years from a new plant along the coast, which Sekhar described would increase the salinity of seawater by discharging 'brine' at 35000-70000 ppm back into the sea. He said you could taste the chemical treatments of the water. Domestic RO reduces only to 2000 ppm. At home, residents of the block boil and filter water from the wells, but on our visit we also taste rainwater straight out of a holding tank that is receiving rainwater directly from the roof terrace, via a sump which removes the 'first wash' of rains along with any material that collects on the roof during dry spells. This is part of the harvesting process, but more important are the percolation pits—15' deep and 3' wide—dug at several points around the blocks to recharge the local aquifer. Utilising the ground as storage is a response to the abundance of rain in short periods, and the lack of capacity in the surface tank: 'It gets flooded, and a lot of water goes to the street, and gets wasted. So we are trying to keep it.' The ground is sandy, so water flows in relatively quickly, and the benefits are hyper-

[326] Ballukraya and Ravi, 'Hydrogeology of Madras City Aquifers', pp. 95–96.
[327] Srinivasan, 'An Integrated Framework for Analysis of Water Supply Strategies in a Developing City: Chennai, India', pp. 124–25.

local: this water will be drawn back through the open wells in the development, and very little will go elsewhere.

The system also creaks and fails. In the course of an earlier conversation at the Rain Centre, set up nearby as a prototype and centre for rainwater harvesting, Sekhar had demonstrated a scale model of an apartment block which 'rains' by means of a water pump and sprinkler headset into the case. Over years, water infiltrating the glued joints had split the parapets, sending water down the cardboard and discolouring its surfaces. I think of this entropic model as we talk about the ways in which the harvesting system in his block requires constant maintenance and repair, as it becomes clogged with silt and leaves, or as plastic pipes crack and split.

Sekhar talks about the poor implementation of rainwater harvesting in other developments, that it has not been done properly, but also that the rain centre has reviewed their advice after realising that the narrow infiltration pits they proposed in the early stages get blocked, cannot be cleaned, and are left ineffective: the wider infiltration pits allow a person to crawl inside and clean away the residues.

I dwell also on the possessive language Sekhar used during our visit, like 'my rainwater', and technical terms used by others such as 'puncture', which give groundwater a shape, as well as a kind of structure. To 'inject' is medical: treating groundwater like a body. Later, back in London, Sekhar sends me an updated excel sheet of monitoring data, including the current water levels during the water crises of summer 2019. At that time, on my drawing board at home is a section-in-progress from the apartment complex to the sea, so I go to it and mark a point for where the water has now fallen to, noting that it is below sea level. These three measures—the description, the spreadsheet, and the drawing—materialise groundwater in different ways.

Intra-active knowledge in practice

In January 2018, not far from the high-water point of the year, after the retreating monsoon has passed bringing most of the city's annual rainfall in a few months, I meet Sekhar and others in Mylapore, where he is advising on the installation of rainwater harvesting systems for a school. The purpose of the visit is to assess the level and quality of groundwater in a number of shallow open wells within the school grounds. As we walk around the complex of buildings and courtyards, Sekhar points, advising on locations in which to dig pits for the percolation of rainwater into the sandy strata.

Less than a kilometre to the east of us is Marina Beach and the Bay of Bengal, into which run the three rivers that brought material down from the central Indian plateau to settle here. In coastal neighbourhoods in the south of the city a thick mat of sandy alluvium exists above a rocky base and holds fresh water, often only a few metres below ground level. This water is extracted by residents via open wells and replenished during rains via constructed percolation pits, which compensate for the lack of permeability of urban surfaces.

Sekhar will advise the school on the design and installation of such structures, meant to improve vertical infiltration of rainwater into the near-surface sandy strata. As we stand in the courtyard, the saline waters of the bay continue underneath our feet as a wedge of saltwater permeating the alluvial deposits, below the freshwater layer. Removing the concrete cover from an open well near the edge of the dusty courtyard, we peer into the cylindrical chamber, as two others lower a small copper vessel tied to a heavy rope, determining that the current water level is 4.1 metres below where we are standing. As they tell me this, I am drawing the section in my mind, the information corroborating those curved lines in sections I have seen in diagrams. The next stage is to determine the general quality of the drawn well water by measuring TDS using a handheld meter, which is an inexpensive and readily available tool.

But the meter is broken, or the batteries are dead. No problem: stepping in, Sekhar tastes the water in the pot, thinks for a moment, and confidently states: 'It must be around three-hundred to four-hundred ppm. I have tasted a lot of water, so I can say from experience. I have calibrated myself!' [328] This exclamation returns me immediately to the discussion about the transformation of materials and material relations earlier proposed by Barad, following Bohr: that 'we are part of that nature that we seek to understand', and that 'our knowledge-making practices are social-material enactments'. Natasha Myers' asked whether it was, in the case of plant science, 'possible that practitioners' sensoria get 'vegetalized' over the long duration of their experimental inquiry'.[329] Similarly, Nicholas Shaprio tells of a chemically-sensitive subject who becomes 'jarringly attuned to the vast chemical infusion of the world around her'.[330] But here, forms of measure and the physical, sensory practice of groundwater abstraction are deeply intra-active. How in Raghavan's training as a physicist, decades of inspecting wells, a lifetime of tasting water, did he 'calibrate himself' to this particular sensorial method and mechanical scale? How does this

[328] Sekhar Raghavan, Chennai, January 25, 2018. Conversation with the author.
[329] 'Conversations on Plant Sensing : Notes from the Field', *Natureculture*, 3, 2015, 35–66 (p. 42).
[330] 'Attuning to the Chemosphere: Domestic Formaldehyde, Bodily Reasoning, and the Chemical Sublime', *Cultural Anthropology*, 30.3 (2015), 368–93 (p. 383).

affect his ongoing work with groundwater and how might he perceive differently to other bodies, machines, and registers?

Figure 28. Gazing into holes in the ground: inspecting open wells in a school compound in Chennai, January 25, 2018. Photograph by the author.

Raghavan has lived in Besant Nagar most of his adult life, and observed from his apartment complex the flows of water around the neighbourhood change as the area became more developed.[331] From this lived experience, he developed a methodology alongside 'masons, plumbers, and well diggers' for implementing RWH structures. He has for several decades been testing and tasting water and relating this information to the ways in which the political programme quantifies groundwater: because he *had* to relate groundwater in these terms as part of his role as an advocate for RWH. In order to communicate with policy makers, journalists, and the public, groundwater needed to become something universal and translatable, rather than just the particular way in which he understood it.

[331] Kaveri Bharath, 'Dr. Sekhar Raghavan: The Rain Man', in *Champions of Chennai*, 2018, pp. 28–30.

Modelling and Forecasting Groundwater

> What I can measure I can improve.[332]

Later that year, I am seeking out other perspectives in managing groundwater resources and speaking with Tom Herard, a French expatriate living in Auroville since the 1980s, and a key figure in the development and management of water resources for the intentional community 100km south of Chennai. 'Whatever we do, we have to look at it in different scales'.[333] Tom describes the problem of reliance on flowing groundwater resources, which move seaward to the east from recharge zones in the upper catchment, eventually into the Bay of Bengal ('the whole thing is collapsing'). He talks about deforestation in Gingee and Thiruvanmayur hills, about rates of extraction by sugar-cane farmers being ten times the rates of recharge, meaning rain water only replaces losses at the source, not contributing to increasing flows, leaving the water cycle 'very thin' when it should be 'fat'. And how, because of the sharp divide between the settlement and surrounding communities, Auroville's water management programme is increasingly inward-facing, with projects outside of the city itself (such as the construction of check dams) now being replaced by a 'micro-scale' focus on rainwater and wastewater recycling.[334]

Groundwater, Tom tells me, is extracted here at different depths of strata: shallow (40-50 m), medium (100-120 m), and deep (220-250 m). The latter, Vanur sandstone, is severely depleted, has lost pressure, and if affected by seawater intrusions. Depletions started with technologies of drill and pump. They don't know where the seawater interface is, so abstraction is trial and error. They are working with saturation principles: 'plentifulness' as another kind of measure, not explicitly concerned with quantity but with security.

They are starting to measure the subsidence resulting from groundwater over-extraction. Tom describes how sand is maintained in a 'floating' situation by the presence of water (see next chapter), and of the different qualities of soil, and their compaction, which allow water to be stored in eris, or infiltrate deeper. Of contour bunding, planting, and soil development.

Throughout the conversation, Tom returns to questions of scale: 'what is the right scale?'. 'Auroville depends on the bioregion for its water management'. Tom makes clear the importance

[332] Tom Herard, Auroville, 24 June 2018. Interview by the author.
[333] Ibid.
[334] Jukka Jouhki, 'Imagining the Other: Orientalism and Occidentalism in Tamil-European Relations in South India' (University of Jyväskylä, 2006); Jessica Namakkal, 'European Dreams, Tamil Land: Auroville and the Paradox of a Postcolonial Utopia', *Journal of the Study of Radicalism*, 6.1 (2012), 59–88.

of what was once called *context*, but which it is apparent from the way it is being described, is not anything like background.

Data Maintenance

Forecasting and prediction relate broad spatial and temporal scales to local groundwater interactions and futures. Water risk assessments look at the whole basin area, infrastructure, land use, hazards (e.g. seawater intrusion, tectonics). Models are themselves both processes (of software, data, measurements), and processual (constantly being run and re-run):

> People make this mistake of integrated water resources management and thinking of that as a noun, that it's an actual thing, but it's more a way of life and it's a process. […] a process that's never ending. This is not problem that we will ever solve. [335]

This is a constant process of adjustment between model and world. It means bringing physical parameters into the world of the model in order to project future events back onto material structure. As Kathryn Yusoff observes, geology is a discipline of ideas as much as observation: of speculation, assumption, and prejudiced-agendas.[336] The initial work of 'data maintenance' [337] filters observations through structures of data which can reinforce existing social inequality.[338] As Nair noted, the implementation and audit required of the rainwater harvesting programme required standardisations:

> If we wanted to make rainwater harvesting have an impact on groundwater aquifers […] it has to be universal, standardised, and something that the whole city and state follows. [339]

These processes, perhaps necessarily, reduce this complexity of landscape to things that can be directly observed and measured. Catharina Landström and Sarah Whatmore, writing of modelling as 'a new way of doing science', describe how researchers learn about environmental processes through computer simulation modelling.[340] The process of modelling is based upon improvisation: experimentation with available data, parameters, and software. Where does the data come from? Modelling parameters are more often guessed or inferred—not based on data

[335] Aaron Salzberg quoted in Brett Walton, 'The Next Urban Water Crisis? Inadequate Data Clouds the Forecast', *Circle of Blue*, 2019 <https://www.circleofblue.org/2019/wef/the-next-urban-water-crisis-inadequate-data-clouds-the-forecast/>.
[336] 'Geologic Life: Prehistory, Climate, Futures in the Anthropocene', *Environment and Planning D: Society and Space*, 31.5 (2013), 779–95.
[337] Shannon Mattern, 'Maintenance and Care', *Places Journal*, November 2018 <https://placesjournal.org/article/maintenance-and-care/> [accessed 21 June 2019].
[338] Richard Heeks and Satyarupa Shekhar, *An Applied Data Justice Framework: Analysing Datafication and Marginalised Communities in Cities of the Global South*, Development Informatics, 2018; Satyarupa Shekhar, 'Does Technology Reinforce Real-World Inequities?', *Transparent Chennai*, 2013 <http://www.transparentchennai.com/does-technology-reinforce-real-world-inequities/> [accessed 2 September 2019].
[339] Santha Sheela Nair, Besant Nagar, Chennai, 17 August 2017. Interview by Lindsay Bremner,
[340] Catharina Landström, Sarah J. Whatmore, and Stuart N. Lane, 'Learning through Computer Model Improvisations', *Science Technology and Human Values*, 38.5 (2013), 678–700.

—with statistical analysis tools used to identify outliers and clean data sets. In any case, data is dispered between physical and institutional environments: 'there are reports available, government bodies are doing direct measurements: agriculture, central ground water board. I will get the letter from here, I will go to that library…'.[341]

On my last day in Chennai in 2018, after many visits to the geology department at Anna University and field visits with research students, I meet up again with Ruban, a PhD researcher working on integrated groundwater and surface water modelling, so that he can tell me more about his work. Ruban has been using using a public-domain tool called SWAT (Soil and Water Assessment Tool) developed by the United States Department of Agriculture, integrating both quantity and quality data to 'predict the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungaged river basins'.[342] Considering water balance for the purpose of agriculture. Ruban uses SWAT at the river-basin scale simulating ('accounting for') water movement (surface water, unsaturated and saturated groundwater flows) in order to predict impacts of land use, management, and climate change on floods, droughts, domestic water supply, and pollution. The model is shallow, that is it covers only near-surface recharge, not deep percolation. He couples it with another tool—MODFLOW—to study the groundwater portion in more detail

Unlike event-based models (e.g. to simulate flood events, as the majority of researchers are doing in Chennai), Ruban's model is a physics-based 'continuous time model' made up of various parameters,[343] both distributed (meaning parameters are linked to geospatial data rather than 'lumped' averages),[344] and semi-distributed:

> Semi-distributed is like, um… the representation. I can say it is a representation of a process. I mean, this is based on the physical process, right? So it is going to give you the water movement, sediment, nutrients, everything… I am only looking for the water movement. Water movement from ground to subsurface, subsurface to again to the surface, and it is going to be in the atmosphere. This is the hydrologic cycle, right? So when the process is happening, how are you going to account it? How are you studying? That is the distribution, and that kind of thing.[345]

[341] Anandaruban P., Chennai, 17 July 2018. Interview by the author.
[342] USDA Agricultural Research Service, 'SWAT - Soil and Water Assessment Tool', 2018 <https://data.nal.usda.gov/dataset/swat-soil-and-water-assessment-tool> [accessed 2 September 2019]; P. W. Gassman and others, 'The Soil And Water Assessment Tool: Historical Development, Applications, And Future Research Directions', *Transactions Of The ASABE*, 50.4 (2007), 1211–50.
[343] Parameters include: baseflow factor; groundwater delay (recharge); return flow; evaporation coefficient; soil composition; hydraulic conductivity; bank storage; available soil content; and soil moisture.
[344] Behnaz Khakbaz and others, 'From Lumped to Distributed via Semi-Distributed: Calibration Strategies for Semi-Distributed Hydrologic Models', *Journal of Hydrology*, 418–419 (2012), 61–77.
[345] Anandaruban P., Chennai, 17 July 2018. Interview by the author.

Ruban's model covers the Adyar basin, 40-50% of which is within the Chennai Metropolitain Area.[346] The river only has minor daily flows, 'not a river flow—only wastewater from industry'. 'This is a rather complex basin: everything is there, flood, drought, groundwater quality, groundwater contamination, everything […] It is critical, and it is part of Chennai'. Compositing the model means combining existing maps of tanks, and green areas, with rainfall data, 'digital elevation model, land use, land cover, soil data, geology, geomorphology, rainfall data, Chembarambakkam reservoir storage, and inflow, outflow'.[347] The SWAT tool divides the river basin into HRUs (hydrological response units) comprised of land use, soil type, and slope factors—integrating land use surveys with satellite topographic data (SRTM).

Ruban has so far spent 1.5 years developing and 'calibrating' his model. First the surface water model, and later the integrated model. 'When you want to do a model, you have to calibrate, and you have to validate. To validate those models, you have to know the discharge, the previous measurements'. Calibration, or 'inverse simulation' is the core task here: simulating what has already happened, and comparing the model's (retrospective) prediction to observed data. Across 15,000 simulations each run, the model will identify the best combination of parameters, those which give the best results, narrowing down to a set. Whilst we are talking, Ruban is not showing me forecasts but an 'estimation calculation for previous years'. This is the basis of the exercise of forecasting: looking back.[348]

> So if you believe this data is giving some good quantity, it is reliable—if you *feel* that, you can predict.[349]

Calibration requires some knowledge of what happens at the edges of the model, the inputs and outputs of the basin unit, which causes trouble due to data availability.[350] At this point Ruban starts to talk about missing data, such as the missing measurements of outflow into to the ocean, due to equipment being regularly stolen from storm water drains.

> The important thing I have to tell you is that it is not gauged, there are no measurements of discharges. This is the problem you can see in almost every part of India, there is no proper measurement, or proper gauging to measure the discharge or to measure the outflow from storm water drains in the city.[351]

[346] Pre-2018 expansion.
[347] Data for Chembarambakkam is since 2005, since it has been part of the municipal water supply.
[348] 'An inverse simulation uses a search algorithm to find parameter values that minimize (or maximize) an objective function that reflects how well the model output matches measurements.' Stephanie K. Kampf and Stephen J. Burges, 'Parameter Estimation for a Physics-Based Distributed Hydrologic Model Using Measured Outflow Fluxes and Internal Moisture States', *Water Resources Research*, 43.12 (2007).
[349] Anandaruban P., Chennai, 17 July 2018. Interview by the author.
[350] Kampf and Burges.
[351] Anandaruban P., Chennai, 17 July 2018. Interview by the author.

There is no way to calibrate the model from this data that is not there, so he goes back further, to an original 'state' based on panchayat-level maps and data of eris and temple tanks: 'with the model you can simulate the original condition. So this was the original water spread area, this is the depth, and this is the storage. That is the data I have collected only last week. I was trying for 2 years to get that data. That was written data.'

This effort of matching, syncing the programme with the physical world, striving for statistical performance indices, it's a constant process of adjustment. 'You have to check continuously.' [352]

> You cannot simulate the exact nature, no? [..] Hydrology is a complex system, you are not going to represent everything in detail. Like, I am just going to consider that this is a built-up area. What are the buildings? What is the road? **Everything is changing.** We can make it as a 'lump' quantity. I mean, for entire urbanisation I am going to give it as a built-up area, so I am going to represent it as a single value. Any modeller will tell you this. And I cannot tell you that this model is completely wrong. […]
>
> So what is the purpose of any model? If you have a calibrated and validated model, if there are any future events you can just simply predict. […] I can put various scenarios: if the rainfall is increasing 10%, 0r 20%, what is the runoff? What is the flood? What is the groundwater condition? What is the lake condition? I can give you the suggestions. So based on the suggestion they can have some idea. So that is the ultimate aim of these kind of models, whatever is the model.[353]

Ruban here seems to describe modelling as a heuristic exercise: constructing a kind of speculative fiction that, nevertheless, is able to accurately reflect certain aspects of real-world conditions. He is keenly aware of the detachment from physical processes when his model 'runs', but speaks about this calibration as if a physical process, borrowing the hydrological as metaphorical language for the relations between data in the model:

> A tight couple is like a simultaneous process, like when the rainfall comes it goes to infiltration—the movement is continuous. That is tightly-coupled. This is different: I am doing the surface water process in a different model, and I will take that result, and I will give it to another model. This is loosely-coupled.[354]

[352] Ibid. 'So, I will tell you: this should be '1', OK? R-factor should be '1'. P-factor should be '0'. So if that happens, what it means is your simulated model gives the exact result of the measured, across the data. So it is not possible, actually.'
[353] Ibid
[354] Ibid.

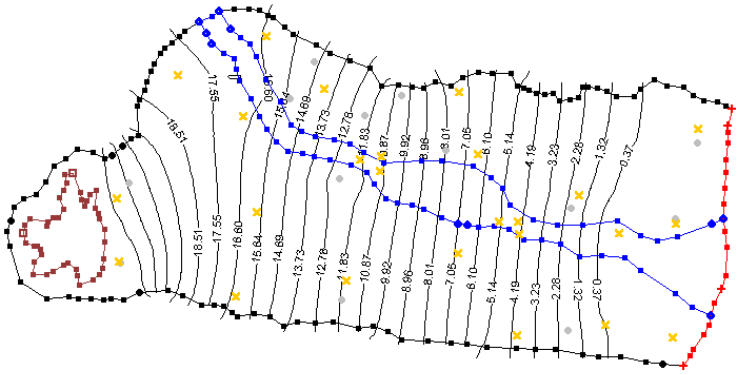

Figure 29. Numerical simulation of groundwater flow. Kumar and Elango.[355]

The allusions to other forms of sense—feeling, tension—in these account mirrors the ways in which Andrea Ballestero notes 'how vision and touch are conceptual resources that people use to describe the technicalities of satellite imagery'.[356] It requires us to think of the social lives of technologies beyond the digital and 'moving away from a narrow understanding of sensing as embodied, phenomenological practice'. There is also a strict relation to physical experience and gained knowledge:

> You cannot simply change a particular parameter like trial and error. You should know what it means to use that particular parameter, you should have some basic knowledge about your basin. I have told you about the basin, no? **Based on the field visit only you can understand the basin, and based on that understanding only you can do the model.**

This is intuitive, part of the skill of 'the modeller', and their relationship with their area of study both real and virtual. Ruban's language ('my basin') echoes Raghavan's earlier ('my rainwater')—language of care and attachment. I ask about some extreme concentrations shown on the mapping of rainfall data:

> Actually I am OK with these points, this is a concentration, this is also OK… at this [other] point, maybe the data is not good.

Nick Beech, describing ground exploration as a state mode of production, comments that workers were acting on a 'socialized process (the technical apparatus), rather than an 'unmediated', or 'natural', thing (soil)':

> [the] expert engineer, who gains understanding of a given soil through subjective experience and intuition, is replaced by a 'network' of institutions and practices, competences and knowledges that produces (or reproduces) a system of 'soils. This implies an already fragmented 'body/subject'—the individual labourer or engineer cannot possibly understand the soil mechanics of the South Bank in

[355] M. Senthil Kumar and L. Elango, 'Numerical Simulation of Groundwater Flow Regime in a Part of The Lower Palar River Basin, Southern India', in *Modelling in Hydrogeology*, ed. by L. Elango and R. Jayakumar (UNESCO-IHP, 2001), pp. 115–26.
[356] Andrea Ballestero, 'Touching with Light, or, How Texture Recasts the Sensing of Underground Water', *Science Technology and Human Values*, 2019, 1–24.

> toto, but can only contribute to an already socialized process of knowledge production. The very forms of the apparatuses—the auger boring equipment, the wax-sealed cylinders containing the soil, the mechanical trial apparatus in the laboratories—preclude individual 'judgement' on the quality of the soil, requiring a social process of production to get any meaningful result.[357]

In fact, I would like to argue that 'individual judgment' in additional to the technological apparatus of hydrological modelling, has a huge role in establishing both representations and future materialities of groundwater—partly due to the individualisation of the data network. Embodied knowledge and the presence of the modeller in the running of the model troubles such a neat progression from haptic, sensory 'testing' to a standardised, mechanical and digital processes, in this case. The modeller making own measurements, in contrast to the more 'stratified' systems of analysis common to ground exploration in soil mechanics, 'entails asking how sense is enrolled into our habits of thought and theories of materiality'.[358]

[357] Nick Beech, 'Ground Exploration: Producing Everyday Life at the South Bank, 1948-1951', in *Urban Revolution Now: Henri Lefebvre in Social Research and Architecture*, ed. by Christian Schmid, Łukasz Stanek, and Ákos Moravánszky (Farnham: Ashgate, 2014), pp. 191–205.
[358] Yusoff, 'Geologic Life: Prehistory, Climate, Futures in the Anthropocene'.

Politics of Translation

I have used this chapter to describe various ways in which sensory, material, technical and representational practices are entangled in knowing groundwater: each leaves a residue or sediment in the next. These knowledges are incomplete—in both formation and degradation. The chapter traces structures of knowledge(s) and how 'different but comparable worlds' (Strathern 2002) come into conversation. In one sense, we see that ways of knowing groundwater are not so different. Modelling foregrounds problems with scale and interchangeability: translation trouble.[359] At the same time, modelling is not a process of deriving knowledge linearly from scientific precedents, but of an experimental practice with both data and sense.[360]

There are, however, also very different politics to these material epistemologies: Kumar referred to the fact that chemicals within groundwater are identified, located, and discussed in poor neighbourhoods, but because of the ways in which they are recounted—metaphors based on embodied knowledges—and who they are recounted *by*, they can be safely ignored. Raghavan's sensory practices of knowing groundwater, his having 'calibrated' himself, are a means to make sense of groundwater in a language that can be translated into policy and monitored, by someone whose knowledge is also embodied, but which is recognised due to his status as an expert. Ruban's model is of the kind of quantitative forecasting that lead to engineering decisions and policy, but which also rely heavily on individual judgement and inference.

Stacey Alaimo, in her work on environmental activism, reflects on how different forms of knowledge and experience get taken on board (in media, or policy) and others left out, leading to her to argue for 'epistemological humility' as a mode of environmental ethics.[361] This echoes the work of Harding and Haraway on the relationship between science and politics, as well Barad's foregrounding of the intertwined nature of knowing and becoming: 'We don't obtain knowledge by standing outside the world, we know because we are of the world.' [362] Barad's term 'onto-epistem-ology' reflects the lack of separation not just of knowing/becoming, but also of the politics of such knowledge: 'the intertwining of ethics, knowing, and being'. This knowledge

[359] Anna Lowenhaupt Tsing, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins* (Princeton: Princeton University Press, 2015).
[360] Catharina Landström and Sarah J. Whatmore, 'Virtually Expert: Modes of Environmental Computer Simulation Modeling', *Science in Context*, 27.4 (2014), 579–603.
[361] Stacy Alaimo, *Exposed: Environmental Politics and Pleasures in Posthuman Times* (Minneapolis, MN: University of Minnesota Press, 2016).
[362] Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, p. 185.

does not emanate from the human but from the human-nonhuman working group (to recall Bennet's term again).

Difficulties in translation are foregrounded when accounting for the 'multisensoriality' of groundwater.[363] I had thought of this chapter as describing how groundwater moves between the two 'poles' of sensory and representational. In fact, in the trying to position modelling and other knowledge practices in terms of these binaries, the accounts reveal how the actual practices and people involved do not sit at either one. At the same time, we note the continuing experimentality of the planet, that sometimes runs away with itself, troubling the suggestion made by Jane Bennet that nonhumans do not have politics by themselves.

Groundwater is drawn into consciousness, and remade through physical and conceptual programmes, as well as by intuition and sense. In all cases, 'practices of knowing cannot fully be claimed as human practices'.[364] The movements of groundwater in and between practices of knowledge and sense, figure and ground, exceeds all the ways in which it is framed: it is not a process of the relations between people and a 'thing' but of relations that are always both provisional, excessive, and that do not translate.

[363] Sarah Pink, *Doing Sensory Ethnography* (London: SAGE Publications Ltd, 2009).
[364] Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter', p. 829.

Chapter 2: The Relational Materiality of Groundwater

Leaking, Sinking, Swelling, Cracking

On April 20 2017, multiple news outlets reported that 'huge amounts of sludge' had flooded into a Muthiah Street in the North-Chennai residential neighbourhood of Washermanpet.[365] The sludge had not been carried in like floodwaters, however, but had rather erupted, or 'bubbled forth', from the apparently stable ground. There seemed to be no clear way to describe the substance, which was not obviously industrial effluent, nor sewerage. An even, grey, cement-like and smooth material, had occupied the ground floor of several houses, early in the morning, before spreading into the street (figure 30).

Since 2015, tunnel boring machines had been worming through the strata directly beneath the street as part of the construction of the first phase of the Chennai Metro Rail network. The final section of tunnel, from Saidapet to Washermanpet, included a 3.4km rocky stretch from Chennai Central to Washermenpet at a depth of 28m.[366] This rocky stretch presented particular problems for the engineers, and geologists, directing the project: navigating through a variegated and poorly-mapped geology. Speculation suggested that additives injected onto the tunnel face to modify the plasticity, texture, and permeability of the soft ground, and mixed with disturbed soils at high pressures, had been forced into a crack in the geological strata, and erupted into a nearby

[365] Pheba Mathew and Soumya Chatterjee, 'Chennai Street Flooded with Sewage Sludge, Blamegame between Residents and Metro Officials', *The News Minute*, 2017 <https://www.thenewsminute.com/article/chennai-street-flooded-sewage-sludge-blamegame-between-residents-and-metro-officials-60668> [accessed 10 May 2019].
[366] Sunitha Sekar, 'Chennai Metro Tunnels near Completion', *The Hindu*, 5 November 2016 <https://www.thehindu.com/news/cities/chennai/Chennai-Metro-tunnels-near-completion/article16437160.ece>.

borewell—which had earlier been ordered closed [367]—eventually bubbling and spreading through the street and into houses. Advertising around this time for the metro network, which opened in 2018, promised 'fluidity, part of every passenger's daily experience'.[368]

A week earlier, following the opening of a massive sinkhole on Anna Salai , which had pulled a public bus deep into the formerly smooth pavement, further cracks were appearing in the road (figure 31). A certain entropy was apparent: the fragile and capricious nature of the ground was becoming inescapable. In total, nearly a dozen collapses and eruptions were connected to the construction of near-surface tunnels and stations by Chennai Metro Rail Limited (CMRL) between 2015 and the opening of the first underground sections in 2018. At the same time, anxious residents blamed the tunnelling for reduction in groundwater levels, at a time of severe drought and lack of water supply. [369]

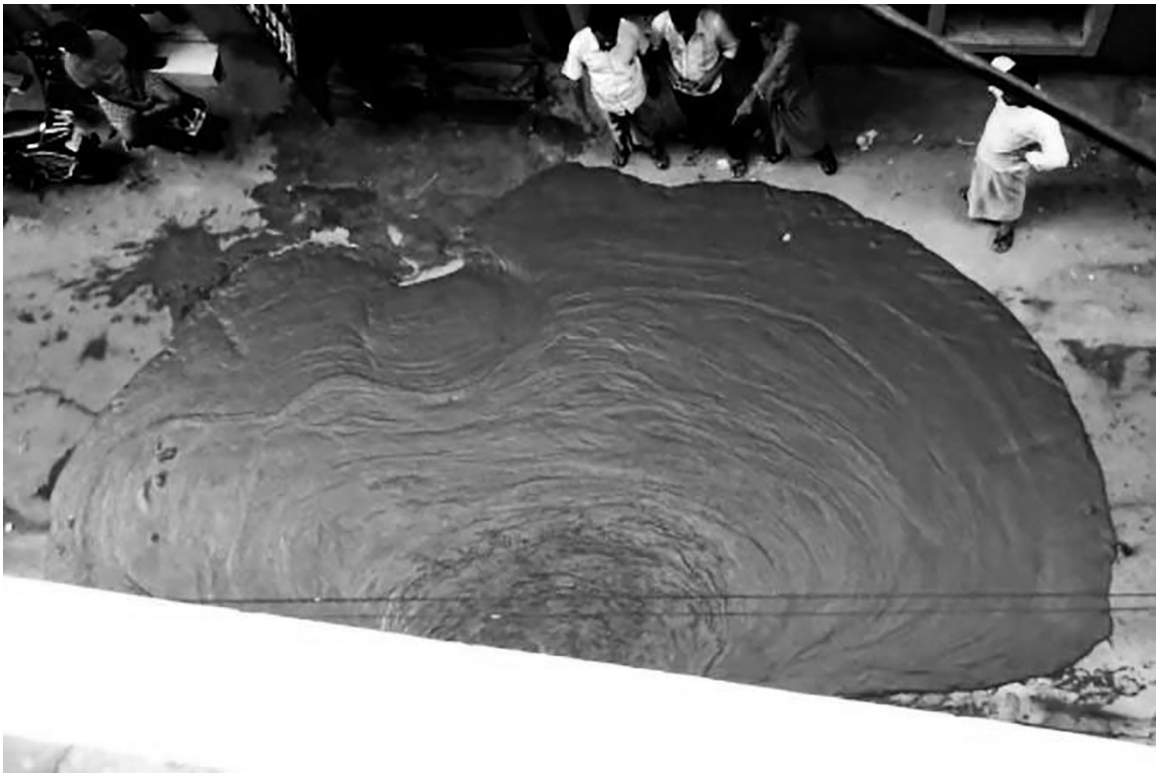

Figure 30. 'Sludge' in Washermanpet, North Chennai, April 2017. The News Minute.[370]

[367] CMRL, 'Closure Of Bore Wells Along Tunnel Alignment', 2011 <https://chennaimetrorail.org/wp-content/uploads/2015/11/pres16.pdf> [accessed 20 June 2017].
[368] CMRL, 'CMRL Video on Animated Train', 2013 <https://www.youtube.com/watch?v=Tcn05fP5tSg>.
[369] J Sam Daniel Stalin, 'Chennai Residents Blame Metro Tunnel For Groundwater Depletion', *NDTV*, 2019 <https://www.ndtv.com/tamil-nadu-news/chennai-residents-blame-metro-tunnel-for-groundwater-depletion-2035543> [accessed 10 May 2019].
[370] Mathew and Chatterjee.

Figure 31. Cracks in Anna Salai, April 2017. The News Minute.[371]

The attribution of blame (was this the fault of the engineers, the residents, the boring machine, the geological strata?) is not the direct purpose of this chapter. Instead, by concentrating on the materiality of groundwater and how it is known, I hope to offer provisional glimpses into urban processes that are highly charged and highly political: fleeting assemblages around the materiality of groundwater, which have potent political consequences. How can we use these moments as ways into knowing better how human and nonhuman forces collaborate in the making of urban space, and in its deterritorialization? Such moments of shock destabilize the material and conceptual categories that otherwise condition stable urban life, but they are also reminders of an ongoing and unseen dynamic reality that is the rule, not the exception.

During my fieldwork in Chennai I had picked up a copy of Shubangi Swarup's novel *Latitudes of Longing*, in which a character, suddenly confronted so directly with the fluid nature of the planet,

[371] 'Fresh Cracks Emerge on Anna Salai near Gemini Flyover Sparking Fears of Another Cave-In', *The News Minute*, 2017 <https://www.thenewsminute.com/article/fresh-cracks-emerge-anna-salai-near-gemini-flyover-sparking-fears-another-cave-60159> [accessed 10 May 2019].

abandons his rocking chair for a stationary one after 'he realises that the earth is as fidgety and temperamental as a senile old man', '[t]he ground that he took for granted is a superficial crust floating on top of a fluid interior'.[372] It is this realisation that I wish to explore in this chapter: that the ground on which we stand, and in which we build our cities, is capable of much more than static, passive, support: that it has the capacity to surprise and disrupt, as well as to make life possible in multiple ways. There is not one single thing called ground, but multiple grounds, variously saturated, seeping, sinking, and subtended by others. Living with these grounds is living in conditions of unstable hydrogeological emergence.

Whilst this is about the instability of the material itself, it is also about the ways in which we attempt to render chaotic agents as stable environments. I say 'render' because this process is something that occurs through the generation of representations. Groundwater both produces and is reproduced in representational and visual cultures.

Groundwater seems broadly unknowable, because of its physical invisibility. Aside from, for example, seepage meters groundwater is rarely measured directly: hydrologists rely on signs, tracers, responses, and patterns (including tidal fluctuations, and surface temperatures) that can be used to infer a behaviour or parameter.[373] As H.B.N. Hynes observed that rivers are manifestations of the landscapes they drain, groundwater is a kind of archive of urban development, but one that is reciprocal with(in) it.[374] Because groundwater is defined by continuity and contamination, and the impossibility of isolating any particular element, it is less an archive and more like a 'ruin': a congregation of matter, very clear in some places, and entirely distorted in others, which presents a 'quasi-phenomenological way of thinking past correlationism', forcing us to think past human representations of non-human things, by constantly exceeding and confounding them.[375] Groundwater yields *traces*—not records—of multiple pasts. Reading these traces is not a case of constructing through observation a logical path backwards from effect through to cause. The ways in which elements actively change within groundwater in unexpected and unpredictable ways opens up the way we must think about the material to worlds beyond the human: groundwater does not present as something to be *read*, in the way that we think of records or archives. The histories are there, but turbulent and troubled,

372 *Latitudes of Longing* (Noida, UP: HarperCollins India, 2018).
373 David Robert Lee, 'A Device for Measuring Seepage Flux in Lakes and Estuaries', *Limnology and Oceanography*, 22.1 (1977), 140–47.
374 H. B. N. Hynes, 'The Stream and Its Valley', *SIL Proceedings, 1922-2010*, 19.1 (1975), 1–15.
375 Levi R Bryant, 'Ruins and Post-Correlationist Thoughts', *Larval Subjects*, 2018 <https://larvalsubjects.wordpress.com/2018/08/10/ruins-and-post-correlationist-thought/> [accessed 28 August 2018].

limited to the way that 'the pebble left on the beach displays the form of the wave that brought it there' [376].

How do I research something with 'no clear records', and how does anyone enact this knowledge through construction in a way which recognises the variability of the material? My means of access to these processes are partial, mediated, and indirect. I read the subsurface through representations of others. Even then, the experiences of others are already highly mediated through the technologies used to extract information, their calibration, and the assumptions used in the selection of appropriate techniques and representations. Data exists only within networks of people and things, and these assumptions and positions condition the way we read the subsurface. [377] Part of the purpose of this chapter is to investigate the form of an 'archive': groundwater is not an archive, but it generates one. Groundwater is not the only material to have these qualities, nor the only area of scientific research that is confronted with problems of measurement. But the 'technical difficulties associated with sampling the underground aquatic environment' [378] combined with 'the methodological challenge that some of the most interesting anthropocene science poses to geology' [379] makes groundwater a useful case study. Keeping this in mind, I try in what follows to pursue groundwater as a *material*, albeit though its records and traces.

A Fluid Interior

In this chapter, I utilise the growing archives of information connected with the Chennai Metro Rail construction project—geological surveys, borehole logs, live construction sites, press coverage, and conversations—as a way to start to think with groundwater as a vital component of urban infrastructure. I use the word 'vital' here because I am not talking merely of an infrastructure which is about *us* (humans), but which also has relations beyond, and outside of the service of human habitation. In this way, and although much of literature around sub-surface construction particularly draws on dramatic events of failure (in certain terms), and though this is where I began, I will be emphasising the everyday processes of the construction project over these more dramatic events. This relies on newspaper reports, odd site visits, interviews, and (mostly importantly) the tender documents released by CMRL containing a wealth of drawings, geological surveys, and construction data. The argument I make is based upon this kind of

[376] Bergson, p. xx.
[377] Beauregard.
[378] Gibert, Danielopol, and Stanford.
[379] Neel Ahuja, 'The Anthropocene Debate: On the Limits of Colonial Geology', 2016 <https://ahuja.sites.ucsc.edu/2016/09/09/the-anthropocene-debate-on-the-limits-of-colonial-geology/> [accessed 19 May 2020].

'archival' research, which takes as its material the many physical holes the construction project opens up as it transects the city, but also through the ways in which engineers, geologists, and others professionals represent and understand the groundwater environment, and eventually work with(in) this material.

I have already suggested that there is not a single 'thing' called ground, and in this chapter I make particular use of the term 'groundwater' not to describe *water in the ground*, but rather a hybrid materiality of ground*s* and water*s*, establishing groundwater as a relational material. Hugo Reinert describes seawater, and it's endlessly-shifting materiality, as 'a restless substance, in continuous movement and transformation, simultaneously singular and not singular, identical and not identical with itself'.[380] Similarly, groundwater is not a simple substance but a thick and complex three-dimensional environment, an intra-active relationality between water and ground: one upon which we rely for many aspects of our own lives, but which is not there purely for our ends.

It is a further aim of this chapter to make an argument for the (under)ground in-itself as a site of enquiry, that we need to think with groundwater as an active element of cities beyond its direct utility (as in the previous chapter). In this, I follow others in arguing for the 'epistemic, physical, technical, and conceptual' importance of subterranean spaces as a site of multidisciplinary enquiry in the Anthropocene,[381] and of the particular importance, and challenges, of 'voluminous' thinking.[382] Much of the existing work in these sub-fields of environmental humanities, science and technology studies, and political ecology, focusses on extractive industries (fuels, minerals, and water) and contestations around sites of extraction,[383] or otherwise the imaginative, literary, and cultural representations of ground which are generated by new technologies of extraction and investigation.[384] For Rosalind Williams, subterranean environments, 'whether real or imaginary', are the ur-examples of predominantly human-built spaces, which 'furnish a model of an artificial environment from which nature has been effectively banished'.[385] I prefer to make an argument for the (under)ground in itself as a site of

[380] Hugo Reinert, 'On the Shore: Thinking Water at a Prospective Mining Site in Northern Norway', *Society & Natural Resources*, 29.6 (2016), 711–24 (p. 7).
[381] María de Lourdes Melo Zurita, Paul George Munro, and Donna Houston, 'Un-Earthing the Subterranean Anthropocene', *Area*, 50.3 (2018), 298–305.
[382] Bridge; Steinberg and Peters.
[383] Anthony Bebbington, 'Underground Political Ecologies: The Second Annual Lecture of the Cultural and Political Ecology Specialty Group of the Association of American Geographers', *Geoforum*, 43.6 (2012), 1152–62; Abby J. Kinchy, Roopali Phadke, and Jessica M. Smith, 'Engaging the Underground: An STS Field in Formation', *Engaging Science, Technology, and Society*, 4 (2018), 22–42.
[384] Rosalind Williams, *Notes of the Underground: An Essay on Technology, Society, and the Imagination* (Cambridge, MA: MIT Press, 1990).
[385] Williams, p. 2.

enquiry, which is to say that the ground doesn't only become relevant when we humans poke, drill, or step down into it.

Ruptures, such as that which I began this chapter with, don't offer special insights into groundwater-in-general, but they are a good place to start. Such instances are extraordinary because they are the moments that *become* records—where the materiality re-enters public consciousness. The cross-cutting of the urban terrain by drilling machines would normally go unnoticed, were it not for moments like the sludge and the sinkhole. As Adey and others put it in their reading of the 2010 Eyjafjallajökull ash cloud, 'the event revealed the fragility of a tightly coupled, complex and quite fragile network'.[386] This moment provides an example of such a 'rupture', destabilising the material and conceptual categories that otherwise condition stable urban life, and—like the 2015 floods—highlighting their fragility.[387]

[386] Peter Adey, Ben Anderson, and Luis Lobo Guerrero, 'An Ash Cloud, Airspace and Environmental Threat', *Transactions of the Institute of British Geographers*, 36.3 (2011), 338–43 (p. 338).
[387] Miles-Watson, Reinert, and Sooväli-Sepping.

The Metro Construction Project

Begun in 2007 as a joint venture between the Government of India and the Government of Tamil Nadu, the Chennai Metro Rail project uses a mix of underground tunnels and elevated sections. Construction began in 2009, with tunneling work commencing in 2012. Work on corridor 1 of the Metro was stalled for more than a year after a Russian contractor abandoned the project in May 2015, and eventually completed in 2017. Corridor 2, running westward from Chennai Central towards the business district of Anna Nagar, had been completed in late 2016 and was commissioned in May 2017. An elevated extension of corridor 1, northward towards Ennore, is under construction. Phase 2 of the Metro Rail project, currently in planning, consists of an elevated route following the 'IT Corridor' arterial road southward, as well as extensive tunneled sections.

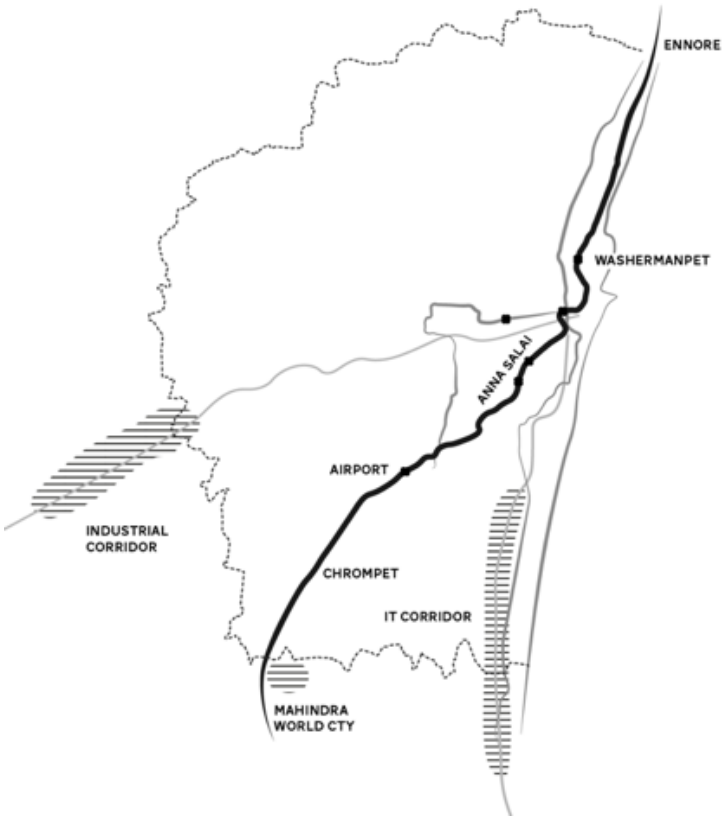

Figure 32. Metro corridor 1 (black). Drawing by the author.

This chapter proceeds by exploring groundwater in terms of three concepts—ways in which the metro construction project renders groundwater—namely *strata*, *porosity*, and *pressure*. These are concepts that bring into view the materialities of groundwater and help us think with it, both because they are ideas that groundwater helps to generate, but also that groundwater continually exceeds. These are 'deep' as opposed to 'surface' concepts—a set of *relational* modes from

groundwater which are also methodologies. Writing about the tunnelling in this way—rather than through the economics, machinery, and other processes— is 'letting surprising themes narrate the argument'.[388] I unpack ways in which the project utilises certain disciplinary concepts and methodologies in order to remake the groundwater environment as something which can be intervened in: the tension between stability of representations and instability of material forces, as well as how disciplines have tried to account – both implicitly and explicitly—for this tension. I close by drawing from this discussion a possible further set of concepts which groundwater generates—dynamic states which are common to human and material life—suggesting that a relational theory of groundwater materiality, based on leaking as opposed to bordering, might better respond to the ways in which groundwater troubles knowledge.

In giving an account of groundwater through these concepts, I will make use of material from manifold sources, knowledge traditions, and discursive conventions. There is a particular justification for taking such a hybrid and fragmentary approach, in relation to hydro-geological study. That is: the field of hydrology is itself highly fragmented. Knowledge is produced 'across the engineering-science interface', incorporating pure and applied, mathematical and descriptive work, field and laboratory studies.[389] Its authors are trained in engineering, geography, geology, chemistry, biology, and ecology. Published work is 'scattered' across manifold sites each with different conventions of structure, description, and representation.

Documents issued by CMRL, for instance, are full of representations that mix technical information with visually-derived imagery. Photographs and technical drawings are mixed in curious ways such as the overlaying of a perspectival projection of the tunnel path onto a photograph from the surface above (figure 3). Though techniques of geological investigation "abstract and dematerialise […] the vertical element of volume", these drawings somehow seek to retain the liveliness of the city surface.[390] In others, this produces a speculative assembly of different kinds of information, some experimentally derived, some projecting, and also leaves much out.

The point of the following critique is not to slur technological and scientific imaginations, or to dismiss the utility of specialised representations, but to recognize their limits and understand where they come from. In Stephen Shaviro's account of Alfred North Whitehead's approach to science and technology he reminds us that Whitehead saw representation as *indispensable*: 'we

[388] Jussi Parikka, 'Deep Times of Planetary Trouble', *Cultural Politics*, 12.3 (2016), 279–92.
[389] McDonnell and Anderson, p. v.
[390] Steinberg and Peters.

cannot live without abstractions; they alone make thought and action possible'.[391] There is nothing inherently 'bad' about these forms of knowledge production, it is vital only to know their limits, for beyond those applications is what Whitehead called 'the fallacy of misplaced concreteness'.[392]

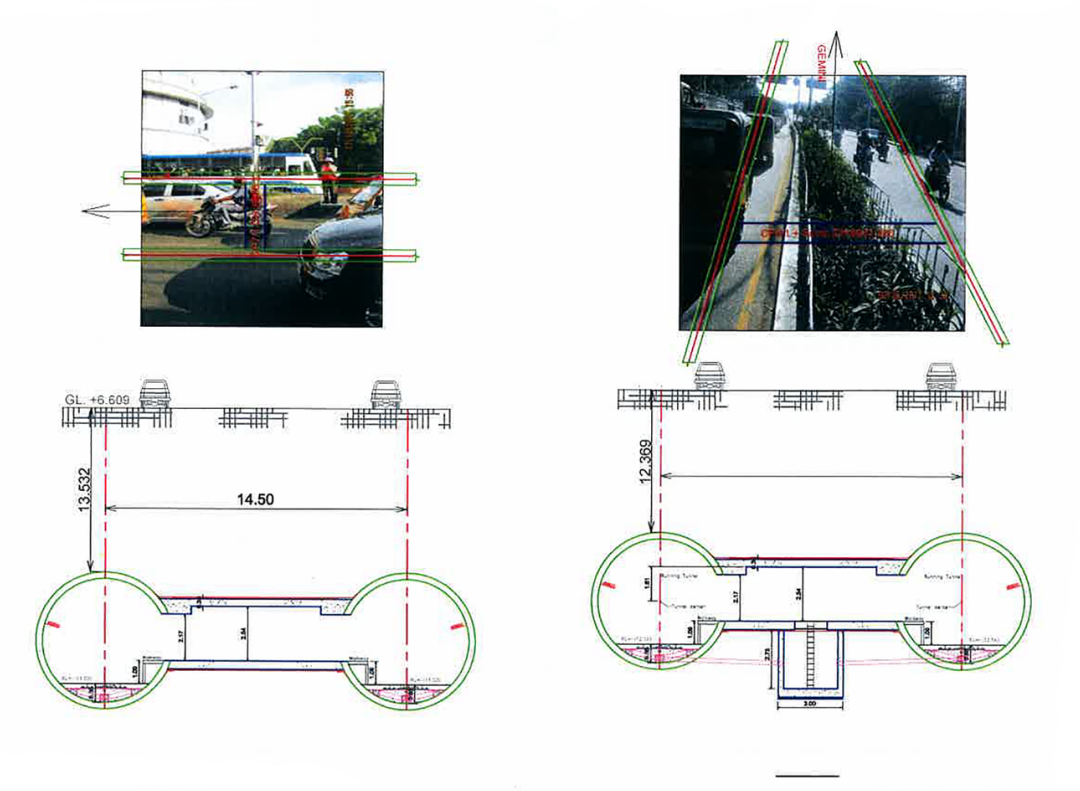

Figure 33. Representations of ground in CMRL tender documents: surface alignment. CMRL.

I will say, again, that I am not trying to give an account of *how* or *why* a certain event happened. It is the intention, rather, to inhabit a hybrid space of murky and muddled coming-togethers, to bring into the conversation a number of the multiple other kinds of productive forces. Jussi Parikka has outlined a 'cultural politics of geology' as an understanding of the two-way dynamic between media-making and wider material worlds of matter-making.[393] He quotes Seth Denizen's work on urban soils: 'geological sciences are not only called on to reconstruct the past, but also participate in the construction of the present'; 'the technoscientific practices are essentially

[391] Shaviro, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics*.
[392] Whitehead, *Science and the Modern World*, p. 52.
[393] Parikka.

involved in how a *sense* of the present is produced'.[394] Ambiguities within both media and material are to be amplified and explored—rather than eliminated. This is not a project in which I wish to exercise the authority of a professional mastery,[395] but to be 'always both more and less than the categories which name and divide us'.[396] To put it another way, I am less interested in what the metro does to groundwater, as in what groundwater does to the metro: how it becomes an intransigent collaborator in the making of the metro, but also what more groundwater potentially does (or might do) to ways of thinking about infrastructure.

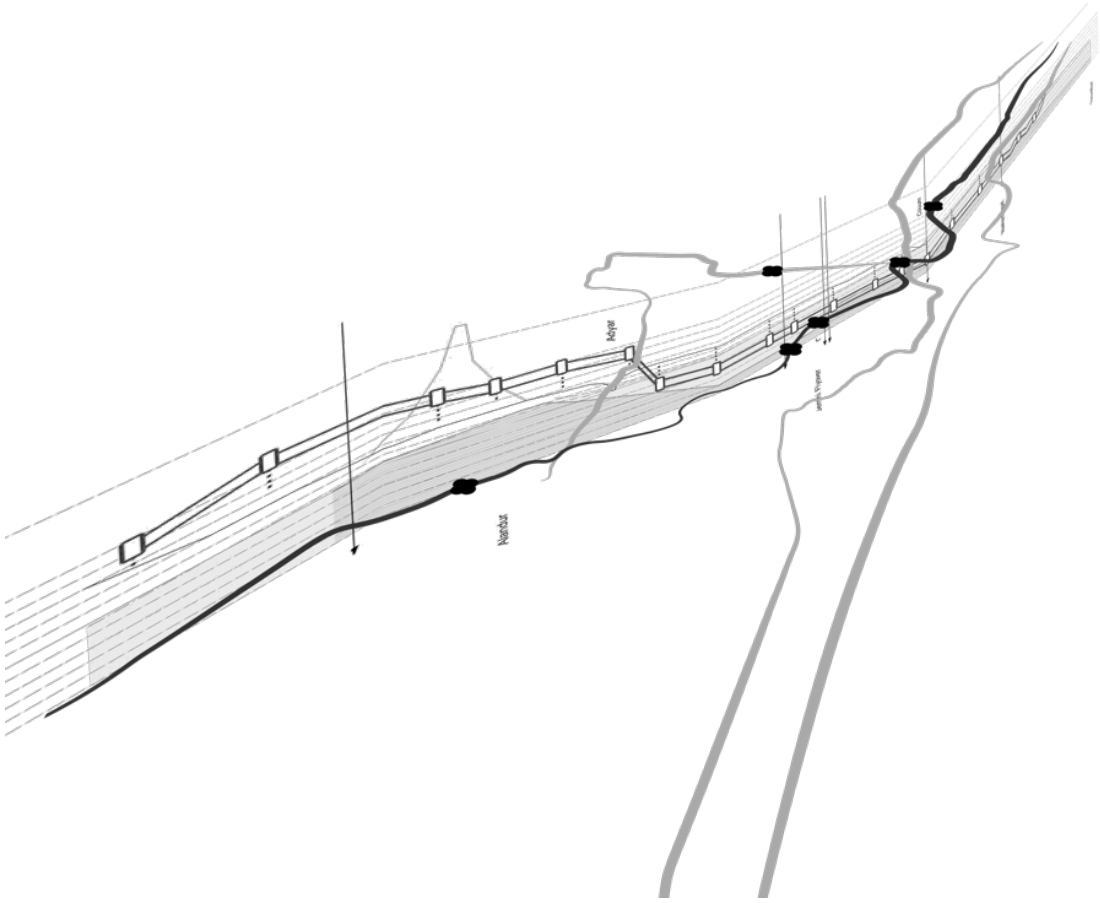

Figure 34. Chennai tunnelling transect, showing depth of tunnel and locations of surface collapses (arrows). Drawing by the author.

[394] Seth Denizen, 'Three Holes in the Geological Present', in *Architecture in the Anthropocene: Encounters Among Design, Deep Time, Science and Philosophy*, ed. by Etienne Turpin (Open Humanities Press, 2013), pp. 29–46. Emphasis added.
[395] Iain Biggs, 'Hybrid Texts and Academic Authority: The Wager in Creative Research', in *Thinking Through Art: Reflections on Art as Research*, ed. by Katy Macleod and Lin Holdridge (Abingdon: Routledge, 2006), pp. 190–200 (p. 193).
[396] Geraldine Finn, 'The Politics of Spirituality: The Spirituality of Politics', in *Shadow of Spirit: Postmodernism and Religion* (London: Routledge, 1992), p. 113.

Three Relational Concepts

Strata

Each phase of the metro construction has been preceded by detailed geotechnical survey work, which provides the bulk of the archival material for this section. Survey work for the section of corridor 1 beneath Anna Salai was done twice, in 2005 and 2009.[397] I will read these with reference to the road collapses that occurred outside Church park school on Anna Salai in March and April 2017, and another in January 2018 dear DMS. Survey work for the phase-1 extension, from Washermanet, was begun in January 2015 and is ongoing as of January 2018.[398] This will be read with reference to the eruption of 'sludge' in April 2017.

Figure 35. Geotechnical Investigations at Kolathur, Chennai, July 2018. Photograph by the author.

Stratigraphy is the science of describing and classifying rocks for the purpose of 'arranging them in the chronological order in which they were lain down on the surface of the earth'.[399] Stratification, the process, the way these materials are laid down, has always been reflected in

[397] Contract UAA-02 from AG-DMS to May Day Park. Survey work undertaken December 2005-January 2006 by RITES (depth 30 m) and September-October 2009 by Geo Foundations & Structures PVT. LTD (depth 30 m).
[398] Contract UAA-08 from Washermanpet to Korukkupet. Outline report (systra) January 2015. Detailed survey work undertaken in November-December 2016, and ongoing (IGS).
[399] Krishnan, p. 89.

modes of understanding broader societal/political dynamics. Certain laws of geology—subtension, superposition, continuity—become fundamental to thinking with strata. The physical process, the way these materials are laid down, though, has always been secondary to the system of classification. Stratification is here a means of conceptualising the composition of the ground.

Strata are less often directly viewable (as in an excavation, or a cliff) but rather 'inferred' from the boreholes collected as part of geotechnical survey work—cores of earth which provide the raw material for the stratigraphic section. The methodology of the survey work privileges, above all else, the borehole, and the core sample—a process and a physical archive, which together are used to produce a drawn record of sub-surface lithography. With this method, a boring rig sits upon 'made ground'—recycled and compacted rubble—and drives a 150mm-diameter hollow casing attached to an auger, to a depth of 30m into the ground. The drilling rig, and type of casing used, are selected according to the presumed ground conditions. Disturbed samples, direct from the drill head, are taken for use in physical tests, and 'undisturbed samples', of 450mm length and sealed with wax in 100mm-diamater tubes, are taken every 3m.[400]

The material core is instrumentalised, in order to undertake physical tests: visual lithography, and grading of samples according to weathering (in the case of rock), or grain size analysis (clay—silt—fine/medum/coarse sand—fine/coarse gravel), in the case of unconsolidated material. Lab testing included standard penetration test (SPT), shear tests (stress/strain), consolidation testing, and compressive strength testing (for rock). The hole is also utilised, for measuring permeability, and depth of water table. In more detailed surveys, chemical analyses of water extracted from the holes is also used.

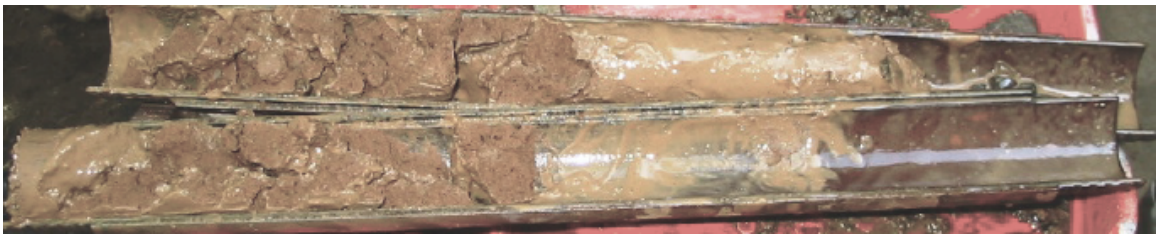

Figure 36. Disturbed soil sample. Systra/IGS.[401]

[400] Indian Geotechnical Services, *Geotechnical Investigation Report for DDC-101 - Chennai Metro Rail Project Phase-1 Extension from Washeranpet to Wimco Nagar: Proposed Underground Section* (New Delhi: Indian Geotechnical Services, 2015).
[401] Indian Geotechnical Services.

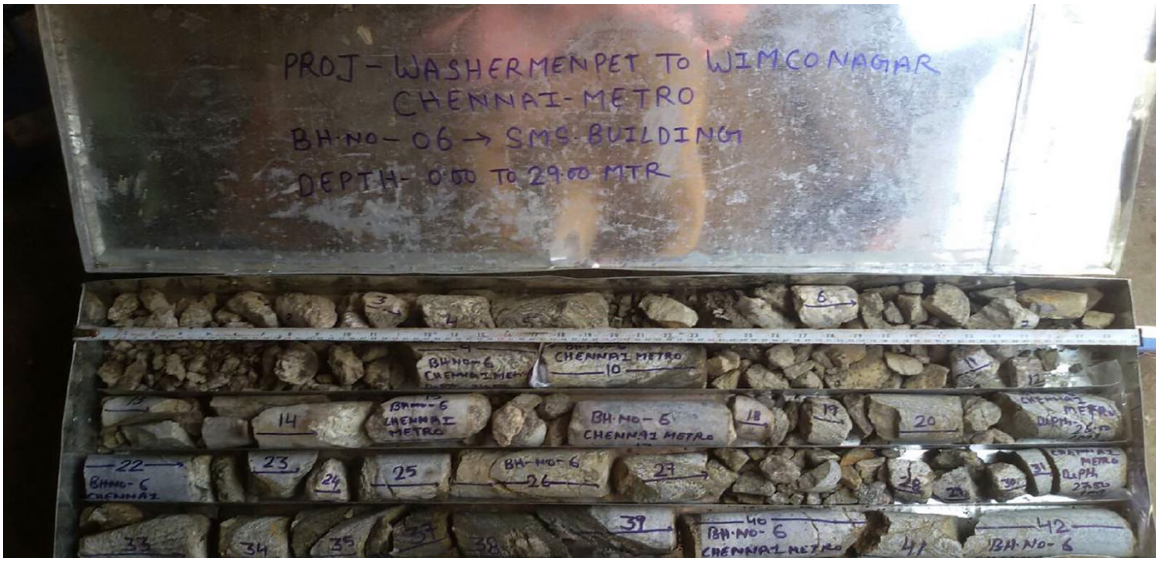

Figure 37. Box of rock core samples from Washermanpet survey. Systra/IGS.[402]

From these cores and holes, a picture of the subsurface is developed through the description and classification of strata: a way of setting boundaries by classifying matter vertically. The borehole locations are drawn and subdivided according to the agreed set of strata, then connected to form horizontal bands of material (though which often subtend and consume one another). Whilst the boundary between hard rock, and silty sand, is easier to define (though the sand may penetrate fractures in the rock), the classification of different alluvial strata requires a judgment from the surveyor to mark where a named stratum ends, and another begins. Strata must be defined. Guesswork adds to the partiality of the knowledge produced.

The translation from individual holes, to flowing horizontal strata in two-dimensions, occurs (explicitly) within the section drawing as means of communication. This is a process of 'inference', whereby a box of core samples (vertical, linear) becomes a flowing, two-dimensional section, which may eventually be turned into part of a quasi-three-dimensional diagram, or by further inference become part of a three-dimensional model—estimating (guessing) what goes on in the regions between where the samples have been taken.

Geological sections like this are speculative, they draw something unseen, and un-viewable. Both in the hidden-ness of underground structures, and in the evasive and anti-pictorial movements of the material itself. As a compromise, they draw only the solid strata, as if its saturated-ness were irrelevant. Or perhaps just too awkward to draw? Philip Scarpino recalls the inscription of extinction events in sedimentary rock, as a fossil record 'in effect serves as the 'database' or the

[402] Indian Geotechnical Services.

'archive' that documents the evolution of life on earth'.[403] Groundwater is not like a geological record. As Shannon Mattern observes: 'the climate archive (like most archives) gets wilder and dirtier the deeper you go'.[404] In the case of groundwater, the archive is sufficiently churned and bowed just below the surface, such that it is almost impossible to understand as neatly-delineated strata. There isn't really any absolute difference between rock, clay, sand, and water: these are useful distinctions to a point, but in fact we are discussing relations between clayiness, siltiness, sandiness, wateriness, rockiness etc.—their relative concentrations and absences.

Unlike the 'biorecords', the 'big and slow' data sets of sediment collections, which act as proxies for processes we cannot or do not see, groundwater does not become physical 'documents'. [405] Some dirt, such as the disturbed and undisturbed core samples, become data in (an) archive, but it hasn't taken with it the conditions from whence it came. In any case, material data are irreducible to digital data: it doesn't translate.

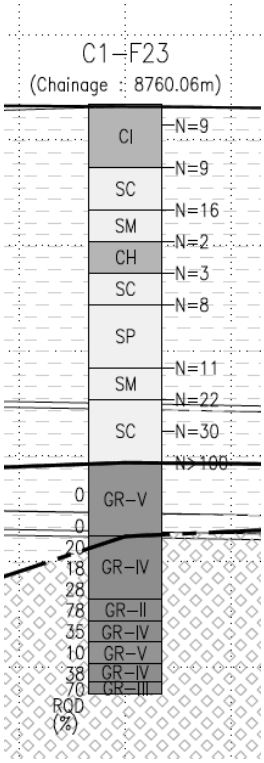

Figure 38. Borehole Log. CMRL/Systra, from UAA-08 tender pack, 2015.

[403] Philip V Scarpino, 'Anthropocene World / Anthropocene Waters: A Historical Examination of Ideas and Agency', in *Rivers of the Anthropocene*, ed. by Jason M. Kelly and others (Oakland, CA: University of California Press, 2018), pp. 101–15 (p. 15).
[404] Shannon Mattern, 'The Big Data of Ice, Rocks, Soils, and Sediments', *Places Journal*, November 2017 <https://placesjournal.org/article/the-big-data-of-ice-rocks-soils-and-sediments/> [accessed 5 December 2017].
[405] Mattern, 'The Big Data of Ice, Rocks, Soils, and Sediments'.

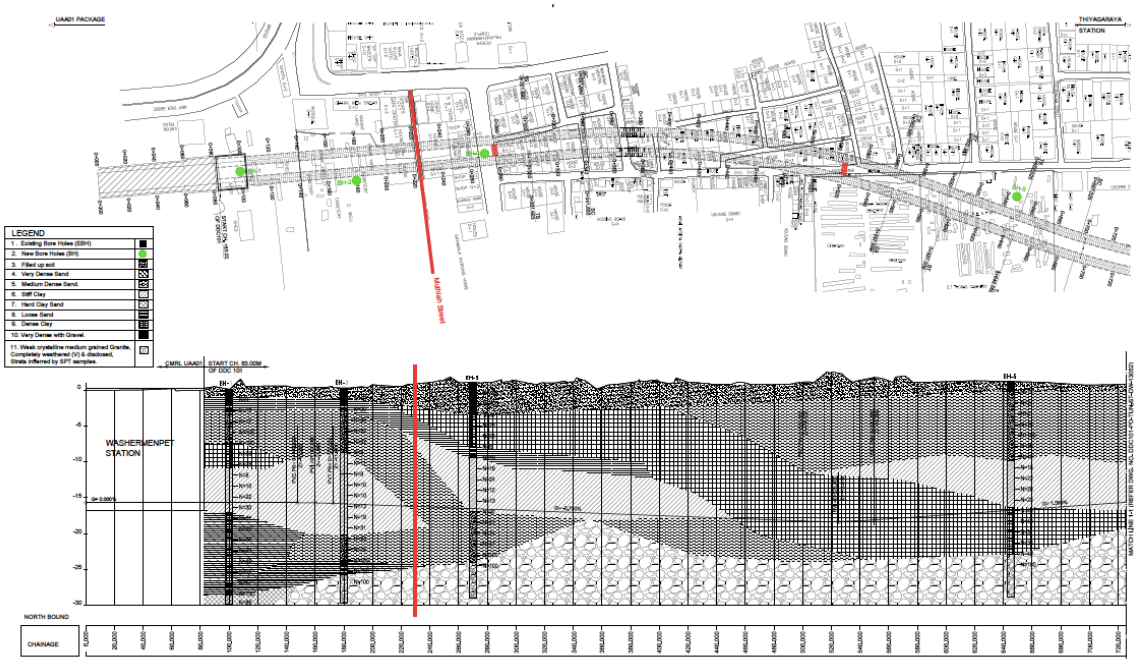

Figure 39. Detail of Washermanpet tunnel section from geotechnical surveys prior to construction, with location of the 'sludge' added (red line). CMRL/Systra, from UAA-08 tender pack, 2015.

The particular section reproduced above (figure 39), which includes the area where the eruption that began this chapter occurred, renders strata as neatly distinct from one another, distinguished by hatches relating to material classifications based on particle size (clay, silt, sand, gravel). But at the same time they seem to flow into one another. The authority of the borehole logs superimposed onto the section—its source material—is undermined by the forced, immaterial geometries the supposed strata are forced into. You could be forgiven for forgetting that such an environment has dynamic capacities because of the ways in which it is stabilised in the representation.

Several roads in Chennai are now dashed with the tripods of auger rigs, as well as the sites of construction and collapse. I visited one of these holes, two days after a collapse near DMS in January 2018. The hole had been filled, covering the shattered asphalt so that the site looked just like any other hole, dug from above rather than formed from beneath. Near-surface strata of concrete, clay, and gravel were visible, but so were the chaotics of any construction site: rubble, rebar, hoardings, tape, generators, and piles of graded materials.

Figure 40. Collapse site, Anna Salai near DMS, January 2018. Photograph (left) by the author; (right) The News Minute.

Strata and assemblages

Just as strata here is a method of composition derived from physical science, Deleuze and Guattari's concept of 'strata' is way to think both of 'assemblages', and how such formations might 'impl[y] a before, a beneath, a beyond to the human presence that draws our attention to other modes of relating'.[406] For Deleuze and Guattari, as Manuel DeLanda describes, strata are on a continuum with assemblages, assemblages being looser or less tightly held formations. Delueze and Guattari remind us that the geologic is not some static or absolute base, but as an always shifting platform, an 'inheritance', which the earth constantly flees and destratifies. But strata as fixed and reliable entities persist in both the philosophical texts and the representations above: the Chennai Metro Rail project utilises scientific knowledges and technologies in 'a new organising of the general flows of the earth'.[407] These methods are, in themselves, moments of destratification and recomposition. But groundwater escapes its geological holding structure—the drawings show only the ground, not the water, the solid (or very slowly moving), but not the more dynamic.[408] Delanda suggests doing away with the term altogether, since strata are simply more stable forms of assemblage.[409] Yusoff suggests that we recognize strata 'as planes of social production that both constrain and are expressive of relations', and which organize modes of expression: 'the relations between the material and expressive elements of strata offer a methodology for political geologic analysis that excavates the constitutive power relations that

406 Povinelli, *Geontologies: A Requiem to Late Liberalism*, p. 137.
407 Kathryn Yusoff, 'Geosocial Strata', *Theory, Culture & Society*, 34.2–3 (2017), 105–27.
408 Ballestero, 'Spongiform'.
409 Manuel DeLanda, *A Comparison of Deleuze's Assemblage Theory and the New Materialist Approach*, *Assemblage Thinking Symposium 2017, University of the Aegean*, 2017; Deleuze and Guattari.

derive from geologic forces that exceed but continue to animate the social field'.[410] Clark argues for an understanding of conditions as a layering of actions (assemblages) upon one another, each action or assemblage bequeathing 'worlds left for others to inherit', the former organising and enabling the latter as the 'condition of later existence'.[411]

What this account of groundwater problematises, though, is the rather passive and inert nature of these immaterial strata. In this account, groundwater is constantly destratifiying—not being destratified, but doing the work itself of reorganizing social-subterranean relations. What is crucial, if destratification is to be a useful concept, are the gaps (or intrastratum) between these unstable and destabilising environments, and their static representations in law and politics. Accounting for this means to describe the intra-strata assemblages: how operations traverse different strata and bring their productions into novel arrangements.

> vital components of any social form are biologic and geologic: […] every social formation is to some degree constructed through its own specific 'machinic processes' of tapping into the flows and stratifications of a complex, eventful earth [412]

We might also think here of the other possible qualities of strata. Yusoff writes that 'Geologists can only speak of geology in certain material terms. They cannot, for instance, talk of the virtual characteristics of geology: its corporeality, potentialities, contractions and future actualizations'.[413] Arguing for a 'vitalist' approach to earth science, Clark and Yusoff have laid out an argument for looking at social worlds through their relationship with particular geological forces and formations. Beginning with Clark's description of the earth as a dynamic and volatile force that exists beyond its relationship to human life, Clark and Yusoff ask us to engage with variability 'through the issue of the relationship of social existence to the forces of the earth', and to expose 'the inherited concepts of and categories of social thought […] to the forces, magnitudes, and durations with which the earth sciences work'.[414] Grounds can't be cut off from their formation (or their futures). This sense of a restless, temporal instability must also be retained. 'It makes little sense to agonise over our contributions to earth processes without as full an understanding as we can get of the dynamics and potentialities that are constitutive of material reality in and of itself'.[415]

[410] Yusoff, 'Geosocial Strata', p. 109.
[411] Clark, p. 50.
[412] Nigel Clark and Kathryn Yusoff, 'Geosocial Formations and the Anthropocene', *Theory, Culture & Society*, 34.2–3 (2017), 3–23 (p. 13), after Deleuze and Guattari.
[413] Yusoff, 'Geosocial Strata', p. 123.
[414] Clark and Yusoff.
[415] Clark, p. xiv.

Porosity

The identification of ground as distinct *strata* attempts to render it knowable, and workable: quantifying its particle, strength, and consolidation attributes produces an image of a material which is consistent and knowable, but also static and lifeless. The concept of *porosity* challenges this view, by demanding that we engage with changeability, movement, and uncertainty. As a geologist in Chennai told me, 'water is there everywhere'.[416] Water can occur within the ground because of voids, or pore spaces within materials. And 'flow occurs through the small passages of porous rocks'.[417] 'Storage' is the ratio of free space (pores/voids) to the total volume, and 'permeability' the facility with which fluids through the material.

Hydrology in the nineteenth century developed around quantifying these properties of porosity, conductivity, flow, and developing written equations to account for them. Groundwater hydrology as a science, and understanding of the surface-ground interrelation, developed out of necessity, initially during the late industrial revolution, as utilization of groundwater increased along with industrialisation, population rise, and urbanisation.[418] It became necessary to develop groundwater resources, by developing ways of knowing them.

The need to develop filtration methods in the nineteenth century directly led to the production of Darcy's Law governing flow through porous media, the foundation for quantitative analysis in groundwater hydrology.[419] So, at the inception of the discipline, it is founded as a quantitative one, and one which is concerned with mapping groundwater *as a resource*.[420] As Mary P. Anderson notes, most foundational concepts and major developments in hydrology were established during municipal surveying operation motivated by the quantification of water resources for the purpose of extraction. Although, Darcy's Law is in contrast to almost all future developments in the science, which are derived from field observations. Much later work, in fact, eschews quantitative measurement in favour of attempts to describe principles of behaviour.

Henry Darcy's work was empirical, and experimentally-derived. As part of a report to the city of Dijon on the efficacy of various methods of filtration, along with the engineer Charles Ritter, Darcy constructed an apparatus within a local hospital to hold a measurable column of sand, within a 350mm-diameter pipe, through which a flow of water could be passed.[421] Using graded

[416] L. Elango, Chennai, 25 January 2018. Interview by the author.
[417] M. King Hubbert, 'The Theory of Ground-Water Motion', *Journal of Geology*, 48 (1940), 785–944 (pp. 796–97).
[418] Robert Bowen, *Groundwater*, 2nd edn (Barking, Essex: Elsevier Applied Science Publishers Ltd., 1986), pp. 12–13.
[419] McDonnell and Anderson, p. 1.
[420] See also R. Allan Freeze and John A. Cherry, *Groundwater* (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1979).
[421] Henry Darcy, *Les Fontaines Publiques de La Ville de Dijon* (Paris: Dalmont, 1856).

sands from the Saone river, varying the pressure at the top of the column, and noting the rate of water discharge at the base of the column, Darcy and Ritter showed that 'for an identical sand, it can be assumed that the volume discharged is [directly] proportional to the head and inversely proportional to the thickness of the sand layer that the water passes through'.[422] That is, that there is a linear relationship between hydraulic head (or pressure gradient) and the rate of flow through a porous medium. The factor that relates the two is the hydraulic conductivity (porosity) of the material.

What was really important here, as later shown by Hubbert, was that the coefficient of permeability in Darcy's equation is 'a specific conductivity parameter depending on *both* the properties of the fluid *and* the medium'.[423] This means that groundwater is a relational material, indivisible into 'ground' and 'water': its properties are the result of the interactions in and between multiple parts.

Impermeable models

Despite this, the quantification of such processes remained based upon the division of ground and water: flows, which are multi-directional and unequal, were reconceptualised as two-dimensional, with secondary flows relegated as downward and upward leakage, and defined by a parameter. Hubbert, broadly considering energy transfer, defined flow as based on 'fluid potential'—a value which developed beyond simplistic understandings of flow being based on pressure, but still reductively stated that 'The flow of a fluid is a mechanical process'.[424] In Chennai, layers of water-holding materials such as sands, are confined below and between beds of clayey, less-porous materials (or 'aquitards'). In such situations, the vertical transmission of water is crucial. 'In ground-water motion in general, the direction of flow may have any inclination from vertical to horizontal'.[425]

The theory of 'leaky aquifers' is a means of thinking about these heterogenous systems, by accounting for multi-directional and unequal flows.[426] A material is defined as *isotropic* when it is equally permeable in all directions, but this is rarely the case, since groundwater also form

[422] Darcy, p. 456.
[423] Hubbert, p. 785, emphasis added.
[424] Hubbert, pp. 796–97.
[425] Hubbert, p. 794.
[426] Mahdi S. Hantush, 'Modification of the Theory of Leaky Aquifers', *Journal of Geophysical Research*, 65.11 (1960), 3713–25.

strata.[427] In order to deal with this, geologists reconceptualise secondary flows as variables to a primary chosen directionality:

> Strictly speaking, the actual flow in such systems is three-dimensional. However, with certain assumptions […], the flow can be treated as two-dimensional, augmented or diminished in the direction of flow by downward and upward leakage. [428]

The process is this: geologists first attempt to understand the zones through which this fluid is moving. After that, they apply laboratory-derived metrics to determine the expected flow rate in each zone. 'The fluid that is moving beneath the surface is controlled by a mathematical equation. After you decipher this, you simply calculate the flux of water using the equation'.[429] In order to enable such working, the ground is divided into 'cells' at different resolutions, such as 1km x 1km, or 500m x 500m (the finer resolution producing a more accurate result, but more complex calculations). 'For each small cell you need to feed in the required parameters: how much is the storage, how much is the transmission capacity.' This is difficult to assign, and requires a lot of guesswork. When this is established, though, the modeller can discern how much water would have come from any point, based on estimated rainfall and pumping data. Flow is controlled by the gradients already established by the parameters assigned to each block. 'If the water table is inclined, only then it moves. If it is flat, then there is no flow. So based on that we carry out the computation. It is actually very, very simple'.[430]

I raise this, most of all to note that the procedure employed in groundwater modelling is two-dimensional, and quantifies vertical flow only as a proportion of the total: 'it is an approximation of real-world conditions […] To reduce the complexity.' [431] Additionally, data itself is very difficult to get, and the authenticity is always questionable. So modelling is highly contingent on what is available:

> This is the problem you can see in almost every part of India, there is no proper measurement, or proper gauging […] So, when you want to do a model, you have to calibrate, and you have to validate. To validate those models, you have to know the discharge, the previous measurements, and we don't have that measurement […] My accuracy will be based on the data I am using.[432]

Data is cleaned, averaged, manipulated: the porous medium is again separated from the fluid flowing through it, in an attempt to make flows, 'manageable'. But as I am arguing, the solid

[427] The artist Shezad Dawood—whose recent work negotiates the material geographies, and cartographic histories, of ocean space—would also remind us that 'the sea has strata as much as the land does'. *EX-ART: Liquid Imaginary* symposium, University of Westminster, 20 July 2018.
[428] Hantush.
[429] L. Elango, Chennai, 25 January 2018. Interview by the author.
[430] Ibid.
[431] Ibid.
[432] Anandaruban P., Chennai, 17 July 2018. Interview by the author.

material and the fluid cannot reasonably be divided. It is currently fashionable for urban designers to describe the ground of cities as a "sponge", but this way of thinking denies its relational materiality. Just as Barad's intra-action reminds us that object and observation cannot be subtracted out, these elements are as much of each other as they are independent, and thinking with groundwater should not rely on separation.

What is lost in this 'cleaning' of data that is particular to disciplines, and epistemologies? 'Analysing a whole into parts and then attempting to model it by adding up failed to capture any property that emerged from complex interactions'.[433] The data left over reflects the priorities of the person making the records: that work 'delineates what come to matter'.[434] There are then difficulties to bringing the cleaned-up data back into conversation with dirty matter: they compete.

Pressure

Key to the development in the characterisation of groundwater as a combination of both water and ground, was Oscar Edward Meinzer of the United States Geological Survey (USGS), whose work developed the insight that aquifers are *compressible*. Meinzer developed his theory from Karl von Terzaghi's pioneering work on effective stress and consolidation—the way that particles within a material behave in relation to one another under pressure.[435]

Using the example of a train coming into a station, and leaving some time later, Meinzer demonstrated that the load on the ground above was 'squeezing water out of storage'. Under the increased load of the train, the porous material (ground) is compressed, reducing the available pore space and forcing the groundwater out of storage, resulting in increased water table and greater yield to nearby wells. When the train exits the station, the reduction in potential recharge results in land subsidence.[436] If this water is removed, then the effect of the train leaving the station later on would be for the land to subside as there was no longer the same quantity of water to hold it up. Stress is transferred from pore water to the skeletal structure of the porous material—i.e., the pore pressure, along with the structure of the material (as per Terzaghi), does

[433] DeLanda, *A Thousand Years of Nonlinear History*, p. 17.
[434] Hird and Yusoff.
[435] Oscar Edward Meinzer, 'Compressibility and Elasticity of Artesian Aquifers', *Economic Geology*, 23.3 (1928), 263–91.
[436] There are a number of contemporary examples of cities dealing with problems of subsidence, such as Mexico City and Tehran. In contrast, no one I spoke to in Chennai was concerned about subsidence: it is invisible since it is far exceeded by new construction, which typically raises the ground level by up to 3m.

the holding up of the ground surface.[437] When the pore pressure is decreased, the overall stress on the ground-water complex remains the same, and so the effective stress in the structure of the porous medium—'grain-to-grain load'—must increase. Depending on the consolidation and compressibility of the material, this may lead to subsidence. This was only conclusively documented as recently as 1969.[438] Before, it had been thought that the structure of the material operated independently of the fluid part.

This moment is transformative because it establishes an important principle: that land is not a holding vessel for water (as per the 'sponge' metaphor) but that land and water are intimately connected—that the storage and flow of groundwater are essential to the land. The combination of pore pressure, along with the structure of the material, does the holding up of the surface:

> The pore space in an artesian aquifer is filled with water that is under hydrostatic pressure. Thus the artesian water exerts a force that acts against the weight of the overlying rocks. […] There are several lines of evidence that the artesian water, especially in strata of sand or soft sandstone, supports a part of the load of the overlying rock and that the aquifers are compressed when the artesian pressure is decreased and expanded when it is increased.[439]

Unlike Darcy, whose controlled experiments pictured sand and water as separate entities, which interacted under his control, Meinzer 'had described the physics of hydraulic capacitance in hydraulic materials'.[440] Hydraulic capacitance is relational, produced within the intra-action between ground and water.

Groundwater in this description has become what it had always been in practice: a material with capacities and relations. The qualities of groundwater come out through the intra-action of ground and water. This is a crucial point: that its relationality is primary. Thinking in terms of pressure, not strata, offers an image of the ground as a squashy co-ordination of surfaces, wedges, beds: degrees of saturation, densities, and flows.

Groundwater in this view has become a material whose relationality is fundamental to its capacity as a resource that makes Chennai liveable. It is a constellation of forces in tension and compression. It becomes clear that these 'more complex hydrogeologic environments […]

[437] Joe F. Poland and George H. Davis, 'Land Subsidence Due to Withdrawal of Fluids', *Reviews in Engineering Geology*, 2 (1969), 187–268.
[438] Recounting the history of groundwater science in the US is relevant, since this professional knowledge was directly exported to India via the USGS International Water Resources Programme in the 1950s. George C. Taylor, Jr., *Historical Review of the International Water-Resources Program of the U.S. Geological Survey 1940-70* (Washington, DC: United States Government Printing Office, 1976); Acciavatti..
[439] Meinzer, 'Compressibility and Elasticity of Artesian Aquifers', p. 263.
[440] T. N. Narasimhan, 'Hydraulic Characterization of Aquifers, Reservoir Rocks, and Soils: A History of Ideas', *Water Resources Research*, 34.1 (1998), 33–46.

cannot be represented by the idealised configurations' of strata and porosity, that balance and change are both essential to their behaviour: [441]

> Groundwater is much more complex, but we are representing a few factors only. We have put some basic parameters—hydraulic conductivity, porosity—we are generalising things, you know? This is not actual representation. We cannot say what is happening inside, we are just representing, that is what I mean.[442]

Tunnelling groundwater

Pressure is a means of thinking about groundwater which is central to tunnelling: 'There is probably no engineering project that requires a more compatible marriage between geology and engineering than the construction of a tunnel.' [443] Maintaining soil pressure is increasingly difficult where the strata is inconsistent through the height of the tunnel, and 'an alternating sequence of more-permeable and less-permeable formations', as in Chennai, creates a constant inconstancy that is near impossible to predict. Unconsolidated sand and gravel deposits and permeable sedimentary strata such as sandstone and limestone create slippages, cracks between spaces:

> It is very difficult to do watertight excavations, nobody can do 100% watertight construction, there are always leaks and sediments. They have faced a lot of problems with the construction: surprises, things that were different to survey information.[444]

All the conversations I've had with engineers render water as a separate, and problematic substance, to be considered (and dealt with) apart from rather than together with 'ground'. But we have seen how groundwater as an irreducibly multiple material presence starts to come through in thinking about it as coupling, as stress. But this complexity is negated by the formats in which groundwater is modelled and quantified, formats which then provide the 'evidence' to inform the real material construction activities that take place within it.[445] Thinking through porosity and pressure shows us that the tunnels are not just being dug through ground, but through *groundwater*—such that statements like 'the primary geotechnical problem encountered during tunnel construction [is] the inflow of groundwater' no longer make sense.[446]

Though water tables are often temporarily drained to allow for construction activities to take place, no dewatering was undertaken in Chennai—due in part to the reliance of neighbouring

[441] Freeze and Cherry.
[442] Anandaruban P., Chennai, 17 July 2018. Interview by the author.
[443] Freeze and Cherry, p. 487.
[444] Architect working for CMRL, 29 June 2018. Phone call with the author.
[445] 'Coupling' is also a concept used in groundwater modelling: 'tight' coupling denotes a simultaneous process, whilst 'loose' coupling refers to interrelated but separated processes, possibly computed by separate models.
[446] Freeze and Cherry.

plots on groundwater.[447] It is striking that the dramatic ruptures in Chennai, which could make classic case-study material for hydrogeologists (as is generally the case where such dramatic faults occur), appear to be dismissed as bad construction, or 'improper work', and not worthy of study.[448]

Groundwater, like the rest of our planet, 'is capable of taking us by surprise'.[449] The footnote to a popular diagram reads 'all groundwater within the hydrological cycle should be regarded as in continuous motion, although granted, some of it moves very slowly'. We have seen how pressure interacts with porosity in simple cases in the train station example above. Because of fluid-to-solid coupling, a change in pore pressure causes a change in volume of a porous material, which is manifested as subsidence. Or, in the reverse, a change in stress within a material causes a change in pore pressure, manifested as water-level fluctuations. Groundwater responds quickly and dramatically to changes in pressure. It is doing this all the time. What is precisely so interesting about groundwater is that it can also *not* flow. The dynamic nature of the material is inherent not in its constant movement, but its ability to move *or not*.

[447] In Brooklyn during the 1930s, sewer construction drained the near-surface aquifer to the extent that seawater intrusion made the groundwater unsuitable for domestic use. The resulting cessation of groundwater pumping allowed the water table to rise again, flooding the newly constructed basements. Bowen, p. 306.
[448] L. Elango, Chennai, 25 January 2018. Interview by the author. Examples of other case studies include the Tecolate Tunnel in California, 1950-55, and the San Jacinto tunnelling of 1930s.
[449] Clark, p. xi.

Leaky Theory

> In vain we force the living into this or that one of our molds [sic]. All the molds crack. They are too narrow, above all too rigid, for what we try to put in them.'[450]

In this chapter I have followed groundwater through its interactions (with)in the processes of construction of the Chennai Metro, focussing not on particular events or sites, conceived as bounded studies, but on relational concepts which enable an understanding of groundwater as 'nothing but change'.[451] The resulting image, or multiple images, are of the ground not as a resource, a 'sponge', or a tank, but as a site of ongoing dynamic and spontaneous relatings. I read the metro construction project through the borehole logs of early geological investigations, the daily accounts of tunnelling, and the moments when material ruptured the surface. What emerges is an account of the material dynamics where groundwater erupts into and is disrupted by human agency (the city), offering the possibility to read groundwater's relational materiality through its intersections with knowledge practices, and how these material dynamics are socialised.

The escalation of concepts between the previous chapter and this one—from the abstract towards the dynamic—follows the historic development of the science of hydrology: from estimating static parameters, to analysing flows, engaging with uncertainty and the interaction of groundwater with other water bodies and materials, incorporating contaminant transport and chemical reactions, and eventually towards an ecological approach at various scales. We now understand that 'groundwaters represent the most extensive array of ecosystems on our planet'.[452]

One thing we can take from this account is the idea of leaking as an indispensable and relational aspect of groundwater, and good to think with. Leaking brings out the intra-active relationality not only of groundwater as material but also of its resistance to absolute classification. This definition is in contrast to infrastructural 'leaking', which is cast as anomaly or failure. The modelling theory of leaking renders the constant vertical movement of groundwater between geological strata as secondary and incidental—a factorable anomaly rather than something central to the behavior of the system. But what if we refocus leaking as primary, not secondary?

[450] Bergson, p. xx.
[451] Bergson, p. 2.
[452] Gibert, Danielopol, and Stanford.

> Every thing is constantly leaking ... the only way to point to something is by bordering it, but the border (embankment) isn't a border, it is a site of exchange, it is constantly being maintained [453]

Leaking is not a glitch but a process which enables things to exist. Through leaking, groundwater exceeds categorization, it reminds us that strata, porosity, and pressure are relational concepts that describe dynamic states of being. These moments—the collapse, the slurry—are characterised as failure, but they are just moments of excess, when we come to experience an unconstrained character of a material vitality. As Ingold so powerfully evokes, 'As the underbelly of things, materials may lie low but are never entirely subdued.' It is the emphasis on properties of materials over material objects that I find so important here: to focus on what they do and how they change rather than what they are. To say that matter, specifically groundwater, is always processual and relational, means it is hopeless to try and characterize it based on separation and division. Its resistance to the clarity of classification, to the status of and object, or a number of objects, is its ontological strength by which it makes its own argument for itself as a 'be-ing' not a 'th-ing'.

The project of hydrology throughout the twentieth century has been the development of written equations to account for groundwater flow (below the water table, typically towards a pumping well), and unsaturated flow (in the unsaturated layer above the water table)—gaining increasing complexity as they took into account such parameters as earth tides, gravity drainage, compressibility, and delayed response processes.[454] These techniques, as employed in the Metro Rail surveying and monitoring, were developed for specific, industrial processes: core sampling relating to fossil fuel extraction, soil analysis to agricultural production. They are ways of getting at (and intervening within) specific aspects of a complex materiality, and which are often caught out by those aspects which they neglect.

Hydrology is based on developing analytical solutions, estimates, parameters. As T.N. Narasimhan, of Madras, stated in his now-classic survey of the discipline: 'Estimation […] is a fundamental task in many branches of Earth sciences and engineering.' [455] But this is only one system of knowledge and understanding, with a particular history and motivation. Instead, paying attention to the ground as a kind of ludic infrastructure offers a way out of representation as an attempt at control, and demands that we work with not just in or on. My argument here is not about discounting certain concepts in favour of others, but refracting—to use Barad's

[453] Elizabeth Povinelli, 'The Aesthetic Mark and the Cultic Difference [Talk]', *Showroom Gallery* (London, 30 October 2017).
[454] See e.g. Shlomo P. Neuman, 'Theory of Flow in Unconfined Aquifers Considering Delayed Response of the Water Table', *Water Resources Research*, 8.4 (1972), 1031–45.
[455] Narasimhan.

term—certain codified and insufficient concepts though and alongside those which are incomplete or emergent, in order to better understand their interplay.[456]

Whilst 'knowledge projects entail the drawing of boundaries', what groundwater does, because it is so elusive, is to take away authority from all of these perspectives, these processes of pointing to something and bordering it, of performing an act of identification.[457] It questions such authoritative framings. It says that no image can be more-than-partial. In this way, infrastructural questions go (well) beyond human intentionality and return to worlds of materials and flows, again to materials as 'nothing but change'.

Groundwater is a fundamentally relational material, composed of the intra-actions between water and ground. The nature of groundwater—its unpredictability, indeterminacy, elusivity—is not a vulnerability, something which we are forced to adjust to, but fundamental to its being and also to what it gives to us. What I hope I have started to do here is to articulate an image of the grounds on which we draw and with which we live as thick, deep, and complex—sites of interaction and relation—and whose support is not unconditional. The turning of the earth, or the portion of groundwater parcelled off as 'leaking', or the cracking of strata, or the sinking of surface: these things are not faults but processes that enable the system to exist. Leaking, sinking, swelling, and cracking are all conditions of relationality, which materials like groundwater help us to know.

[456] Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning.*
[457] Barad, 'Meeting the Universe Halfway: Realism and Social Constructivism without Contradiction', p. 183.

Chapter 3: Dynamics of Contaminated Groundwater

Dispersal, Toxicity, Collaboration

On the long side wall of the central corridor of the Geology department at Anna University, notice boards are full with photocopied newspaper articles quoting members of the department, pinned alongside academic papers published by faculty and graduate students. A large number focus on incidences of industrial contamination in areas of Chennai such as Chromepet in the south-west, and Tondiarpet in the north: areas in which pollutants that appear in groundwater make apparent chemical and biological processes across multiple timescales. One of these spreads features two news articles, side by side. The first, 'Clean Up Time in Tondiarpet', offers a brief but detailed description of a process of attempted groundwater remediation by a US-based engineering company on behalf of Bharat Petroleum Corporation Limited (BPCL), following a series of leaks from nearby oil pipelines.[458] Processes of survey, sampling, monitoring, as well as physical remediation techniques are described using infographics, and photographs of equipment. There is also a timeline of events leading up to the work, and an indication of where the spillages occurred. Alongside, under the heading 'Polluted water all over north Chennai', is a summary of the wider extent of groundwater contamination that references a long-term study by Anna University geologists into groundwater quality in the neighbouring district of Royapuram, as well as quotes from campaigning residents and activists.[459]

[458] Deepa H. Ramakrishnan, 'Clean-up Time in Tondiarpet', *The Hindu*, 14 May 2015 <https://www.thehindu.com/news/cities/chennai/phase-ii-of-oil-clean-up-in-tondiarpet-commences/article7204465.ece> [accessed 30 June 2018].
[459] K. Brindha and L. Elango, 'PAHs Contamination in Groundwater from a Part of Metropolitan City, India: A Study Based on Sampling over a 10-Year Period', *Environmental Earth Sciences*, 71.12 (2014), 5113–20.

The variety and density of information in these two articles and across the related papers encapsulates something of the enmeshments of image and text, observation and understanding, sensing and acting, that are the subject of this thesis, and will be developed in this chapter through an account of contaminated groundwater. Dense and congested urban sites are not only complex geologic environments, but create significant difficulties in site investigation, and remediation.[460] Difficulties and variations in access, equipment, and process generate multiple images of an event. This in turn leads to the circulation of contradictory certainties: fixed representations produced to define—*generally*—something which is particular to a momentary assemblage, and nether static, nor able to be absolutely described. Problems of approach, sensing, and representation have something in common with the content of previous chapters, but in this chapter I discuss the non-linear dynamics not only of groundwater movement but of transformation: the ways in which groundwater is not only wholly mobile but also internally mutable. This is a key development of this chapter, in the context of this thesis, as it takes us beyond an understanding of groundwater as a dynamic but compositionally relatively stable substance, into thinking with its interior vitality and unpredictability.

Following these dynamic transformations is also a historical question, and speaks to ways in which conditions of diversity emerge over generations. The two articles above begin to indicate many interconnected stories, about pH, dissolved salts, heavy metals, and bacteria: stories of industrial effluents, municipal drains, domestic wells, and microbial groundwater communities. These stories which explicitly link historical and current urban development, provide a starting point for following contaminants into the ground. The multiple narratives in this chapter include chemicals used by tanneries in Chromepet, leachate from a dumpsite, and bacterial pathogens re-emerging during a flooding event.[461] What follows is a discussion of how knowledge is generated of contaminated groundwater—both in particular neighbourhoods, and across geographic and temporal scales—and how this is enacted, and what it *does* to the contaminated groundwater.

What does it mean to be contaminated? In the well-known phrase made famous by Mary Douglas in *Purity and Danger*, 'dirt' (and by extension Douglas's central figure of pollution, which I take as a synonym for contamination) is 'matter out of place': not 'dirt' due to some inherent property of dirt-iness but 'the by-product of a systematic ordering and classification of matter'.[462]

[460] Indumathi M. Nambi, 'Inland Petroleum Spills – Environmental Issues and Cleanup', in *Oil Spills India*, 2014.
[461] G. Gowrisankar and others, 'Data Descriptor: Chemical, Microbial and Antibiotic Susceptibility Analyses of Groundwater after a Major Flood Event in Chennai', *Nature*, 2017.
[462] Mary Douglas, *Purity and Danger: An Analysis of Concepts of Pollution and Taboo* (New York: Routledge, 1966), p. 36. It should be noted that although this phrase is often misattributed to Douglas herself, it has a much longer usage, going back to the mid-nineteenth century, as Douglas refers to.

So what do we mean by contamination? To whom? The word 'deleterious', for instance, which is well-understood by architects for its regular usage in building regulations, invokes harm or damage. Despite the OED defining this harm in non-anthropocentric terms ('to a person or thing'), what is implicit by its usage is that we are talking about harm to people, though not necessarily all people.

Max Liboiron describes the power relations implicit in the vocabulary used to define substances, for example as 'toxin' or 'toxicant': the former are produced within living cells, and disrupt regular biotic activity; the latter are synthetic, and tend to make things act in ways they were not supposed to (e.g. in the case of carcinogens, or endocrine disrupting compounds).[463] The scale, politics, and temporality of toxins are different from those of toxicants. Furthermore, the formation of 'out of place' in Douglas's work is about power (especially in culture, and morality). Liboiron, writing with Manuel Tironi and Nerea Calvilo, notes the role of toxicity as a metric for distribution of risk and maintenance of existing systemic violence:

> toxicity is produced by and reproductive of different orders of life. [W]e articulate harm as that which disrupts order and existing relations, while also showing that toxic harm also maintains systems, including those that produce inequity and sacrifice.[464]

That is, 'the contravention of an established order within a system, toxic harm can be understood as the contravention of order at one scale and the reproduction of order at another'.[465] Douglas develops her definition from William James, who defined dirt as certain 'elements' that essentially have no place, and therefore, 'from the point of view of any system which those elements make up, can only be considered so much irrelevance and accident'.[466] In this case, the primary contaminants that figure in this chapter are not there by accident: there has been no attempt to keep oil, chromium, or perchlorate out of Chennai. They have been brought into Chennai purposefully, and it is only that they have escaped their intended purpose, or are pursuing a different, deleterious, one. Their presence in drinking water, and its general permittedness—despite or through the ways in which it is measured—are also what allows tanneries to operate at a certain profit, or oil companies to pipe crude in unstable structures beneath residential neighbourhoods.

[463] Max Liboiron, 'Toxins or Toxicants? Why the Difference Matters', *Discard Studies*, 2017 <https://discardstudies.com/2017/09/11/toxins-or-toxicants-why-the-difference-matters/>.
[464] Max Liboiron, Manuel Tironi, and Nerea Calvillo, 'Toxic Politics: Acting in a Permanently Polluted World', *Social Studies of Science*, 48.3 (2018), 331–49.
[465] Liboiron, Tironi, and Calvillo.
[466] William James, 'Varieties of Religious Experience: A Study in Human Nature' (New York: Longmans, Green, and Co., 1902), p. 133.

The formation of contamination that I will pursue in this chapter, then, is not of matters being somewhere they shouldn't ('out of place') but matters *performing* in ways that they were not intended to. Groundwater here is speaks to what Anna Tsing calls 'the contaminated diversity of ecological relations', whereby life and ways of living emerge through and in relation to processes of neglect and dilapidation, ongoing disturbance and environmental destruction.[467] There is no implicit value judgement here: humans move materials, accelerating and distorting contamination processes, transplanting relationships and generating new assemblages. It is not just about what is released into the ground and later brought up, but how the ongoing vibrancy of the substance, saturated within the groundwater environment, produces something different, harmful—and how this toxicity then comes back into human bodies. The point is not to distinguish between 'natural' and 'anthropogenic' contamination (Tsing also uses 'collaboration', synonymously), but to consider how the two are interrelated, and how these processes might be fundamental to understanding groundwater in terms of 'who we are and what we have as available working partners for a liveable earth'.[468]

Contaminated practices

We can think of the decomposition of chemicals by microbes, and the movement of contaminated plumes due to hydrological conductivity, as groundwater phenomena. Rather than examine these phenomena in themselves as bounded processes that in some way or another exist in themselves, this chapter is structured around different ways of producing knowledge about contaminated groundwater that begin to account for groundwater's inherent *unboundedness*—its movements and affects beyond the subterranean. Apparatuses for producing knowledge are agential cuts through phenomena, which provide a sense of separability but do not disentangle.[469] In Barad's terms, these apparatuses are 'specific material configurations, or rather, dynamic (re)configurings of the world through which bodies are intra-actively materialised'.[470]

The apparatuses described here are primarily mapping and visualising, although I will describe ways in which they are constituted by and related to other, non-visual, sensory practices. In this, I rely heavily on existing applied research both within and without Tamil Nadu, and India as a whole. I also utilise field visits, newspaper reports, interviews, central water quality standards, baseline monitoring data of TWAD and PWD, and policy documents of Tamil Nadu Pollution

[467] Anna Lowenhaupt Tsing, 'Contaminated Diversity in "Slow Disturbance": Potential Collaborators for a Liveable Earth', in *Why Do We Value Diversity? Biocultural Diversity in a Global Context*, ed. by Gary Martin, Diana Mincyte, and Ursula Münster (Munich: Rachel Carson Centre, 2012), pp. 95–97.
[468] Tsing, 'Contaminated Diversity in "Slow Disturbance": Potential Collaborators for a Liveable Earth', p. 95.
[469] Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, p. 384.
[470] Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, p. 169.

Control Board (TNPCB). These diverse sources are employed in order to establish a wider picture of the ways in which contamination is registered and understood.

The first section looks at survey and monitoring techniques used to map and predict the movements of contaminants arising from petrochemical installations in north Chennai, and is concerned with the politics implicit within these forms of knowledge production. This is then discussed as a form of experimental practice with groundwater in order to produce data—in relation to the networks in which these studies are performed and in which knowledge is produced.

The second section is concerned with the effects of contamination as it circulates through the city, and through bodies. It engages with chemical speciation and groundwater ecology through an account of contamination arising from a cluster of tanneries in the south-west of the city, drawing on other forms of visualisation including those derived from material interactions of the chemicals themselves. I conclude by describing how transcorpoeral groundwaters disrupt scientific notions of chemical 'species', and develop both anthropological and ecological notions of 'community'.

My approach in this chapter, following specific contamination events, shares some aspects with the emerging discipline of landscape forensics, which (somewhat distinct from recent uses of the term 'forensic' in architecture) raises questions on the insufficiency of measure, necessity of speculation, and the hidden, the invisible, and the unseen.[471] Where evidence and interpretation are sometimes conflated in service of so-called truth telling, there is always a hard-to-decipher mosaic of conflicts and tensions between different actors, agents and processes. Exploring this mosaic is itself productive, and landscape forensics is engaged in thinking critically about landscape knowledge production, to 'entertain multivalency and dissonance or which encourage dialogue between conflicting viewpoints'.[472] Landscapes are not one thing but many things, and it is the relations between things that are important.

Here, then, I explore existing conceptualisations, material interactions, practices, techniques, and technologies related to the city and groundwater—with the figure of contamination initially placed as the bridge between the two. I show how and where representational and knowledge practices are situated and generated, then discuss how excesses, contradictions, etc. demonstrate

[471] Joni Palmer and Joern Langhorst, 'Landscape Forensics 2.0', in *AAG Annual Meeting* (Washington, DC, 2019) <https://aag.secure-abstracts.com/AAG Annual Meeting 2019/sessions-gallery/24395>.
[472] Zoë Crossland, 'Evidential Regimes of Forensic Archaeology', *Annual Review of Anthropology*, 42 (2013), 121–37 (p. 127).

that groundwater is excessive of, resistant to, and itself productive of new conceptualisations of it. Both sections describe the diversity of how things are made sensible, the models put into action to make this world thinkable, and how definitions of reality yield a different set of 'characters'.[473]

[473] Povinelli, *Geontologies: A Requiem to Late Liberalism*, p. 12.

Mapping and Tracing an Oil Leak in North Chennai

The North Chennai neighbourhoods of Royapuram and Tondiarpet lie to the north and east, respectively, of Washermanpet (referred to in the previous chapter). Both are affected by significant levels of groundwater contamination relating to existing and former industrial sites. Royapuram was laid out in 1799 following the colonial method of creating districts for workers of particular professions to live and work. It is situated along the coast immediately to the north of what is now George Town, for boatmen who would unload goods and cargo in the years before a harbour was built, when ships landed near the beach.[474] It is now bounded to the north by Kasimedu harbour, the centre of the local fishing industry, and to the east by the container terminal of Chennai's main port, along with its oil storage tanks. Tondiarpet, further north, was one of the existing villages amalgamated into the English settlement at the end of the seventeenth century, around the time that the local government was established.[475] It later became a desirable suburb, progressively densifying in coastal areas whilst industries clustered around the railway further inland.[476] To its immediate east, across the railway and its marshy hinterland, lies Nethaji Nagar Market, leading to the Buckingham Canal and on the other side the large Kodungaiyur dump site and sewerage treatment plant. To the north, straddling the canal, there is a significant area of large petrochemical refineries (figure 41).

The geology of this part of northern Chennai is in keeping with the rest of the city: a complex and varied coastal plain formed of Pleistocene alluvium, but with deeper bedrock than other parts of the city, and therefore a thicker zone of alluvium. Ballukraya and Ravi describe the thickness of the alluvium in northern Chennai as being up to 50 m, indicating in section that the crystalline bedrock forms a ridge that peaks roughly 5 km inland at around 15 m below ground level, falling to over 40 m below ground level nearer to the coast.[477] Above, a complex and unconsolidated formation is variously classified as sandy, silty, and clayey strata based upon particle size and plasticity. Groundwater occurs at relatively shallow depths, though deeper than much of the city and especially the other coastal regions, and flows towards the sea.[478]

[474] Susan M. Neild, 'Colonial Urbanism: The Development of Madras City in the Eighteenth and Nineteenth Centuries', *Modern Asian Studies*, 13.02 (1979), 217 (p. 228).
[475] C. S. Srinivasachari, *History of the City of Madras* (Madras: P. Varadachary & Co., 1939), p. 112.
[476] Srinivasachari, p. xlvi.
[477] Ballukraya and Ravi, 'Hydrogeology of Madras City Aquifers'.
[478] P. Oppili, 'Monsoon Ends, Level of Groundwater up in Chennai', *Times of India*, 4 January 2020 <https://timesofindia.indiatimes.com/city/chennai/monsoon-ends-level-of-groundwater-up-in-chennai/articleshow/73092749.cms> [accessed 15 July 2020].

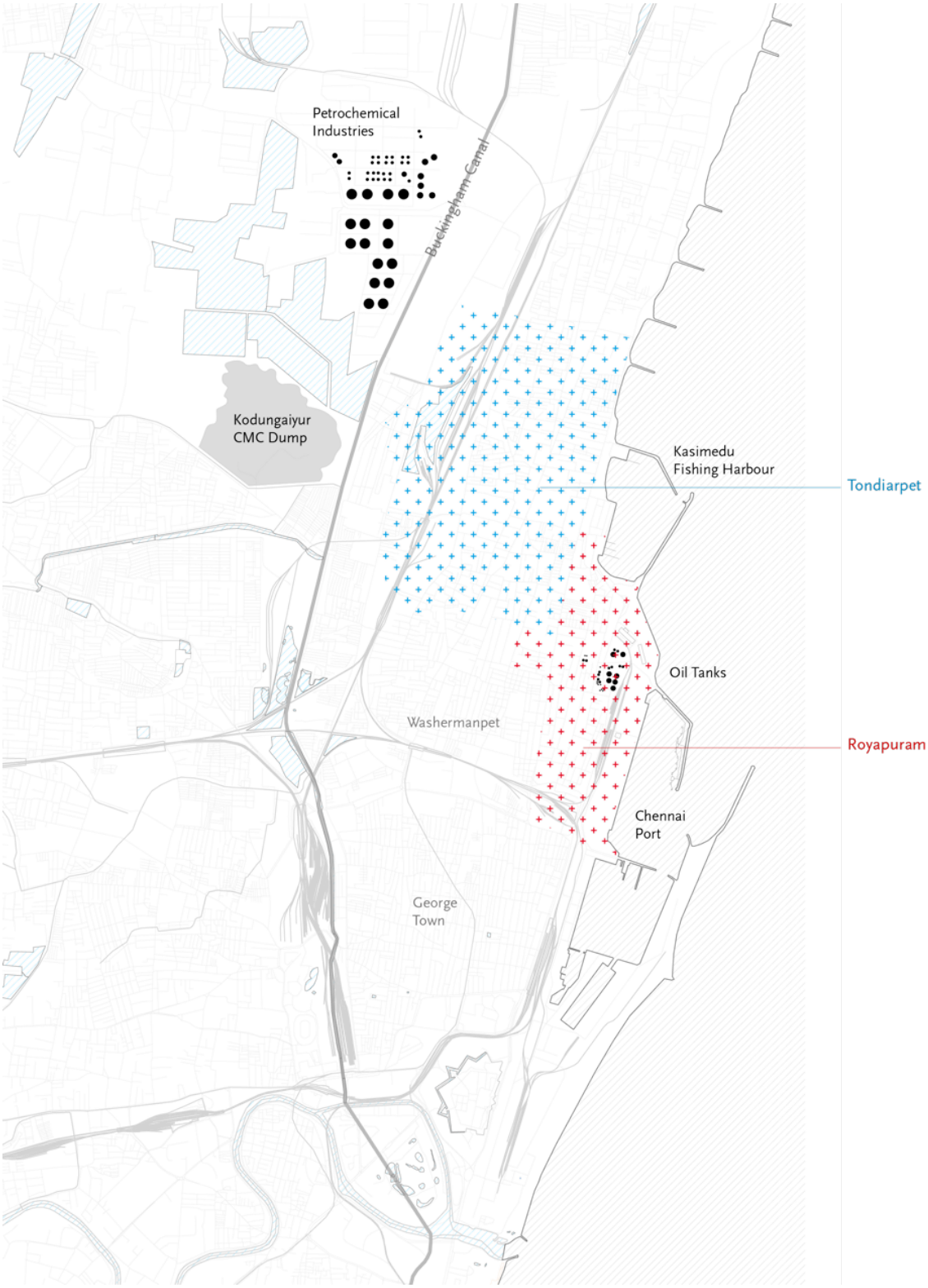

Figure 41. North Chennai Orientation. Drawing by the author.

The industries, pushed out of the densifying suburbs towards the edges of the city, left their imprint in the form of buried and redundant oil storage tanks, as well as underground pipelines connecting to the storage tanks near the port, through both neighbourhoods to the newer and larger industrial areas in the north west. During 2012 and 2013, a series of reports from residents

spoke of significant oil deposits found in groundwater pumped from domestic wells in the area. At the same time, petrochemical companies also registered a leak via a drop in pressure in their pipelines.[479] A report by the IIT Madras Environment and Water Resources Engineering division (EWRE), for TNPCB, and paid for by BPCL, identified hydrocarbons such as benzene and toluene in groundwater supplies, pointing to an underground oil leak.[480] That study would be later published in a series of academic papers, tracking the source of the contamination with a variety of sensing and modelling techniques.

Spill

In an earlier study, Brindha and Elango had inferred the location of the contaminants through sampling of polycyclic aromatic hydrocarbons (PAHs)—a group of common pollutants produced in large quantities in combustion processes common to the urban environment such as vehicle emissions, industrial processes, wood burning or tobacco smoking.[481] Hylland draws a distinction between those derived from combustion (pyrogenic) and those derived from oil (petrogenic).[482] Tobiszewski and Namie propose a method for determining the source of the contamination based on the ratios of certain PAHs.[483] PAHs are present in water, soils, sediments and plants, and pose significant hazard to human health particularly in sites where groundwater is used for domestic consumption.[484] They are dispersed by run off and circulate in the atmosphere. PAHs undergo biotransformation in humans, generating metabolites which interact with cellular DNA, and have been linked to cardiovascular disease, cancers, and reduced fetal development.[485] This is also a source of biomarkers which can be used to infer the presence of environmental pollutants from blood samples.[486]

[479] 'Experts Collect Water Samples at Tondiarpet', *The Hindu*, 26 July 2013 <https://www.thehindu.com/news/cities/chennai/experts-collect-water-samples-at-tondiarpet/article4953534.ece#>.
[480] R. Sivaraman, 'Murky Waters in Tondiarpet', *The Hindu*, 3 April 2014 <https://www.thehindu.com/news/cities/chennai/chen-infra/murky-waters-in-tondiarpet/article5864195.ece>; Indumathi M. Nambi, R. Ravikrishna, and Vijay Loganathan, *Environmental Site Assessment of Tondiarpet Oil Spill Site* (Chennai, 2014).
[481] 'PAHs Contamination in Groundwater from a Part of Metropolitan City, India: A Study Based on Sampling over a 10-Year Period'.
[482] 'Polycyclic Aromatic Hydrocarbon (PAH) Ecotoxicology in Marine Ecosystems', *Journal of Toxicology and Environmental Health, Part A*, 69.1–2 (2006), 109–23.
[483] 'PAH Diagnostic Ratios for the Identification of Pollution Emission Sources', 162 (2012), 110–19.
[484] World Health Organization, *Guidelines for Drinking-Water Quality*, Fourth Edi, 2011, p. 411.
[485] Uzochukwu Cornelius Ugochukwu and Alfred Ochonogor, 'Groundwater Contamination by Polycyclic Aromatic Hydrocarbon Due to Diesel Spill from a Telecom Base Station in a Nigerian City: Assessment of Human Health Risk Exposure', *Environmental Monitoring and Assessment*, 190.249 (2018).
[486] Leah D. Banks and others, 'Polycyclic Aromatic Hydrocarbons', in *Biomarkers in Toxicology* (Elsevier, 2014), pp. 451–58.

Brindha and Elango made use of existing bore wells, whilst a picture of the local geology was inferred from borehole logs 'from different agencies, as well as drilling companies'.[487] Samples were drawn and analysed in labs in 2001, and again in 2011, whilst domestic bore wells were observed in 2012 for their physical properties such as smell and colour.[488] Five samples, all drawn from the area around an abandoned, underground storage tank in 2001 exhibited high levels of hydrocarbons. In 2011 samples collected from the same well were tested for 16 different PAHs, and five were found. The approach to testing the groundwater was altered based on the earlier study, focussing specifically on PAHs rather than the broader category of total petroleum hydrocarbons (TPH). The authors note that there is no evidence to link the two sets of results, since different tests were performed at different periods: clearly, here too the intra-active nature of knowledge production is producing different results from different investigations. They could have arrived from different contamination events, or the latter deposits could be the traces of the former. PAHs are biodegraded by microorganisms under aerobic (i.e. dewatered) conditions: fairly rapidly in the first year and more slowly after.[489]

To develop the theoretical connections between the multiple observations of PAHs in the samples collected, and the event of the oil leak, the authors later map these locations in plan along with the physical characteristics observed from observations of open wells. The deposits are hydrophobic and form aquatic sediments, as well as giving off odours. These observations are then used to delineate with thick line those areas in which visual or olfactory senses were piqued. The resulting drawing combines the observations of different wells sampled at different times, and in different ways: lab testing for TPH, lab testing for PAH, and physical observation. The areas shaded as exhibiting smell of oil follows roughly the entire study area: the authors of the study found what they had been commissioned to find. The different types of tests, and results, are here combined in service of a hypothesis: that contamination has moved towards the east of the study zone, due in part to groundwater flow but also to the issuance of hydrocarbons into groundwater by newer tanks in that area.

[487] L. Elango, Chennai, 25 January 2018. Interview by the author.
[488] Brindha and Elango, 'PAHs Contamination in Groundwater from a Part of Metropolitan City, India: A Study Based on Sampling over a 10-Year Period', pp. 5115–16.
[489] Joop Harmsen and René P.J.J. Rietra, '25 Years Monitoring of PAHs and Petroleum Hydrocarbons Biodegradation in Soil', *Chemosphere*, 207 (2018), 229–38.

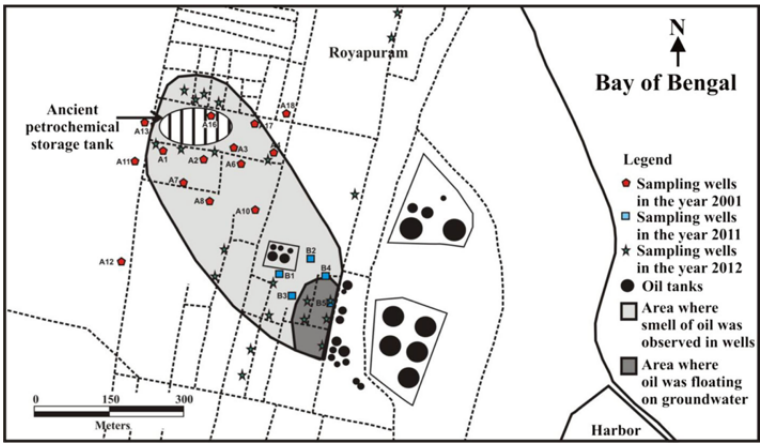

Figure 42. Tracing an oil plume above and below the surface. Brindha and Elango.[490]

The article also mingles field interviews with 'elderly residents', chosen because they might be able to provide long-term accounts of the changes in water quality. Words like 'ancient' are employed to describe a twentieth century structure, whilst the 'olden days', when groundwater quality was poor, is referred to broadly as a category of time.

The study, then, unable to reach a causal assessment of groundwater quality, darts between different techniques of assessment, both quantitively and qualitative, which get at very different aspects, indeed very different *parts* of a compound material—all in search of a view of a historic trend in a particular area. The article closes by suggesting that soil and sediment samples be examined for the presence of PAHs.[491] The illustration points to the need to make point data spatial, to hypothesise and infer, to track across time and space. But in drawing conclusions from data gathered across temporal and spatial scales, it not only freezes the groundwater flow, but compresses long-term events into a single moment, and imagines disparate events as synchronous effects.

Plume

Throughout global oil and gas industries, where leakage and spillage almost constantly release petroleum-based hydrocarbons into environments, the need for spatial assessment and forecasting is met by applying conceptual models to try and understand the transport and

[490] Brindha and Elango, 'PAHs Contamination in Groundwater from a Part of Metropolitan City, India: A Study Based on Sampling over a 10-Year Period', p. 5118.
[491] Brindha and Elango, 'PAHs Contamination in Groundwater from a Part of Metropolitan City, India: A Study Based on Sampling over a 10-Year Period', p. 5119.

attenuation of chemicals in the subsurface—a process 'fundamental to effective management of risks posed by chemicals and their possible impact on groundwater resources'.[492]

The later IIT report makes significant use of spatial inference, specifically through the conceptual model of the contaminant *plume*, in order to specify 'the area extent of the oil spread in the aquifer and soil contamination'.[493] Plume brings together three key spatial factors used to understand contaminants: *source*, *pathway*, and *receptor*. The pathway, which I will focus on here, means both the kinds of groundwater flows and aquifer characteristics discussed in previous chapters, but also the movement of chemicals within that wider transport, as determined by both the properties of the chemical itself, and the physical properties as well as other occupants (chemicals, organisms) or the groundwater environment.[494] Chemicals will move in different ways to the overall flow, as attenuation process (sorption, dispersion) are generated by combinations of chemical and geologic environments. Different chemicals will generate different attenuation processes depending upon the makeup of the groundwater environment. The modelling of chemical transport and attenuation processes, then, is a combination of these multiple properties.

In chapter one, I discussed how total dissolved solids or 'TDS' is a key measure of water quality, describing the concentration of dissolved ionic compounds based on electrical charge. Interactions within groundwater deposit such compounds, as rocks decompose under saturation. The classic conceptual model for the transport of such is illustrated below (figure 43), showing the incorporation of a dissolved plume from a contaminated site, through the unsaturated zone to the groundwater table, into the bulk flow, and towards a well where it is drawn up in.

[492] M. Rivett and others, 'Chemicals: Health Relevance, Transport and Attenuation', in *Protecting Groundwater for Health: Managing the Quality of Drinking-Water Sources*, ed. by O. Schmoll and others (London: IWA Publishing, 2006), p. 82.
[493] Sivaraman.
[494] Rivett and others, p. 83.

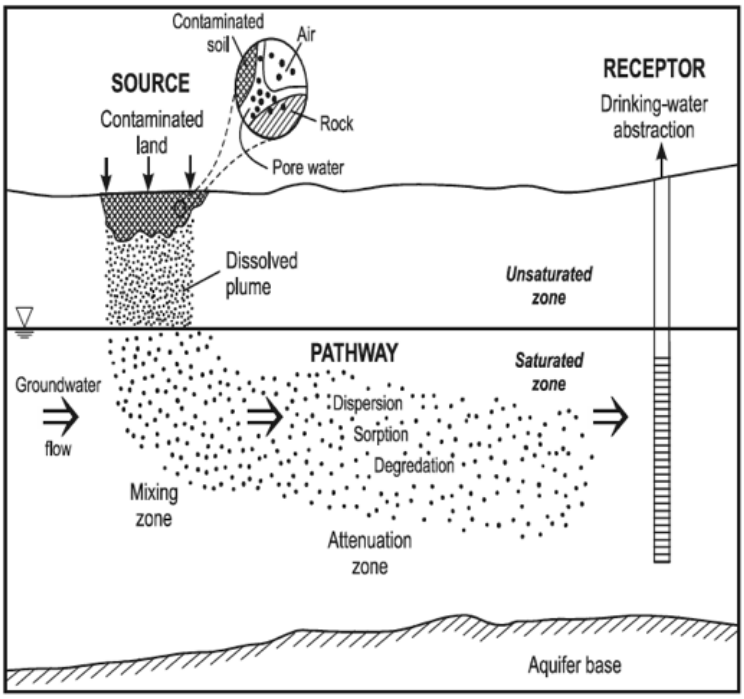

Figure 43. Dissolved contaminant transport. Rivett and others.[495]

The basic movement of chemicals in the saturated zone is referred to as advection: the movement along the same trajectory and velocity and the bulk flow. This is modified by attenuation processes such as dispersion, the mixing of the contaminant plume with uncontaminated groundwater, and is governed by hydraulic conductivity. Predicting this, then, requires a high degree of knowledge of the geologic environment, and is complicated by highly complex stratigraphic sequences. Other process such as sorption (i.e., the chemicals attaching to other material in groundwater) can slow down or retard the flow. Hydrolysis and other abiotic chemical reactions take place, transforming chemicals and/or altering their phase/state .[496]

The above model is used by Parameswari and Mudgal to describe the leaching of contaminants from a dumpsite in south Chennai.[497] However many other substances are present in groundwater, which are not dissolved, and this model does not apply to many organic contaminants, which are classed on a scale between 'hydrophilic' and 'hydrophobic'.[498] For the latter, which applies to most organic compounds, hydrogeologists consider a broad series of groundwater contaminants under the term non-aqueous phase liquid (NAPL). That is, liquids that do not dissolve in water, and which therefore form a separate liquid phase. These are

[495] Rivett and others, p. 86.
[496] 'Abiotic' meaning not involving bacteria.
[497] 'Geochemical Investigation of Groundwater Contamination in Perungudi Dumpsite, South India', *Arabian Journal of Geosciences*, 7.4 (2014), 1363–71.
[498] Rivett and others, p. 106.

categorised further as either light (LNAPL) or dense (DNAPL) indicating their density relative to water. LNAPLs float on top of the water table, whilst DNAPLs percolate through and penetrate groundwater environments as deep as porosity and permeability allow. The physical qualities of both LNAPLs and DNAPLs allow them to move and flow, whilst also ensuring they difficult to track and to image. Though they might not dissolve fully, groundwater flows will partially dissolve, and disperse the discrete liquid in the form of blobs and ganglia into large plumes.[499]

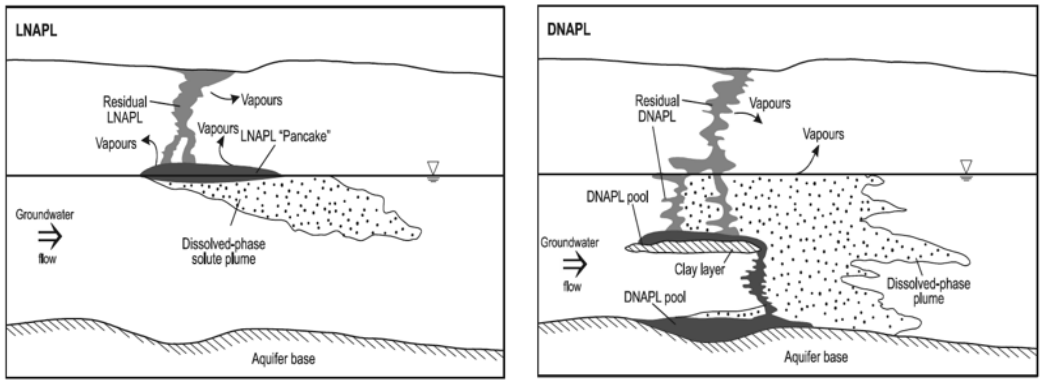

Figure 44. Conceptual models for NAPL transport. Rivett and others.[500]

The movement described in the diagrams above is one of 'invading' pore spaces under sufficient pressure to displace either air or water. Whereas a DNAPL may do so quickly,[501] PAH-based hydrocarbons may be particularly viscous and take years to migrate downwards towards a resting position.[502] The purpose of describing these terms, here, is to consider the relations they infer between oil and groundwater from the perspective of my definition of contamination. Established remediation practices such as 'pump-and-treat', where a portion of water is removed, treated, and replaced, leave behind 'discontinuous fraction[s]': blobs and ganglia in and between pore spaces which remain to be diluted in situ.[503] Because of this, theoretical and generalised studies draw on simulations to understand the rates at which different NAPL dissolve, and these results are used to understand the impact of remediation processes—how residual NAPLs in pore spaces might be dislodged—and to define clean up times. [504]

[499] B.H. Kueper and others, *An Illustrated Handbook of DNAPL Transport and Fate in the Subsurface*, R&D Publications, 2003, p. 1.
[500] Rivett and others, p. 108.
[501] James F. Pankow and John A. Cherry, *Dense Chlorinated Solvents and Other DNAPLs in Groundwater: History, Behavior, and Remediation* (Portland, Oregon: Waterloo Press, 1996).
[502] Rivett and others, p. 107.
[503] Dengen Zhou, Leslie A. Dillard, and Martin J. Blunt, 'A Physically Based Model of Dissolution of Nonaqueous Phase Liquids in the Saturated Zone', *Transport in Porous Media*, 39.2 (2000), 227–55 (p. 229).
[504] Pavithra Prakash and Indumathi M. Nambi, 'Dissolution and Contaminant Transport in Aquifers with Spatially and Temporally Variable Hydraulic Properties', *Special Topics and Reviews in Porous Media*, 3.4 (2012), 353–69.

Indumathi M. Nambi, who led the IIT report, describes the movement and spread of hydrocarbons from the 2012-13 oil leaks in a later paper.[505] The annual fluctuations of the water table, falling in summer and rising again with the retreating monsoon rains, progressively raises and drops the floating pollutant 'smearing' the zone by trapping oil in pore spaces. Existing wells were categorised using an oil-water interface meter which, when dropped into a well, identified the presence of free-phase hydrocarbons. This information was then used to map the 2-dimensional shape (in plan) of the contaminant plume, although admitting that 'one cannot completely rely on the collected data to quantify the extent of contamination and/or remediation since the depth of screening of the existing borewells is an unknown'. An additional 20 bore wells were drilled in order to provide additional samples and yield soil samples which could be tested for hydrocarbons as well as physical properties. Free oil collected from existing wells was gas chromatography mass spectrometry to reveal the type and fraction of oil in groundwater.

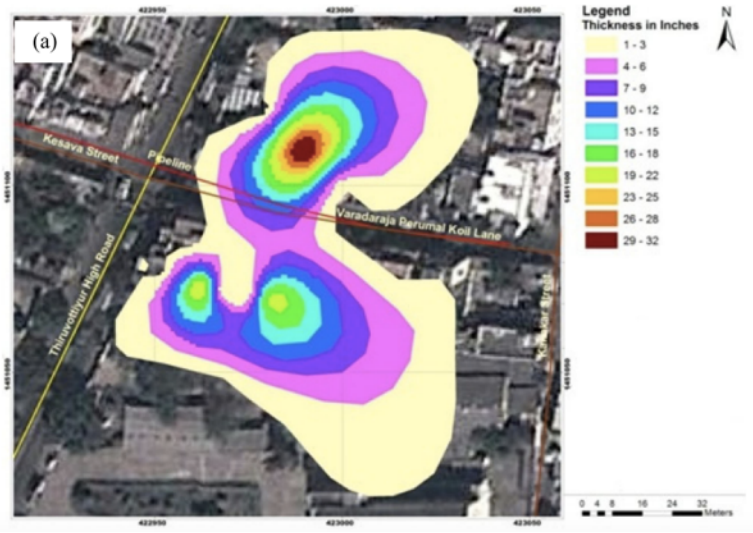

Figure 45. Contaminant plume depth map. Nambi and others.[506]

The study again shows the use of different experimental techniques on different materials to produce different forms of data to produce different illustrations and form different discrete hypotheses within the same study. What emerges though is a picture of a varied ground: oil existing in different states (perched, trapped, dissolved) and both static and moving. Only certain aspects of this varied ground are represented in the conclusions, which suggest that the plume has moved towards areas of high residential abstraction in the south and east, due to the lowering of local water table creating both hydraulic head and concentration gradient.

[505] Indumathi M. Nambi and others, 'An Assessment of Subsurface Contamination of an Urban Coastal Aquifer Due to Oil Spill', *Environmental Monitoring and Assessment*, 189.148 (2017).
[506] Nambi and others, p. 14.

By these conclusions, Nambi and her team were able to propose 'the installation of monitoring wells in the periphery of the plume to monitor the oil removal and groundwater contamination removal'.[507] This is the conceptual model re-inscribed in physical space at 1:1 through the same technology—bore well—as that from which it was inferred. The result of the investigation is therefore that the conceptual model of the plume takes physical shape through re-inscription in remediation measures: the result is a direct translation of the apparatus of sensing back into urban space.

In a paper by M. Vasudevan, Nambi, and G. Suresh Kumar, the plume is subjected to scenario-based (numerical) modelling, which used spatial forecasting mainly focussed on dissolution, but also sorption and biodegradation 'to develop a mathematical model for predicting the transport of the dissolved plume along the predominant direction of groundwater flow at a fuel spill site by incorporating the spatial and temporal variation in spilled fuel composition' i.e. the fate of chemicals under mass-transfer conditions, for the purpose of understanding how they might be removed from groundwater.[508] Given that transport is governed by 'a complex combination of aquifer properties, NAPL properties, and other macro-scale features such as released volume of NAPL, local pumping effects and lithology', the authors claim that 'site- specific mathematical models are necessary for investigating the dissolution and transport of NAPL compounds'.[509] The authors note from field observations that significant amounts of mass have reached the saturated zone, and thus are involved in flow processes. In an illustration, the plume as described by numerical modelling (figure 46) has a very different shape from the area drawn in plan by using observational data. The plume is again superimposed onto a satellite photo, although this time as an oblique angle rather than directly overhead. Its centre broadly correlates with that of figure 45, but concentrations or depths are not described, and its spatial extents are significantly different.

[507] Sivaraman.
[508] M. Vasudevan, Indumathi M. Nambi, and G. Suresh Kumar, 'Scenario-Based Modelling of Mass Transfer Mechanisms at a Petroleum Contaminated Field Site-Numerical Implications', *Journal of Environmental Management*, 175 (2016), 9–19.
[509] Vasudevan, Nambi, and Suresh Kumar, p. 9.

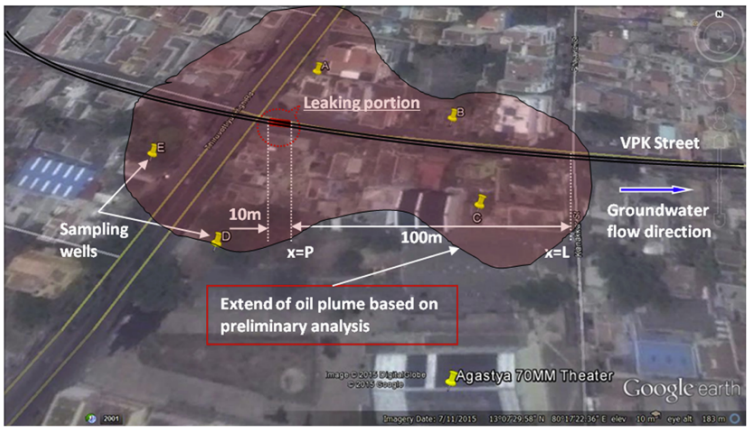

Figure 46. The plume as described by numerical modelling. Vaduvesan, Nambi, and Suresh Kumar.[510]

The drawing combines both a hesitant sense of the extents of the oil plume, and a degree of uncertainty about what it means to be either inside or outside (the semi-opaque fill, and its loose geometry), along with a confident, clear delineation of its extents (the hard line at its edge). One thing this does—like the technique of representing contaminant levels with isopleth contour maps (e.g. figure 47), which define zones of equal concentration of a certain pollutant—is rely on measurable sameness. Much like a stratified section defining multiple conditions as 'silt' or 'sand', the drawing relies on the equivalence of statements about a particular condition (in this case, the presence of certain PAHs), and the ability to define areas as the same by using a line to link the same measurements taken from borehole data. And like the examples of flow nets in the previous chapter, only certain physical properties of groundwater are represented.[511] The contaminant plume is at once something derived from the physical parameters of groundwater discussed in previous chapters—porosity, flow rate, variability of conditions (stratification), obstructions that affect the ability of the plume to disperse, etc—and a conceptual tool used to abstract groundwater not in the sense of extract, but to strip it of materiality. Despite the homogenising implication of contours, the groundwater environment remains heterogenous, despite how measures such as 'geochemical urban footprint index' seek to 'sum up' such diversity into a singular neat measure.[512]

[510] Vasudevan, Nambi, and Suresh Kumar, p. 11.
[511] Zekâi Şen, *Practical and Applied Hydrology* (Amsterdam: Elsevier, 2015), p. 51.
[512] Sukkampatti Palanisamy Saravanan and others, 'Geochemical Footprint of Megacities on River Sediments: A Case Study of the Fourth Most Populous Area in India, Chennai', *Minerals*, 9.11 (2019).

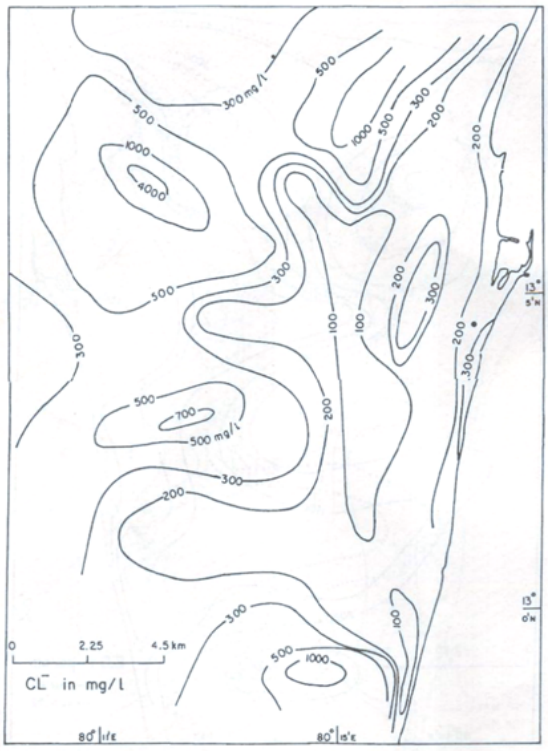

Figure 47. Concentration of chloride ions in groundwater samples represented by isopleth contours at the scale of the city. Ballukraya and Ravi.[513]

Intervention

In *An Ecology of Knowledges*, Micha Rahder offers a Baradian description, that 'knowing is always about intervening, in multiple ways': knowledge-making practices and more-than-human landscapes are 'mutually transformative', as acts of observation leave new traces on the observed.[514] In the pursuit of absolute, fixed and certain understanding of what a landscape is (in order to change it) the observing subject must already transform it in order to know it—at once undercutting idea of generalised knowledge and fusing a particular moment of discovery to its time and setting.

Observation is transformative, but that there is also far more going on than that which we observe: the variety of transformations exceed the variety of observations, and it is only our representations of the materials that are limited. Susan Schuppli uses the term 'failure to appear' to describe how, just as in the case of a defendant failing to appear before a court, the earth's evidence is incomplete. The imaging of a radioactive forest by gamma camera draws into presence the radioactivity of the forest and in so doing the 'camera *makes* the forest radioactive':

513 Ballukraya and Ravi, 'Hydrogeology of Madras City Aquifers', p. 94.
514 Micha Rahder, *An Ecology of Knowledges: Fear, Love, and Technoscience in Guatemalan Forest Conservation* (Durham, NC: Duke University Press, 2020), p. 3.

that is, the trace is not reflective of something past, but of something within.[515] The trace draws this presence into the venerated realm of the visible, from somewhere only sensible to technological prosthetics. The image comes to stand as record of an ongoing event, in place of its material provisionality.

Anna Tsing has elaborated this question of the dual nature of material as comprising both objects of analysis and the nature that surrounds us, suggesting that 'the provocative issue before was representation; now it is animation'.[516] In apprehending (or animating) groundwater contamination, the experimental nature of knowledge practices comes to the fore due to the impossibility of apprehending certain aspects without transforming them (e.g. in chemical experiments). This is a stubbornly literal version of a well-established thesis that to observe is to re-produce, and furthermore that our understanding is limited to ideas about groundwater which are a combination of the material and the experimental subject.

But Barad asks, 'What compels the belief that we have a direct access to cultural representations and their content that we lack toward the things represented?'.[517] I have discussed at length the correlative bond between thought and thing, without applying the same to representation. Signification requires prior knowledge, such that signification works differently based on who is the receiver. This diversity of interpretation becomes vital in the production of knowledge, as shown in histories of the complex ways in which scientific eyes trained on South Asia have evolved theoretical concepts through collaboration between colonial and local scientists, travel between locations, and resulting cartographies.[518]

What I mean by describing the plume as an abstract and conceptual tool, is that for all its positive authority, the plume is also about of conditions of not knowing. The knowledge produced is inconclusive, brought about by the intra-active nature of groundwater and modes of access. Groundwater contamination is mapped through inference and speculation, and generalised conceptual models are put into action in order to make specific predictions thinkable (of present as well as future). Such models and tools are designed to achieve specific purposes.

[515] Susan Schuppli, *Material Witness: Media, Forensics, Evidence* (Cambridge, MA: MIT Press, 2020), p. 257.
[516] Anna Lowenhaupt Tsing, 'When the Things We Study Respond to Each Other: Tools for Unpacking "The Material"', in *Anthropos and the Material*, ed. by Penny Harvey, Christian Krohn-Hansen, and Knut G. Nustad (Durham, NC: Duke University Press, 2019), pp. 221–44 (p. 221).
[517] 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter', p. 801.
[518] Sunil Amrith, *Unruly Waters: How Mountain Rivers and Monsoons Have Shaped South Asia's History* (London: Allen Lane, 2018); Alan E Leviton and Michele L Aldrich, 'The Impact of Travels on Scientific Knowledge : William Thomas Blanford , Henry Francis Blanford , and the Geological Survey of India , 1851-1889', 55.9 (2004), 117–37; Beth Cullen and Christina Leigh Geros, 'Constructing the Monsoon: Colonial Meteorological Cartography , 1844-1944', *History of Meteorology*, 9 (2020).

In this case, forcing an oil company to clean up a spill, designing a programme of remediation, etc., rely on measurable elements and the relations between measures, less so the physical relations between elements. The intense specificity of their conclusions obscure and dematerialise the boundaries between 'contaminated' and whatever sits outside. Each of these instances is a form of historical reporting based on projections of point data, which also project and inform future scenarios.[519]

The question that follows, then, is: what is at stake in defining the spill in this way? Or in the work required to making something like the plume appear? Certain forms of accounting for or modelling contaminants are mobilised in speaking to certain narratives. The IIT report was very successful in achieving political results: where the 'polluter' BPCL had previously denied any connection to the spill, the tracing of the plume centred on a point (in both tracings) under which a BCPL pipeline passed forced the connection. BCPL were ordered by the court to pay large sums to TNPCB both in compensation and to fund remediation measures stipulated in the report, which were begun in 2016, as well as to provide free potable water to residents. Recently, the National Green Tribunal ordered additional costs to be paid after the remediation was determined not to be complete.

> Tondiarpet was one place where we went and did investigations. Now, because it went to the court and became a serious issue, now the industry is cleaning up. So that is one thing where we were instrumental, the report made a difference. It was taken to the court, and I am happy that there is something which happened because of our effort.[520]

The report made the following recommendations:

> 1. Installing monitoring wells in the core area of the plume and in the periphery of the plume to monitor the oil removal and ground water contamination removal.
>
> 2. Removal of free product through a combination of proven techniques such as dual phase pumping surfactant enhanced removal.
>
> 3. Removal of trapped oil from the vadose zone through proven techniques such as soil vapour extraction and airsparging
>
> 4. Insitu treatment of contaminated groundwater in saturated zone by chemical or biological methods.

US-based Stratus Environmental were contracted for the remediation, removing the oil through soil vapour extraction systems, air sparging wells and devices placed in open wells. Remediation required co-ordinating with CMRL, as the northern metro extension passed through Tondiarpet,

[519] S.V. Krishna Chaitanya, 'Tondiarpet Oil Leak: BPCL Told to Pay Another Rs 3 Lakh in Damages', *New Indian Express*, 24 February 2019 <https://www.newindianexpress.com/states/tamil-nadu/2019/feb/24/tondiarpet-oil-leak-bpcl-told-to-pay-another-3l-in-damages-1942864.html>.
[520] Indumathi M. Nambi, Chennai, 23 January 2018. Interview by the author.

with excavations and site compounds preventing additional remediation wells being dug in certain places, and cutting off surface pipelines used to remove waste.

What is groundwater in the context of the report and its results? What is sensed, who is it important to? There are residents outside of the zone of the plume whose water is also contaminated. They know this through sensory practices as well as the information they receive from these very reports, written up in news media. But the extents are different, and not bounded. Groundwater contamination is clearly visible to people who inhabit this area: whilst the oil refineries themselves use flare towers to disappear their waste gases upwards into the atmosphere, Tondiarpet residents have collected oil from open drains for use in the home, oil that saturates the zone that is relied upon for daily water needs.

Thom Davies describes the 'optics of slow violence', borrowing Phaedra Carmen Pezzulo's description that 'witnessing also exceeds the visual' in order to describe the range of ways (multisensorially and across timescales) in which toxic geographies are registered by populations who actually live with them.[521] Pezzulo's use of the term 'witnessing' here refers to a 'social and engaged' act, 'a mode of political subjectivity [that] entails both responsibility and risk, watching and acting'.[522] In this sense, witnessing also raises the possibility of not seeing or registering something, or of deliberately looking away.

Scientific testing relies upon the scientist knowing what they are looking for, but residents, 'they know all about ammonia, sulphur dioxide and dust not from textbooks, but just by breathing the air'.[523] These are pressing and popular subjects, not just the news and in conversation, but also Tamil film and TV.[524] But it is also true that the extent of the danger can be overstated, especially in the shallow aquifer: 'The fear of contamination of water has been fed upon like the drug industry feeds on your fears of sickness and illness'.[525]

Networks of Experimental Knowledge

In order to start to answer questions about the implications and politics of fragmented knowledge, we need to consider the complex network of governmental and other agencies

[521] Thom Davies, 'Slow Violence and Toxic Geographies: "Out of Sight" to Whom?', *Environment and Planning C: Politics and Space*, 2019; Phaedra Carmen Pezzulo, *Toxic Tourism: Rhetorics of Pollution, Travel, and Environmental Justice* (Tuscaloosa: University of Alabama Press, 2007), p. 147.
[522] Pezzulo, p. 146.
[523] Nityanand Jayaraman, 'Unfit for Habitation: Life in Chennai's Industrial Badlands', *Carboncopy*, 2020 <https://carboncopy.info/unfit-for-habitation-living-amid-chennais-industrial-badlands/> [accessed 6 January 2021].
[524] See e.g. *Kodi*, dir. by R.S. Durai Senthilkumar (2016)
[525] Santha Sheela Nair, Besant Nagar, Chennai, 7 July 2018. Interview by the author.

working on groundwater in Chennai and the wider region, in relation to networks of knowledge of contaminated groundwater, and how these affects the kinds of knowledge produced. In the previous chapter, I discussed the significance of inference in translating between experimentally derived material and written data (e.g., boreholes and borehole logs), and objects of knowledge (e.g., the geological section), as well as how the people I interviewed made absolutely clear the partial nature of the knowledge they are producing. The agency of drawings in the world is not just of the drawing itself but the whole world that this knowledge was produced in. They are representations that emerge from particular practices, assemblages and contexts of knowledge production, and the ways in which these drawing function as evidence is also not a characteristic only of themselves but of these networks. 'Any "read" of "what happened" is never just located in material evidence alone, but also comes from the ways in which interpretations of that evidence are situated within interdependent relationships.' [526]

Three main agencies are dealing with groundwater in Chennai. At the state level, firstly, the Public Works Departments (PWD) are responsible for managing water bodies and irrigation systems including dams, tanks, and canals, primarily for agriculture. The water resources department of the PWD contains a specialist groundwater unit which has a network of monitoring wells outside Chennai city. Secondly, TWAD is a branch of the Department of Municipal Administration and Water Supply and is responsible for water supply and sewerage. Thirdly, at the municipal-level, Metrowater, which manages the main reservoirs and supply networks within the city area, have a network of observation wells, and are responsible for the register of private wells, rainwater harvesting, and desalination plants. The Indian government's groundwater authority, the Central Ground Water Board (CGWB) also have offices in the state, with their own set of monitoring wells known as national hydrograph stations,[527] and produce their own assessments which feed into national reports.[528] CGWB are responsible for the production of specialist technologies such as in the National Project on Aquifer Management mapping programme.

In conversation, Nambi points to the 'gaps' in this structure, and the ways in which collaboration is often precluded by institutional structures.: it is the norm, for instance, for each agency to produce their own distinct set of data, using their own engineers and monitoring wells. Additionally, 'most of the decisions are taken within themselves, I don't think they even interact

[526] Palmer and Langhorst.
[527] K.R. Sivaraman and S. Thillaigovindarajan, *Micro-Level Status Report of Chennai River Basin* (New Delhi), p. 115; Balakrishnan.
[528] See e.g. Balakrishnan.

between departments. […] they don't periodically meet with each other and make plans' outside of an annual presentation of reports which also involves academics.[529] None of these agencies are especially focussed on water quality, only supply:

> they just look at water as a resource, nobody looks at contamination per se. If they find that one of their wells is not meeting the standard, they just abandon that well and find an alternative source. So, nobody really wonders about where the contamination came from or can we remediate the groundwater.[530]

The responsibility for water *quality* responsibility lies with the TNPCB, established in order to enforce the Water (Prevention and Control of Pollution) Act (1974), but whose energies are largely committed to regulating large-scale effluent discharge from industries, and 'so they don't really have the time and manpower to take care of water quality issues in the groundwater or even surface water'.[531]

So, these authorities are mostly considering groundwater as a resource, and less interested in its properties: 'a big gap in this country'.[532] This contrasts with the ways in which people describe groundwater colloquially, which are highly sensitive to quality and composition, and to how scientists think about groundwater, which is in respect of measurable aspects of those properties. Engineers at the EWRE consult on behalf of the TNPCB, investigating and reporting on pockets of serious contamination that they call 'hotspots', such as around the Pallikaranai dumpsite, and in relation to the Tondiarpet pipeline leaks. These reports are not predictions but try to identify a source of contamination and propose clean up strategies. The EWRE report was instrumental in forcing the industries to clean up in Tondiarpet, but 'reports don't mean much unless there is public pressure'.[533] Importantly, such studies aren't commissioned or funded by the TNPCB, but undertaken on the initiative of individual researchers and funded by industry, presented to court as independent reports.[534] This means that whilst some places get reported, and overlapping research is done, others are largely undocumented in this way: 'many places are not reported, because people have been drinking it, and it gets diluted, and nobody's documenting it, and some of these things, you can't always detect them'. [535] Auyero and Swistun describe the 'labours of confusion' produced by different interconnected actors.[536] Whether

[529] Indumathi M. Nambi, Chennai, 23 January 2018. Interview by the author.
[530] Ibid.
[531] Ibid.
[532] Ibid.
[533] Ibid.
[534] Ibid.
[535] Ibid.
[536] Javier Auyero and Debora Swistun, 'Confused Because Exposed: Towards an Ethnography of Environmental Suffering', *Ethnography*, 8.2 (2007), 123–44.

intentional or not, this supports a regime of power that works through obfuscation. Contamination exists in different states at different times, and is recognised in different ways, and these regimes of obfuscation enable processes of contamination to continue both below and above ground.

Making Experimental Data

Since data exist within different agencies, inaccessible, researchers in Chennai are forced to go 'out' and make their own data specific to individual studies. Whilst some make use of existing wells as monitoring points,[537] others drill their own wells (depending on funding) in order to get 'the most exact data'.[538] Owners of existing wells which are borrowed for the studies may not know how deep their wells are, how they are constructed, or the underlying stratigraphy. They may cut through multiple aquifers and aquitards. Drilling new wells also offers a means to understand the geology better at the same time, since there may not be reliable surveys accessible to researchers. A fine level of understanding of geological structure is crucial in order to perform such modelling exercises on contaminant plumes as discussed in the previous section, and this is one reason they are so unreliable in complex settings. And drilling a new well produces a core, which can be sampled for pollutants.

This process describes how (all) knowledge is material and (all) research is intra-active: thinking through things demands a 'concrete operation' to perform it, 'testing, not judging'.[539] These questions do not refer only to established criteria but to 'an immanent process requiring the action of something which has the power to dissolve'.[540] That is, all interlocuters within the research process, human or otherwise, are being transformed by its action. It is explicitly apparent in this work on contamination detection that groundwater requires its own and other material transformations to come into view, whether by the pumping of water from an already constructed site, or the mixing with other chemicals in a taxonomic experiment. Thought has to be taken in, experimented with, and put into action. Experimentation here describes a constant re-making of knowledge—'a practical assemblage, a "mechanism" of statements and visibilities'—as something which is in Whitehead's term 'unsafe'. [541] Groundwater does not exist in *forms* but as it *acts*. Barad's notion of the 'real' says that:

[537] L. Elango, Chennai, 25 January 2018. Interview by the author.
[538] Indumathi M. Nambi, Chennai, 23 January 2018. Interview by the author.
[539] Stengers, 'Thinking with Deleuze and Whitehead: A Double Test', p. 28.
[540] Stengers, 'Thinking with Deleuze and Whitehead: A Double Test', p. 29.
[541] Deleuze, *Foucault*, p. 51.

> That which exists is that which we can use to intervene in the world to affect something else: electrons are counted as real because they are effective experimental tools, not because they have been 'found'.[542]

Meaning that the real is not something that can be pointed to, isolated, defined, bounded, but rather that which *does* something, and which can perform as part of a productive community of occasions. In this sense, its own material solidity or persistence is secondary to its active potential, its normativity second to its mutability.

Materially engaged research then becomes essential for ways of thinking with rather than ways of knowing. Representational practices are important stages in this: they include the self-conscious or unselfconscious descriptive/interpretive processes.[543] Experimental images require physical, transformative processes to occur in order to make them: substances are detected by physical tests, cannot be seen without being transformed. In turn, as Keller suggests of earthquake studies, such representations not only communicate but are fundamental to the generation of scientific theories.[544]

So, in this account, knowledge is not a thing that exists within insulated traditions of knowing: it is continually re-produced through interactions and encounters (human, multi-species, non-human) and cannot be discovered as if from the outside. 'It is dynamic and complex, often linked to biophysical and social processes.'.[545] Experimental knowledge is *made*: it is not fixed, possessed by a select few. Thinking in this way might serve to challenge the Foucauldian bond between power and knowledge, or the idea that power—or the powerful—reproduces its / their own forms of knowledge-as-truth. Certainly, 'power produces knowledge', and any body of knowledge is produced within a regime of power.[546] But it does not do so alone. This does not entirely overturn or undercut the bond, but merely complicates the nature of knowledge production by expanding the locations and actors involved, at the same time as weakening universality.

In these examples, we see also how researchers are following not only a singular substance that is invisible, but its combination and recombination with other substances. In many cases, these combinations are essential to its ability to be observed. Testing for specific ions in a solution works through the prompting of a known chemical reaction and observing the output of that

[542] Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, p. 41.
[543] Barad, 'Meeting the Universe Halfway: Realism and Social Constructivism without Contradiction', p. 174.
[544] Keller.
[545] Julie Cruikshank, *Do Glaciers Listen? Local Knowledge, Colonial Encounters, & Social Imagination* (Vancouver, BC: UBC Press, 2005).
[546] Michel Foucault, *Discipline and Punish* (London: Pantheon, 1977), pp. 27–28.

reaction. The ion itself is not observed. A certain kind of material-transformative process is required, and the process or its output is observed, drawing certain conclusions about the presence of substances within a material. Acts of breaking down, and of recombination, then become something common to both groundwater itself and to knowledge-making practices used to make sense of groundwater.

At the same time, knowledge disappears because it has no impact:

> that is also reported by people, a lot of research has gone on, a lot of data is there. They are still deliberating on how to clean up, there's a long-drawn case going on.[547]

This emphasis on the importance of experimental engagements with particular sites (whether physical or simulation) presents a very different form of knowing from the generalised rules described in the previous chapter. Forms of sensing and mapping groundwater contaminants, require specific forms of material experimentation in order to gather—or to create—data. The diversity of scientific practices and diversity of forms of contamination are inextricably linked: different things appear with different intra-actions. Just as soils, groundwater, is not composed (in an additive sense) but comes from the deconstruction of matter as well as its layering. That experimental knowledge needs to be constantly produced, in fragmented networks, undermines the idea of absolute forms of knowing, and has both a progressive and precarious potential. As Stengers writes, 'the sciences are not, by destiny, the allies of power, but they are, by definition, vulnerable to all those who can contribute to the creation of differences, the stabilization of interests, the disqualification of annoying questions'.[548]

[547] Nambi. Interview by author.
[548] Stengers, *The Invention of Modern Science*, p. 125.

Contaminant Ecologies and Embodied Knowledges

Figure 48. 'A resident of Sri Perumal Nagar, Old Pallavaram, showing a bottle of water drawn from the well in his house.' Photograph by K.V. Srinivasan.[549]

A 2004 article in *The Hindu* is illustrated with a photograph of a resident of Old Pallavaram, at the south-western fringe of Chennai city, holding up a bottle of water drawn from the well in his house.[550] The bottle is in focus, as is the man who looks straight into the camera. A number of other men in the background also look into the camera but are blurry, and much of the frame is obscured by the even, near-opaque turbidity of the water in the bottle—an indicator of suspended solids. The accompanying article speaks of this and other waters via familiar domestic methods of detecting contamination: 'white deposits [form] on the surface of the groundwater

[549] Saptarshi Bhattacharya, 'Pallavaram Colony Residents Complain of Water Contamination', *The Hindu*, 21 May 2004.
[550] Bhattacharya.

when it is boiled', milk curdles when it is used for tea, 'soaps do not froth', and rashes appear on skin after washing.

The appearance of the water in this photograph is something similar to Schuppli's reading of the images produced of Fukushima by the Toshiba Gamma Camera: it both reveals and obscures the presence of the contaminant(s), by broadly alerting the viewer to the presence of a threat whilst obfuscating detail. What we are seeing is not what the article is about. The elevated level of salts attributable to industrial contamination—such as sulphates and chlorides, which cause water to be 'hard' or brackish—are not be visible in this way. Indeed, that they must be identified by physical traces in boiling, and the reactions with soap, and skin, suggests something which cannot be visually determined. Industrial contamination of groundwater in Pallavaram and neighbouring Chromepet is far deeper and more complex, and the apparent or immediate might be obscuring the more intricate and protracted.

This is not only a question of the visual, or of the practices of sensing and mapping I discussed in the first section, but of transformation, and embodied intra-actions. Contamination here is not just about the presence of something, but of the dynamic processes that change a substance from something safe into something harmful: what enters the ground is different from what comes back out. This section works through forms of chemical speciation, biologic encounters, human embodiments, and material co-transformations that are provisional assemblages where physical and biotic processes intermingle in groundwater, across spatial and temporal scales, above and below the surface. In a development of the previous account, I focus here on the effects of contamination as it circulates through the city, *and* through bodies. The photograph, in my reading, suggests approaching the visual not as evidence in itself but as a link to other forms of knowledge.

Tracing Contaminant Flows in an Industrial Suburb

It's not hard to find Chennai's tanning industries above ground. The area of Chromepet, at the south-western fringe of the city, past the airport and bisected by the Grand Southern Trunk (GST) road, is named after the method of processing hides pioneered by George Alexander Chambers' Chrome Leather Company which established here—a site that was described as possessing 'a good elevation, and with excellent water',[551] at that time 12km outside the city—in 1913.[552] His factory was to pioneer the process of treating hides with chromium sulphate—a

[551] V. Sriram, 'Lost Landmarks of Chennai #39', *Madras Musings*, 2018 <http://www.madrasmusings.com/vol-28-no-14/lost-landmarks-of-chennai-39/#> [accessed 10 March 2020].
[552] 'Pettai' in Tamil meaning suburb. Chrome + Pettai = Chromepet.

much faster process than traditional vegetable tanning, which also produced softer, stretchy leather. In July 2018 I walked from the station, across the GST road and immediately came to C.L.C Works Road—named after the company whose sign still hangs on the one remaining slender colonial block.

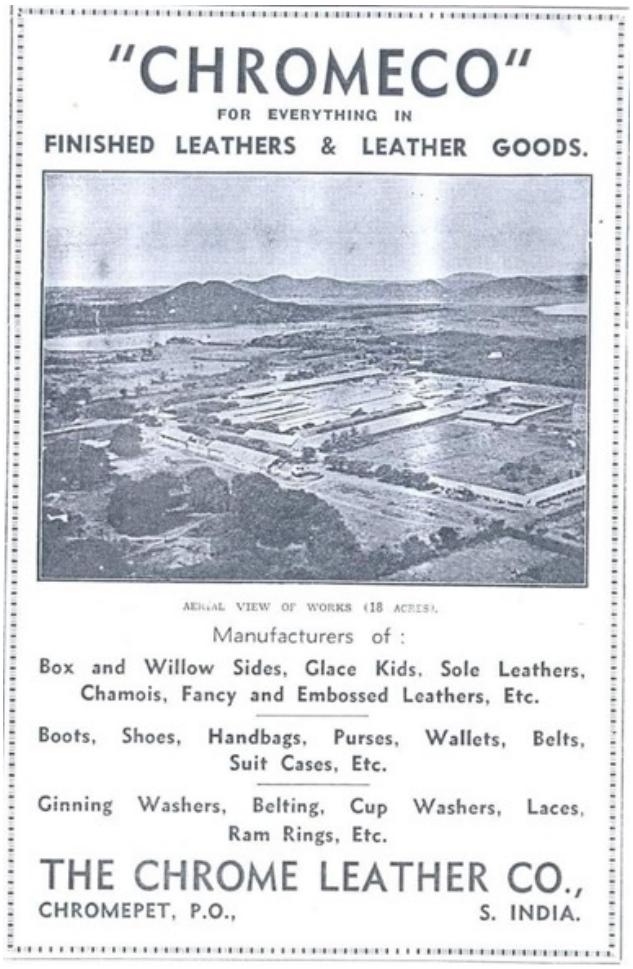

Figure 49. 'An advertisement of the Chrome Leather Works, dating to 1936'.[553]

[553] Sriram.

Figure 50. 'The Chrome Leather Co. Ltd.', Chromepet, 2018. Photograph by the author.

I crossed Light Leather Road and Adam Tannery Street, encountering a number of small-scale tanneries on my way towards Pammal, where the modern leather industries are now concentrated, and where an effluent treatment plant was established in 1995 in order to deal with the problem of untreated industrial effluent from the cluster of around two-hundred tanneries rendering the area's groundwater unusable.[554] That the legacy of this part of Chennai is inscribed in its streets is a clue to the other forms of inscription happening below ground. The enmity of the tannery sites escalates as the small-scale industries morph into larger complexes, shut behind high concrete walls and metal gates. Some, such as VRS Leathers—headquartered on Anna Salai and with the slogan 'Transparency and Integrity to Customers'—bear a notice board on the guard's booth displaying data on use of hazardous chemicals and quantities of hazardous waste generated by the plant. Down one side-street connecting the industrial zone back to the residential streets via a furniture factory, a group of young men were burning rubbish. It sounds dramatically self-important to say that I was warned about coming to this area, but an academic

[554] A. Sahasranaman and K. V. Emmanuel, *Common Effluent Treatment Plant: Pallavaram, Chennai, India*, 2001.

friend had told me that when his team take measurements here, they do so carefully. He advised me, if questioned, not to tell what I was looking at: 'don't mention groundwater, say it is social geography or something like that'.[555] The combination of the walls and the notice board suggests an aspiration to control how the place is seen.

Competition from British companies in the 1930s, and the promotion of chrome tanning to Indian industrialists in the mid-1900s, blunted the CLC's dominance, and by the time Chambers died in 1937 the company was in decline although he had extracted great wealth from it. The land became significantly more valuable as in the 1980s Chromepet was developing as a residential area, and a substantial population began to fill the area. In 1993 the CLC works site was sold off and the land redeveloped. The one remaining block (figure 50.) now hides a large hospital and medical college, which sits in the former factory grounds and receives, amongst others, many workers still affected by conditions brought on by direct exposure to chemicals used in tanneries.[556] Groundwater in this area is not suitable for drinking as it contains elevated concentration of most major ions and chromium. Several contemporary studies attribute this to the recharge of partially-treated effluent discharged by tanning industries into open drains.[557]

The area currently receives no piped supply from the main metropolitan water supplies. Unlike most of central and northern Chennai, the piped supply in Chromepet and Pallavaram is from the regional Palar Drinking Water Scheme (PDWS) operated by TWAD.[558] As the retention capacity of the Palar basin decreases due to sand mining, the water table is reduced by private extraction, and illegal connections along the pipeline reduce the supply, residents say they are receiving water only once every 10-14 days.[559] This water has also been subject to contamination along the way including sewerage ingress.[560] Although CMWSSB are working on extending the supply of water from Chembarambakkam to this area, as of July 2020 this was not complete, meaning that even during periods of very high storage levels in Chennai's municipal lakes, such

[555] Personal communication.
[556] V. Padma and others, 'Occupational Health Hazards among the Workers in Leather Tanneries near Chromepet', *Biomedicine (India)*, 36.4 (2016), 109–12.
[557] Brindha and Elango, 'Impact of Tanning Industries on Groundwater Quality near a Metropolitan City in India'.
[558] T.S.Atul Swaminathan, 'Residents of Chromepet, Surrounding Areas Complain of Erratic Water Supply', *The Hindu*, 25 July 2020 <https://www.thehindu.com/news/cities/chennai/residents-of-chromepet-surrounding-areas-complain-of-erratic-water-supply/article32192438.ece>.
[559] 'Falling Palar Water Table Sparks Concern', *The Hindu*, 26 March 2013 <https://www.thehindu.com/news/cities/chennai/falling-palar-water-table-sparks-concern/article4548317.ece>.
[560] 'Parts of Chromepet Get Contaminated Water', *The Hindu*, 16 July 2019 <https://www.thehindu.com/news/cities/chennai/parts-of-chromepet-get-contaminated-water/article28455470.ece>.

as in early 2020, these areas have still not had a consistent supply.[561] Local water bodies such as Periya Eri ('big lake'—also known as Pallavaram lake) have historically been encroached by building and dumpsites, and polluted by sewerage.[562] In the past few years, restoration work including biomining and clearance of dumpsites, desilting, and construction of bunds and walking paths has taken place.

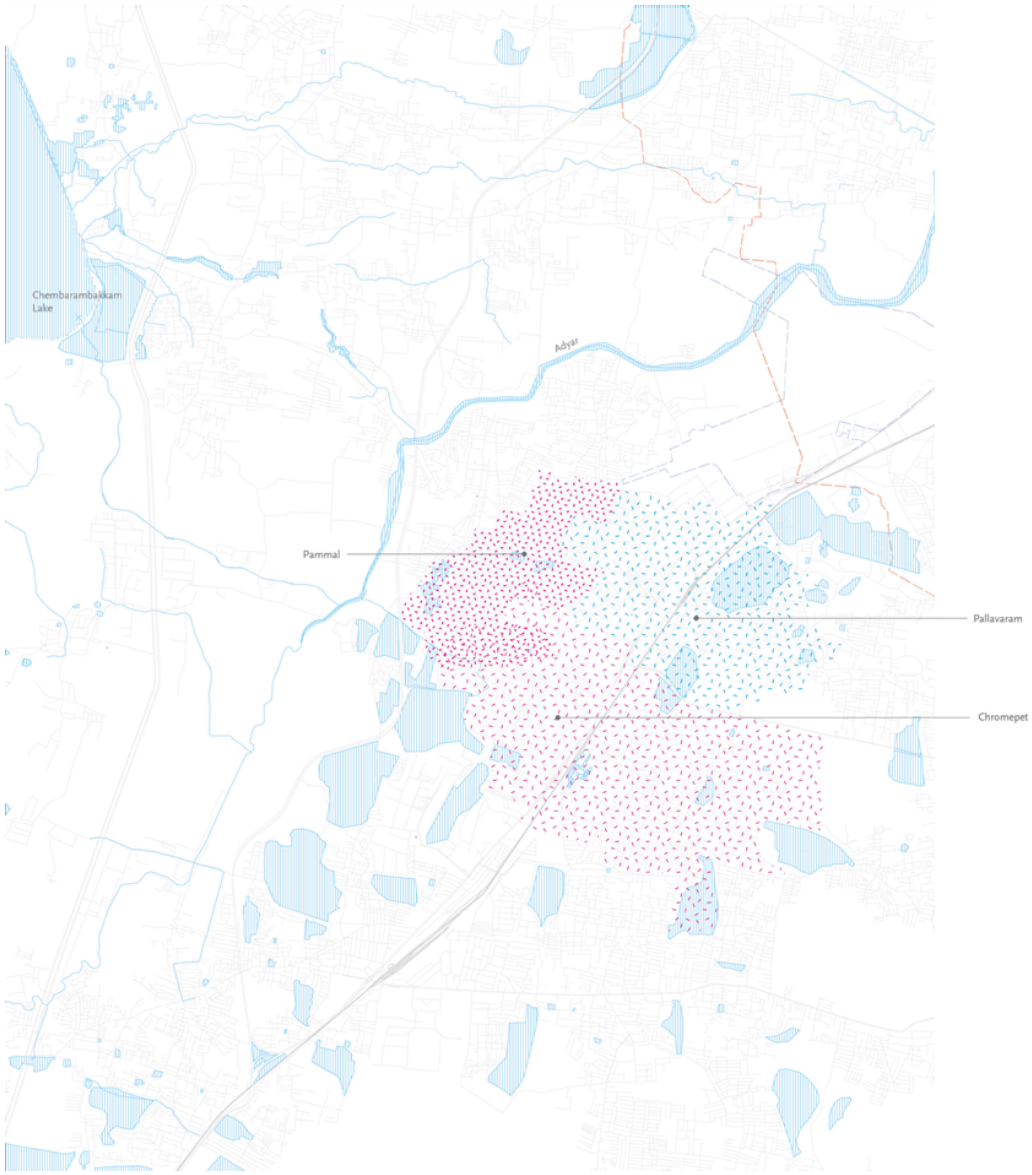

Figure 51. Chromepet Orientation. Drawing by the author.

[561] Laasya Shekhar, 'Where Is the Water to Wash Our Hands Frequently, Ask Residents of Ambattur and Chrompet', *Citizen Matters, Chennai*, 2020 <https://chennai.citizenmatters.in/water-crisis-and-lockdown-in-chennai-suburbs-ambattur-chrompet-15471>.
[562] Laasya Shekhar, 'Flowing Water Bodies Become Parched Lands: Where Did the Water Go?', *Citizen Matters, Chennai*, 2019 <https://chennai.citizenmatters.in/lakes-encroachment-pallavaram-periya-keezhkattalai-eri-chennai-8926>.

These factors increase the pressure on groundwater use, in an area where over a century of industry has saturated the ground with toxic contaminants both fast and slow. Various studies of groundwater in the area around Chromepet made in the last decade—in particular those of Brindha and Elango, Karpagam and Ramesh, and Manivannan and Elango [563]—note both the excessive levels of major ions (identified by electrical conductivity), and the presence of high levels of chromium (Cr).[564] In order to advance the general argument I make in this chapter about the provisionality of knowledge of contaminated groundwater, I will focus here on the particular case of Chromium in relation to tannery waste and domestic groundwater use, not only its deposition and transport but also its transformation.

Treatment

Chromium sludge is a by-product of the chrome tanning process, which utilises chromium sulphate in order to strengthen the leather and make it water repellent.[565] Chromium sulphate, 8-10% of the weight of the hides, is dissolved in water and agitated in a large barrel with the hides. Other chemicals are introduced in order to control the pH of the solutions. Only a certain amount of chromium is absorbed by the pelts, between 4 and 6 percent, so the rest remains in solution. [566] 'About 30–40 l of water is required to process 1 kg of leather', from which '90% of water is discharged as effluent', meaning a large quantity of effluent containing significant concentrations is a by-product of the process.[567]

More than half of all leather processing in India is in Tamil Nadu, with additional tannery clusters in Vellore district (e.g. Ambur, Ranipet) and elsewhere in the state.[568] Disposed of into drains and percolating directly into groundwater through the soft surfaces of compounds, the effluent dramatically increases chromium levels in the groundwater environment. Chromium itself exists fairly abundantly in several mineral compounds but is commercially extracted from chromite—an oxide mineral containing magnesium, iron, aluminium, and chromium 'in varying proportions, depending on the deposit'.[569] A significant proportion of global Chromite mining—

[563] 'Leather Processing and Its Possible Impact on Groundwater Quality in Silk Road Sites: A Case Study from Chennai, India', *Environmental Earth Sciences*, 76.1 (2017), 1–8.
[564] Brindha and Elango, 'Impact of Tanning Industries on Groundwater Quality near a Metropolitan City in India'; V Karpagam and K Ramesh, 'Assessment of Groundwater Quality of Chrompet Industrial Area by Water Quality Index Method', 3.7 (2015), 123–32; Manivannan and Elango.
[565] Brindha and Elango, 'Impact of Tanning Industries on Groundwater Quality near a Metropolitan City in India'.
[566] Peter Bengsten, 'Toxic Chemicals Used for Leather Production Poisoning India's Tannery Workers', *The Ecologist*, 26 October 2012.
[567] Manivannan and Elango.
[568] K Ramesh and V Thirumangai, 'Impacts of Tanneries on Quality of Groundwater in Pallavaram, Chennai Metropolitan City', 4.1 (2014), 63–70 (p. 63).
[569] N. Koleli and A. Demir, 'Chromite', *Environmental Materials and Waste: Resource Recovery and Pollution Prevention*, December, 2016, 245–63 (p. 247).

roughly 10% in 2017—occurs in India, specifically in the 'Chromite Valley' near Sukinda in Odisha where vast open-cast mines and associated spoil heaps have led to extensive contamination of the surrounding environment.[570] As water used to supress dust, as well as rainfall, leaches chromium into groundwater, millions of people are exposed through the water system.[571] In 2007, the Blacksmith Institute identified the area as one of the ten most polluted places in the world, with around a quarter of the population found to be suffering from pollution-induced diseases.[572] The Bureau of Indian Standards prescribe an upper limit for chromium in drinking water of 0.05 mg/l, and most samples collected in this area during recent studies are well above this limit, often by significant factors.[573]

Removing chromium from the wastewater is an expensive process often improperly performed or bypassed altogether. In Chromepet, Pallavaram Tanners Industrial Effluent Treatment Company (PTIETC) established a Common Effluent Treatment Plant (CETP) in Pallavaram in 1995, four years after the introduction of legislation in the Madras high court to regulate wastewater disposal. The CETP has a capacity of 300 cubic metres of effluent per day. In a study to determine the effectiveness of the CETP, Brindha and Elango noted its success in reducing chromium levels, but that its singular focus meant other ions were still present in the discharged water, meaning quality (based on EC) remained poor despite the removal of the Chromium.[574] In effect, 'the groundwater of this region is of diluted version of treated effluent'.[575]

[570] USGS, *2017 Minerals Yearbook: Chromium*, 2020, p. 17.20.
[571] C. S. Dubey, B. K. Sahoo, and N. R. Nayak, 'Chromium (VI) in Waters in Parts of Sukinda Chromite Valley and Health Hazards, Orissa, India', *Bulletin of Environmental Contamination and Toxicology*, 67.4 (2001), 541–48; Haripriya Mishra and Himanshu Bhusan Sahu, 'Environmental Scenario of Chromite Mining at Sukinda Valley – A Review', *International Journal of Environmental Engineering and Management*, 4.4 (2013), 287–92.
[572] Bryan Walsh, 'The World's Most Polluted Places', *TIME*, 2007 <http://content.time.com/time/specials/2007/article/0,28804,1661031_1661028_1661016,00.html>.
[573] A. Ramesh Kumar and P. Riyazuddin, 'Chromium Speciation in Groundwater of a Tannery Polluted Area of Chennai City, India', *Environmental Monitoring and Assessment*, 160.1–4 (2010), 579–91; Brindha and Elango, 'Impact of Tanning Industries on Groundwater Quality near a Metropolitan City in India'; Ramesh and Thirumangai.
[574] K. Brindha and L. Elango, 'Assessing the Changes in Groundwater Quality around Tanneries: The Chennai Example (India)', in *Understanding Freshwater Quality Problems in a Changing World* (International Association of Hydrological Sciences, 2013).
[575] Brindha and Elango, 'Impact of Tanning Industries on Groundwater Quality near a Metropolitan City in India'.

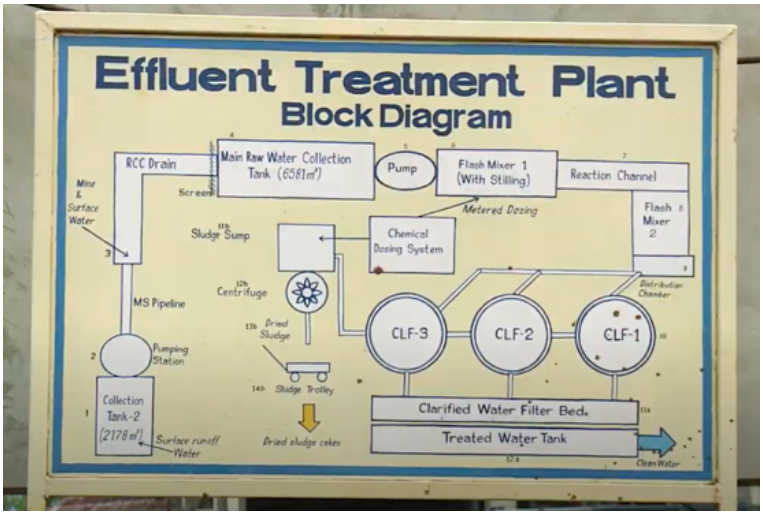

Figure 52. ETP block diagram, from Tata Steel plant, Sukinda.[576]

Chromium sludge appears over generations, long after the factories have been shuttered: 'this chromium [that is now being detected in groundwater] will have been released fifty years ago, probably', though 'it keeps going down, because we are thankful to the monsoonal rains. Every monsoon, step by step it goes down'.[577] In Ranipet, near Vellore, Tamil Nadu Chromates and Chemicals Limited (TCCL) opened a factory in 1975 to supply chemicals to a cluster of tanneries there. It operated until 1995, but the Central Pollution Control Board (CPCB) only noted the issue of left-behind Chromium sludge in 2015.[578] It is also passed into groundwater via solid waste such as trimmings, and semi-processed leather.

[576] Tata Steel, 'Tata Steel Sukinda Chromite Mines - Journey to Excellence' <https://www.youtube.com/watch?v=HVktbI-R52w>
[577] L. Elango, Chennai, 25 January 2018. Interview by the author.
[578] R Sivakumar, '25 Years after Factory Downing Shutters, Chromium Sludge Causes Groundwater Contamination in Chennai', *New Indian Express*, 1 March 2020 <https://www.newindianexpress.com/cities/chennai/2020/mar/01/25-years-after-factory-downing-shutters-chromium-sludge-causes-groundwater-contamination-in-chennais-ranipet-2110455.html> [accessed 10 March 2020].

Figure 53. Hides on transport in Pallavaram, 17 July 2019. Photograph by author.

Intra-actions between contaminants and bodies

On returning to the geology department at Anna University, the afternoon after my first walk around Chromepet, I shared some photographs with the graduate students who had been allowing me to share their office space, using these images as solicitations for conversations about tanning, chemicals, and groundwater. They immediately recognised in the bright red-pink colour of the hides that they had been chemically treated, and which chemicals which had been used to treat them. Ways of knowing about chemicals here were at first visual, related to classroom learning and understandings of the biological through newspaper articles, and public discourse: the pink leather is pink because of the biological intra-actions of chemical and hide. The photograph describes the integrity between the biological and the visual, but also ways in which this relation is more-than-visual: in chromium, we have a substance that is both invisible, insensible, and which itself produces visual images. It is generative of different visual methods and modes of working, including working with the material itself to produce images. Photojournalist Sean Gallagher's evocative study of Kanpur, Uttar Pradesh, focusses on the infrastructures of wastewater disposal, the solid waste piled in heaps, and the human scars of

toxic substances.[579] Such images rely heavily on captioning to tell you what is in there. Other images need to be made through modified photographic processes. An example of such physical making-visible is photographer Harikrishna Katragadda's use of chromium sludge in a modified form of cynatope printing—a photographic process which normally utilises potassium chromate amongst other chemical agents to make impressions/copies of objects on paper. In Katragadda's images the chromium compounds present in tannery sludge dissolve the image reproduction, contaminating the surface just as the surrounding soils and groundwater are full with the same compounds. This 'alternative photography' is another form of knowledge production engaged with 'the materiality of images'—and which becomes a form of journalism making visible not only the presence of chromium but also its dynamic capacities in intra-acting in the production of the image. Working with the chemical allows Kataragadda 'to document the pollution on the photographic print […] like how contaminants go into our skin and affect our bodies, I wanted the contaminants to go and affect the photographic surface'.[580]

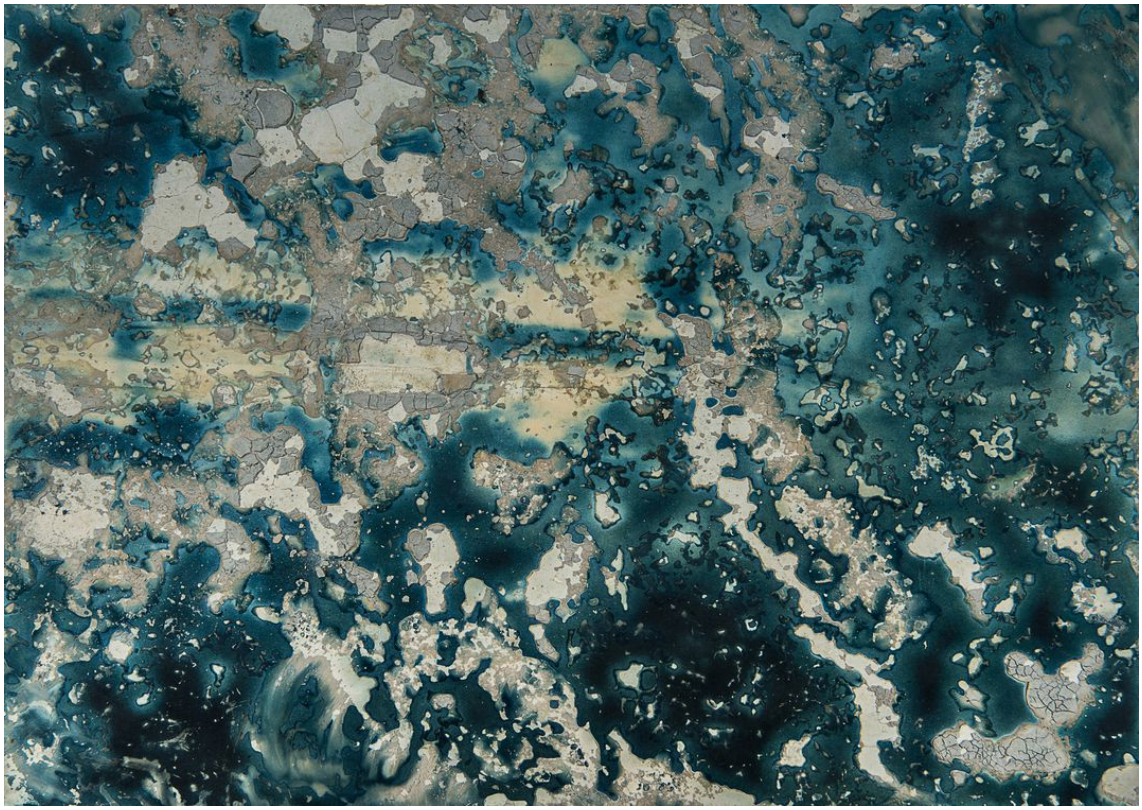

Figure 54. Cyanotype print made with impressions of chromium sludge at a chromium recovery plant in Jajmau, Kanpur, 2016. Harikrishna Katragadda.[581]

[579] Sean Gallagher, 'India: The Toxic Price of Leather', *Pulitzer Center*, 2014 <https://pulitzercenter.org/stories/india-toxic-price-leather-0>.
[580] Invisible Photographer Asia, 'Extending The Materiality And Dimensionality Of Photography – Harikrishna Katragadda', 2018 <https://invisiblephotographer.asia/2018/08/03/harikrishnakatragadda-awardsinterview/>.
[581] Harikrishna Katragadda, 'You Can't Step into the Same River Twice', 2018 <https://harikatragadda.wixsite.com/ganga/ganga-river-pollution>.

In this account, groundwater doesn't just remain below ground, but circulates in industrial machinery, and in people's bodies. Groundwater here enters into what Stacy Alaimo in *Bodily Natures* describes as 'trans-corporeality': the material interchanges across human bodies, animal bodies, and the wider material world; or 'the dissolution between the human self and the world'.[582] We see this also in chapter one of this thesis, but here I emphasise the things it brings with it, how it effects and acts on those bodies, that it is *ground*water not 'water'.

Chemical Species, Geological Facies

Speciation is a term from evolutionary biology used to describe the splitting of populations into distinct species, either by separation, mutation, or selection. It therefore relies, and is fundamental to, both differentiation and classification by fragmentation. In chemistry, species refers to different chemical forms of an element, and there are important connections between chemical speciation of metals and their toxicity, as we shall see. [583] In geology, the term 'facies' is used to describe the physical and chemical characteristics of a piece of rock which can be used to differentiate it from another. It can also be applied to hydro(geo)chemistry where it is used 'to denote the diagnostic chemical aspect of ground-water solutions occurring in hydrologic systems', which are modified and distributed by lithology and flow. [584]

These two terms are connected here in this section as specific tracers of a kind of process-lineage, as well as of classificatory schemata: absolutes that are made indistinct by the possibility and uncertainty inherent to groundwater chemistry, the moments of flight, and potential outcomes. DeLanda drew a similar analogy between speciation and sedimentation, both as processes whereby a loose groupings of behaviours/materials become 'hardened' into more permanent structures.[585] Chromium exists in multiple oxidation states, but in the environment only the two most stable forms exist: trivalent and hexavalent. The chromium salts used in the tanning process contains the trivalent form of Chromium, Cr(III). It is suggested that Cr(III) is required by humans due to its important role in insulin function, and therefore in the metabolism of glucose, fat, and protein.[586] It is proscribed by the USDA as an essential nutrient, though not by the EFSA, mainly due to the impossibility of defining an average requirement, or

[582] Stacy Alaimo, *Bodily Natures: Science, Environment, and the Material Self* (Bloomington, IN: Indiana University Press, 2010); Alaimo, *Exposed: Environmental Politics and Pleasures in Posthuman Times*, p. 112.
[583] Robert A. Yokel, Stephen M. Lasley, and David C. Dorman, 'The Speciation of Metals in Mammals Influences Their Toxicokinetics and Toxicodynamics and Therefore Human Health Risk Assessment', *Journal of Toxicology and Environmental Health - Part B: Critical Reviews*, 9.1 (2006), 63–85.
[584] William Back, *Hydrochemical Facies and Ground-Water Flow Patterns in Northern Part of Atlantic Coastal Plain: Hydrology of Aquifer Systems*, Geological Survey Professional Paper (Washington, 1966).
[585] Manuel DeLanda, 'Nonorganic Life', *Zone 6: Incorporations*, 1992, 129–67 (p. 150).
[586] Richard A Anderson, 'Chromium as an Essential Nutrient for Humans', *Regulatory Toxicology and Pharmacology*, 26.1 (1997), S35–41; Koleli and Demir, p. 257.

Dietary Reference Value, for its intake.[587] But Chromium is commonly available as health supplement marketed to reduce blood glucose, with drug companies claiming it can have a role in helping to build muscle or reduce weight loss.

Although the dominant form released into the environment is Cr(III), the combination of properties of the immediate sludge it is released in, and the groundwater environment itself — 'pH, oxygen concentration, presence of appropriate reducers and mediators'—converts it.[588] Under alkaline and oxidative conditions, the hexavalent form of Chromium, Cr(VI), prevails. Hexavalent chromium is highly toxic, and a strong carcinogen. Ingestion of larger quantities can result in 'severe acute effects such as gastrointestinal disorders, haemorrhagic diathesis, and convulsions',[589] and an association has been found between occupational exposure to chromium(VI) compounds and mortality due to lung cancer.[590]

Chromium changes oxidation state via redox reactions, which occur when an atom loses (reduction) or gains (oxidisation) oxygen electrons. A joint chemical study by the CGWB and University of Madras determined that the groundwater of the Chromepet area is was relatively oxidative, and that the dominant form of Chromium present in groundwater in the study area, in all but one instance, was Cr(VI).[591] Cr(VI) is not only more toxic, but more soluble and more mobile than Cr(III).[592]

Redox reactions intersect new materialist debates on the distinction between life and non-life. Elizabeth Povinelli, for instance, identifies redox processes as central to the distinction between biologic and geologic life.[593] In the former they are categorised as self-organised, and self-contained—performative functions of a purpose-driven subject. In the latter they are characterised as arbitrary, unpredictable, and even problematic. Oxygen as the measure of liveliness of water. Still water is dead, putrefied:

> Then within the water body we make sure that there is life within the water body: we make sure that there is enough oxygen in the water that supports life so there's fish and other life, then it becomes a living water body. If it is simply a stagnant piece of water, without the living form in it, it becomes a place for breeding of mosquitos, and it would be a putrefied water, it would be a dead water not good

587 EFSA Panel on Dietetic Products Nutrition and Allergies (NDA), 'Scientific Opinion on Dietary Reference Values for Chromium', *EFSA Journal*, 12.10 (2014), 3845.
588 J. Kotaś and Z. Stasicka, 'Chromium Occurrence in the Environment and Methods of Its Speciation', *Environmental Pollution*, 107 (2000), 263–83.
589 WHO, 'Chromium in Drinking-Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality', in *Guidelines for Drinking-Water Quality*, 2nd edn (Geneva: World Health Organisation, 1996), II.
590 Padma and others.
591 Kumar and Riyazuddin.
592 Kotaś and Stasicka, p. 264.
593 Povinelli, *Geontologies: A Requiem to Late Liberalism*, pp. 38–39.

> enough for drinking. So it needs to be oxygenated by its natural processes, or surface water — no ground water at all. But it's all water harvesting, we are actually harvesting the water and making sure that the supply channels— which are obliterated—are taken care of.[594]

But live means transformative, which is also a danger to (human) life. The use of chromium(III) sulphate allows industry to boast that tanneries use only chemicals that are not hazardous to health—which is true when they enter the environment, but does not consider the possibility of transformation.[595] It is not just about what is released into the soil and brought up, but how the ongoing life of the substance within the groundwater environment, redox processes, produces something different, and how this toxic substance—a word itself implying that which is below, which underlies or provides support—then comes back into (human) worlds.

These are dynamic processes which mandate thinking about futures. Not what a substance is but what it may (or will) become, and what it does: how it *performs* within or outside of expectations. Processes of decomposition and recomposition. Sites where things are supposedly abandoned but in that become more volatile, toxic, concentrated. To ingest Cr(VI) is to ingest something which exists because of its speciation in the groundwater environment, or to become a part of a groundwater process in its extended environment. Chromium here is an 'essential toxic element': both essential and lethal.[596] The dynamic nature of groundwater as a risk to health is fundamentally related to its intra-actions with surface water, percolation, and the monsoon—such as in the dramatic re-emergence of bacterial pathogens and chemical ions during the 2015 floods as wells and other structures were inundated.[597] Groundwater is not 'just there': it is made, and it re-makes bodies. This is groundwater that is explicitly transcorporeal in circulation, transformation, and affect.

[594] Santha Sheela Nair, Chennai, 7 July 2018. Interview by the author.
[595] Kerry Senior, 'Standards and Use Limitations for Chemicals in Leather Production', *Nothing to Hide* <http://nothing-to-hide.org/LeatherFacts/Chemistry:_not_all_bad>.
[596] Povinelli, *Geontologies: A Requiem to Late Liberalism*, p. 43.
[597] Gowrisankar and others.

Figure 55. 'Impact of Some Major Pollutants in Water on Human Body'. Tamil Nadu State Ground and Surface Water Resources Data Centre.[598]

Figure 56. Display outside VRS Leathers, Pammal, 2018. Photograph by the author.

[598] Tamil Nadu State Ground and Surface Water Resources Data Centre, *Water Quality Information Guide* <http://www.groundwatertnpwd.org.in/report.htm> [accessed 10 March 2020].

From Species to Communities

What the account above suggests is that we need to think not with particular substances as discrete elements, but with the assemblages that produce and transform them: a movement from 'species' to 'community'. The notion of transcorporeality implicitly critiques the concept of species as discrete entities, just as groundwater ecologist Janine Gibert uses the term 'community dynamics' to describe the contiguity between environmental conditions and the ecological status of organisms: 'the collective responses of the set of conditions present in the space-time window of interest'.[599] I find this concept intriguing: it echoes both Tsing's contamination/collaboration and Whitehead's use of the term 'societies' to describe groupings of multiple becomings, which includes humans, and do not have clear ends. Equally, though, the term *community* brings with it a history that suggests something static and bounded, and has anthropological connotations around security and bordering.

Anthropological critiques have described non-essentialist interpretations of 'community' that are unstable, heterogenous, and interconnected—whilst also holding onto the important idea described in the previous section that communities of knowledge *can also be* fairly closed and reproduce their own inaccessibility. I am interested in retaining in the term, therefore (rather than replace it with assemblages), as a means of reinforcing the point that different communities produce different types of knowledge. This is not only an aspect of their composition, but also responds to the demand that we 'work harder to account not only for the context in which the group operates but also for its very rationale'.[600]

Gibert and others suggest that groundwater ecology was ignored for so long because of 'the technical difficulty of sampling associated with the underground environment'—the practical difficulty of separating elements.[601] In fact, groundwater ecology destabilises categories. In this case chromium is in one state a mineral essential to human health, in another it is an industrially produced chemical which accelerates production and maximises profit, and yet another is a highly toxic pollutant emerging in domestic groundwater supplies and rendering them unusable, making large areas of the city uninhabitable. How to draw the line at some point between essential collaborant and deleterious pollutant?

[599] Gibert, Danielopol, and Stanford, p. 20.
[600] Vered Amit and Nigel Rapport, *The Trouble with Community: Anthropological Reflections on Movement, Identity and Collectivity* (London: Pluto Press, 2002), p. 4.
[601] Gibert, Danielopol, and Stanford, p. 1.

In a brief contribution to an edited collection on the theme of diversity, Tsing elaborates her thesis of 'contaminated diversity' which would be central to her later book, *The Mushroom at the End of the World*.[602] Contaminated diversity is a counterpoint to the 'innocent diversity of self-contained evolutionary tracks'.[603] Beings survive by collaborating with one another and 'we are mixed up with others before we even begin any new collaboration'. Contamination makes diversity; productive collaborations emerge out of harmful scenarios. I am not introducing this thesis to suggest that there is some future 'good' to come of this. Rather, because contaminated diversity as an idea 'is recalcitrant to the kind of "summing up" that is the hallmark of modern knowledge'.[604] It denies the a-historicity of knowledge forms in favour of relational forms. Contamination is 'to tell the histories in which diversity emerges'.[605] This is useful for thinking about urban groundwater because it warns us against thinking about one acting on the other: the city acting on groundwater, or vice-versa. This is an impossible formation, Chennai and groundwater are co-constitutive.

Contaminated Groundwater as an Object of Knowledge

In all this, I return to questioning the status of groundwater as *both* a material assemblage *and* an object of knowledge, *either* in a particular situation *or* in a generalised theoretical sense. Ways of knowing groundwater evolve through institutional, disciplinary, and material collaborations that are particular to—and part of—a certain community or society of practice. The diversity of these communities in turn produces a diverse range of representations, concepts, and methods for knowing groundwater. [606]

In the introduction, I defined aesthetics relations as an alternative to cognition, following Shaviro's claim that 'more things are *felt* than can be known', and proposed this as thinking about a multiplicity of sensory and embodied relations with groundwater.[607] Nigel Clark and Bronislaw Szerszynski introduce the terms 'planetary multiplicity' and 'earthly multitudes': the first referring to 'a planet with a propensity for reorganizing its own component parts', at all scales, 'of

[602] Tsing, 'Contaminated Diversity in "Slow Disturbance": Potential Collaborators for a Liveable Earth'.
[603] Tsing, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins*, p. 29. This idea echoes Hustak and Myers' *Involutionary Momentum*, as well as Kropotkin's writings on Darwin, which sought to emphasise the collective and collaborative nature of species advancement over the better-known formulation of competitive struggle.
[604] Tsing, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins*, p. 33.
[605] Tsing, 'Contaminated Diversity in "Slow Disturbance": Potential Collaborators for a Liveable Earth'.
[606] Similarly, Judy Ehlen discusses the many different ways in which geologists, geomorphologists, soil scientists, and civil engineers approach and classify a portion of the subsurface known at weathered mantle. Judy Ehlen, 'Above the Weathering Front: Contrasting Approaches to the Study and Classification of Weathered Mantle', *Geomorphology*, 67.1–2 (2005), 7–21.
[607] Shaviro, *The Universe of Things: On Speculative Realism*, p. 79.

becoming other to itself'; the second for the ways in which groups of humans respond to this emergent multiplicity, its challenges and changeability.[608] Earthly multitudes are therefore composed 'with and through' planetary multiplicity. Thinking with groundwater as both a material and an object of knowledge is also the 'challenge of thinking through the Earth in ways that are open to 'modern' science but also to a world of other knowledge practices and ways of life […] the different ways this planet is engaged with, experienced, known and imagined'.[609]

The review of correlationism at the beginning of this thesis was there to establish the fallacy of any form of knowing which invests itself in, as Sandra Harding puts it, 'the notion of the ideal mind as a mirror that can reflect a world that is "out there," ready-made'.[610] Harding writes that 'nature *simulates* encultured humans in that it always comes to us culturally preconstructed or as a possible object of knowledge'.[611] But to emphasise the structures through which we know materials, and to assert that materials express themselves (only) through these systems, is also to diminish the important claim that groundwater exists outside of its apprehension or representation. Such ways of knowing work 'to cheat matter out of the fullness of its capacity'.[612]

In Harding's important formulation of 'weak objectivity', there is an inherent contradiction between the historically and spatially situated forms of knowledge production practices by some natural sciences and their claims to objectivity. This can be seen as revealing the limitations of such claims, or their lack or universality. So there is more to groundwater than what is known about groundwater. Critically, Harding quotes Joseph Rouse's political philosophy of science, which challenges the view that power operates through the *application* of knowledges, which are achieved through the elimination of power from the structures of knowledge *production*. The mutually-transformative understanding of knowledge production, then, supports the claim that the question is not about more or less accurate representation of something 'out there' but a material exercise of transformative action, successful control of the process.

> Power is no longer external to knowledge or opposed to it: power itself becomes the mark of knowledge.[613]

[608] Nigel Clark and Bronislaw Szerszynski, *Planetary Social Thought : The Anthropocene Challenge to the Social Sciences* (London: Polity, 2020).
[609] Clark and Szerszynski, p. 13.
[610] Sandra Harding, *Whose Science? Whose Knowledge?: Thinking From Women's Lives* (Milton Keynes: Open University Press, 1991), p. 157.
[611] Harding, p. 12.
[612] Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter', p. 810.
[613] Joseph Rouse, *Knowledge and Power: Toward a Political Philosophy of Science* (Ithaca, NY: Cornell University Press, 1987), p. 19.

Harding further suggests then that 'nature-as-object-of-study' takes on the form of 'an intentional being', reflecting back on us the preconceptions used to make it cognisable and presenting itself 'only as constituted in social thought'. Scientific claims cannot be understood as an 'epiphenomenon of nature': scientific claims about nature and the nature-as-object-of study are constitutive.[614] You therefore cannot 'know' groundwater in any fundamental sense, and groundwater appears differently depending upon how it is observed.

> In an agential realist account, human subjects are neither outside observers of apparatuses, nor independent subjects that intervene in the working of an apparatus, nor the products of social technologies that produce them.[615]

Groundwater contamination in this section is the combination of microbial populations and geochemical/hydrological conditions. For example, stygofauna maintain and reproduce voids and pore spaces, modifying redox gradients.[616] Understanding these intra-actions broadens our understanding of the spatiality of groundwater: groundwater doesn't stop there but refers to an environment that extends well beyond the subsurface.[617] Shallow groundwater is contiguous with the 'weathered mantle'—the unsaturated and saturated regions between surface and bedrock, here some 30m thick, a region of dynamic fluxes of matter and organisms.[618] Some stay in place for a long time, whilst others move between surface and subsurface, transforming according to conditions.

Emerging research also seeks to understand the relationship between extreme climatic disturbances such as flood and drought conditions, and the functioning of microbial and other communities. Focussing on the connections 'underlying' soil health in relation to food production. E.g. Soil bacterial networks are less stable under drought than fungal networks.[619] Or bioremediation of contaminated sites via microbial communities in combination with organic supplements.[620] According to USGS hydrologists Sheridan K. Haack and Barbara A. Bekins, who work in biodegradation of groundwater contaminants, the action of such requires a combination of microbial populations *and/with* favourable geochemical and hydrological conditions—

[614] Harding, p. 147.
[615] Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, p. 171.
[616] H.O Nwankwoala, 'Towards a Conceptual Understanding of Groundwater Ecology', *European Journal of Sustainable Development*, 1.3 (2012), 493–508.
[617] Meinzer had already in 1927 written extensively on behalf of the USGS on plant species as indicators of groundwater conditions. Meinzer's work had the important quality of focussing on 'the relation of the roots to the body of water'. Oscar Edward Meinzer, *Plants as Indicators of Ground Water*, Water-Supply Paper, 1927, p. 67.
[618] Ehlen.
[619] Franciska T. de Vries and others, 'Soil Bacterial Networks Are Less Stable under Drought than Fungal Networks', *Nature Communications*, 9.1 (2018).
[620] Suman Nayak and others, 'A Review of Chromite Mining in Sukinda Valley of India: Impact and Potential Remediation Measures', *International Journal of Phytoremediation*, 22.8 (2020), 804–18.

reinforcing the relation of groundwater ecology to hydrogeology not only through existence but process.[621] Groundwater contamination, then, reflects the interdependence of geologic and chemical/biotic processes, and transcorporeal, aesthetic relations.

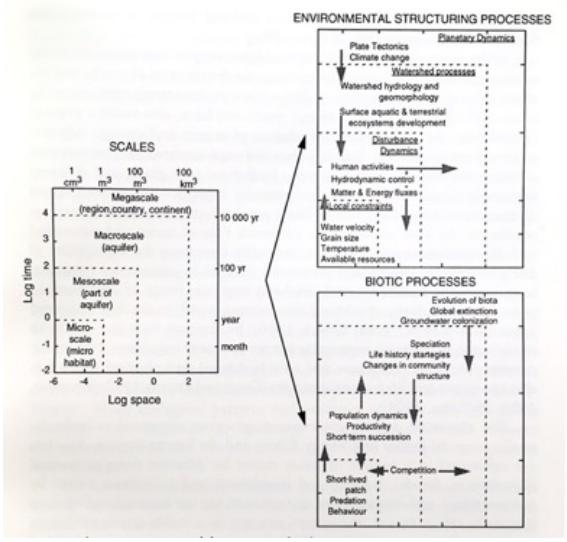

Figure 57. Relation of groundwater scales to physical and biological processes that influence groundwater at each scale. Gibert, Danielopol, and Stanford. [622]

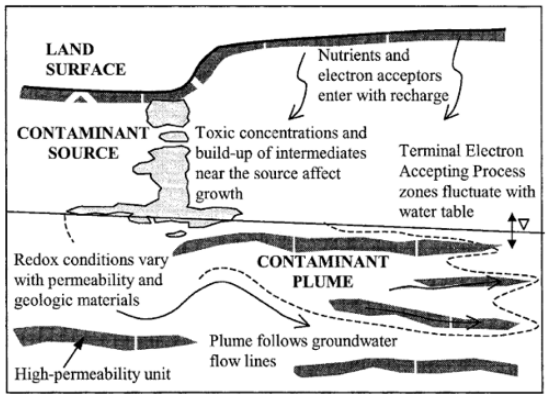

Figure 58. The Dynamic Plume, or 'how subsurface environmental conditions influence microbial populations in contaminant plumes'. Haack and Bekins[623]

[621] Sheridan K. Haack and Barbara A. Bekins, 'Microbial Populations in Contaminant Plumes', *Hydrogeology Journal*, 8.1 (2000), 63–76; W. F. Humphreys, 'Hydrogeology and Groundwater Ecology: Does Each Inform the Other?', *Hydrogeology Journal*, 17.1 (2009), 5–21.
[622] Gibert, Danielopol, and Stanford, p. 17.
[623] Haack and Bekins, p. 70.

Dynamics of Groundwater Contamination

In this chapter I have given two related but very different examples of urban-industrial groundwater contamination whereby substances disposed of in the ground re-enter the world through groundwater and its consumption, through a network of human and non-human interlocuters. These are two examples that bring out different aspects of groundwater, and which are two amongst many different and varied forms of contamination in and around the city. The chapter moves across these two locations—and associated materials, processes, and knowledge—in order to draw out aspects of groundwater relations that might not be apparent from either on their own.

These two cases are also redolent of the diversity of the wider Chennai groundwater landscape. Harmful chlorinated pesticides have been identified by organochlorine compounds in breastmilk from mothers in Chennai, with levels higher in the city than in rural and peri-urban areas.[624] Protests are ongoing in the south of the state, in Thoothukudi (Tuticorin), where groundwater in the area of the Sterlite Copper smelting factory contains high levels of Iron, exceeding Indian water standards by 17-20 times,[625] and where atmospheric pollution both causes and compounds health problems.[626] The closure of Unilever's thermometer factory in Kodaikanal (Western Ghats) in 2001 followed allegations, and later irrefutable evidence, that the company had not been following regulations for the proper disposal of mercury waste. The campaign then focussed on the removal of the waste and remediation of the site. As an interlocuter put it:

> You name it, we will have it. […] we wash our car everywhere, we drop so much oil, organic carbons, poly-aromatic hydrocarbons. Also emerging contaminants such as shaving cream, beauty creams, soaps and shampoo, chemicals such as medicines, pharmaceuticals, are also likely to be there. Also, perchlorate, which is a constituent of fireworks, match industry.[627]

I draw two initial conclusions here which are specific to the arguments of this chapter: First, that groundwater makes itself known in unexpected ways, which go beyond the ways in which groundwater is re-produced as an object of knowledge. This is a specific way in which groundwater troubles conventional geological practices such as mapping through boreholes: 'the methodological challenge that some of the most interesting Anthropocene science poses to

[624] Annamalai Subramanian and others, 'High Levels of Organochlorines in Mothers' Milk from Chennai (Madras) City, India', *Chemosphere*, 68.5 (2007), 928–39.
[625] S. Elango, *Health Status and Epidemiological Study Around 5 Km Radius of Sterlite Industries (India) Limited, Thoothukudi* (Tirunelveli: Department of Community Medicine, Tirunelveli Medical College, 2008).
[626] These protests made international news in May 2018 following a massacre of protestors by police. Sterlite Copper is a subsidiary of London-based Vedanta Resources. The recent protests were targeted against plans to double the plant's capacity, which were halted in the aftermath by the Madras High Court.
[627] L. Elango, Chennai, 25 January 2018. Interview by the author.

geology',[628] or the idea that groundwater exists outside of its apprehension or representation. This is an experience of the failures of survey practices, agencies, and remediation techniques supposed to keep people safe from industrial effluent contamination: 'we experience the consequences of developments in science and technology […] every time we eat or even breathe'.[629] This points to questions of performativity that I will further draw out in the concluding chapter. [630]

Second, that in each instance that groundwater makes itself known, it generates a new instance of knowledge. Empirical references included in this chapter are deliberately selected as the most place-specific and generated from the sites I am discussing: i.e., I am discussing hydrocarbon contaminant plumes through studies made of Tondiarpet; I am discussing chromium based on studies made in Chromepet. The relationship between these things is not constructed out of the relationship between groundwater and chromium in general, for there is no such place and no such substance. But even within this grouping, each is a different assemblage, a different experiment or practice and a different understanding of substance. They do not tell us about hydrocarbons, chromium, or groundwater in general, but only within specific assemblages. Harding calls 'sciences-in-society and the consequent society-in-sciences, or that *this* science is different from *that* science'.[631]

Whitehead, in *Science and the Modern World*, reflects on the shift from deductive, metaphysical rationalism of the middle ages ('the nature of things') to inductive, observational and experimental practices of thought in the early modern period in European science.[632] Whilst considering the limits of induction for establishing or deriving 'general laws', Whitehead defines induction as 'the divination of some characteristics of a particular future from the known characteristics of a particular past'.[633] Significantly, for my argument in this chapter, Whitehead then arrives at the preliminary conclusion that:

> All we can ask of the present occasion is that it shall determine a particular *community of occasions*, which are in some respects mutually qualified by reason of their inclusion within that same community. That community of occasions considered in physical science is the set of happenings which fit on to each other—as we say—in a common space-time, so that we can trace the transitions from one to the other. Accordingly, we refer to the common space-time indicated in our immediate occasion of knowledge. Inductive reasoning proceeds from the particular occasion to the particular community of

[628] Ahuja.
[629] Harding, p. 8.
[630] Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter'.
[631] Harding, p. 14.
[632] Whitehead, *Science and the Modern World*, pp. 49–70.
[633] Ibid., p. 56

> occasions, and from the particular community to relations between particular occasions within that community.[634]

Thinking with contaminated groundwater in this way might be a way into thinking about the fleeting and particular nature of this kind of knowledge when the object of that knowledge is not a material 'nature' but a momentary act of intra-active becoming. As creativity only exists through its actualisations, so knowledge only exists through—and within—its production.[635] Whitehead took it as given that 'each individual entity is apprehended through its characteristics', which I take to mean its traces: 'something about it which we note'. These are measures, and scientific theories are based on the relations between measures, not objects. 'Apart from these qualities we do not observe anything at all'.[636] This makes it important, therefore, that (say) a government-backed programme for rainwater harvesting gets its lithographic data on certain neighbourhoods from records produced by a house builder, or that hydrogeologists researching contamination use existing boreholes drilled for the purpose of groundwater extraction.

These two cases also draw out some particular entanglements of groundwater with above-ground biotic processes and of the specific nature of groundwater, or its spatial historicity by which it is still groundwater when circulating in people's bodies. Both sections are concerned with producing visual material, just of different kinds, achieved in different ways, with a different impact.

[634] Ibid., p. 56.
[635] Debaise, p. 30.
[636] Whitehead, *Science and the Modern World*, p. 66.

Conclusions and Implications: Beyond a Lively Reading of Groundwater

This final chapter concludes by considering the implications of this thesis for ongoing research on groundwater, the wider subterranea of cities, and the wider material relations of such environments. Working back across the thesis's internal stratifications, acknowledging, and arguing for an account of groundwater's relations, I will begin with a short section on reading a series of interrelated conclusions across the chapters.

Materials, Processes, Experimental Knowledge

This thesis had the aim of bringing attention to the ground of Chennai by exploring different ways in which groundwater is known and intervened in. Through the diversity of the modes of access, forms of knowledge, and conceptualisations of groundwater described across the chapters, a first conclusion with which to begin this section is that different knowledge practices resulted in different forms of knowledge. Groundwater is different things depending on how you access it. To put this another way, what has come through with particular strength from these accounts has been the significant differences between images of groundwater produced by different knowledge practices. Groundwater shifts through the thesis, questioning any image as being more-than-partial. There is a tension throughout between the ways in which groundwater is undeniably present in the work, but is also always highly mediated and never direct. This is rooted in the complexities of the opening theoretical section, which stands as an inconclusive summary of the problems of access to non-human materials. This tension is not a limitation, but a developed reading of groundwater as composed not only of material intra-actions but also of the knowledge-production practices through which it is understood, and which groundwater does not exist *a priori* of.

Second, continuing from the above, in all cases the production of knowledge is the result of collaboration between humans and non-humans. The accounts in chapters one and three, in particular, bear out Barad's observation that 'practices of knowing cannot fully be claimed as human practices'.[637] We see, for instance, how knowing is always also about intervening, from within an assemblage of a knowledge production that includes others and implicates the knower, rather than from outside. This overlaps with the ways in which groundwater questions the sites and networks of knowledge production in general, emphasising their provisionally, and the ways in which certain forms of knowledge take precedence when one form or other is deemed insufficient.[638] That knowledge-making is always intervention also applies in reverse: forms of intervention are tightly coupled to the forms of knowledge engaged to develop them. Particular knowledges of groundwater are mobilised in order to intervene both in the present, and in attempts to produce future groundwaters through urban structures.

Third, through a close reading of the processes of knowledge production in different contexts, I have drawn attention to the highly ambiguous boundary between sensory and other, quantifiable or supposedly objective knowledges. This emerges in the account of modelling, and the relation of sensory to communicable data in chapter one, and is expanded in the second part of chapter three through a discussion of the relation between visual and other forms of embodied knowledge.

Fourth, groundwater's agency comes through in each chapters' conclusions—on translation, leakage, and experimentation—suggesting that groundwater itself will undo the ways in which it is understood. Key to this is the relational theory of groundwater developed in chapter two: the inseparability of figure and ground demonstrating how groundwater is not a background to the city's ongoing reproduction, but is both substantially altered by and co-constitutive of lively urban assemblages. This is not only about how groundwater destabilises the material and conceptual categories that otherwise condition stable urban life, but of how *in the process* of doing so it becomes an intransigent collaborator in the making of the city. This suggests a way of thinking about place that is highly provisional and collaborative: place as experiment. Through the focus on ways on knowing groundwater and what groundwater is, I naturally get at certain elements of the city, learning things about the city, but this is not a meta-narrative of the city in general. By concentrating on the materiality of groundwater and how it is known there are provisional glimpses into urban processes that are highly charged and highly political. These are

[637] Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter', p. 829.
[638] Erik Bordeleau, 'The Care of the Possible: Isabelle Stengers Interviewed', *Scapegoat*, 1, 2011, 12–27 (p. 12).

provisional assemblages around the materiality of groundwater, which have potent political consequences. Dimitris Papadopoulos, in *Experimental Practice* describes people working with the material conditions of their existence as a political practice, not as an ideological framing but through material processes:

> creating spaces of political autonomy and self-organization is not just a social affair. It is a practical and ontological affair that goes as far as to change the materiality of the lived spaces and the bodies, human and nonhuman, of communities.

Such a conception of struggles around liveability is reflected in the opening of each chapter: drought, sludge, and plume. These are ever-shifting political processes that are not static, and cannot be rigidified into ideology or structure, are far too fluid.

Fifth, there is a politics to knowledge that arises from forms of data, and the networks in which knowledge circulates. Problematics of 'cleaning', averaging, and manipulating data in order to make it 'manageable', as described in chapter one, are fundamental to the political operations of knowledge. This is reflected in the ways in which science accounts for its own limitations (such as the modelling section of chapter one), but its interlocuters often do not. The political is epistemological: how we interpret the world determines how we occupy it. Boaventura de Sousa Santos refers to the knowledges that emerge from social and political struggles as 'experiential epistemologies', knowledge as something emergent and therefore distinct from culturally-established 'ways of knowing'.[639] Significantly, the figures of performativity and experimentation introduced in the introduction and developed in chapter three undo one of the research questions, which asked (separately) about how knowledges are produced, and how they are (then) enacted. Despite this undoing, I left this version of the question intact in order to show how an understanding of the intra-active nature of producing–enacting knowledge emerged through the material encountered in the thesis, rather than from theory.

Finally, thinking with groundwater as part of the monsoon, from where this project started, helps to support the view across the chapters that groundwater is seen to be not limited to its traditional location of the subterranean: it moves through the city, states, and bodies, extending above and below the artificial line called 'surface'. This occurs both materially, within discourse, and in their intra-action.

[639] Boaventura de Sousa Santos, *The End of the Cognitive Empire* (Durham, NC: Duke University Press, 2018), p. 2.

A Methodology for Engaging with Groundwater: Reflections on the research design

A core part of this thesis, in both its development and presentation, has been about learning new methods for/whilst thinking with groundwater. I said in the introduction that the intra-active relationality of groundwater both requires and is productive of new methodologies. This is borne out in the development of a plurality of ways of thinking with, drawing up, and writing about groundwater. What has happened throughout the thesis, is that the idea of the mode of representation having agency has come to the fore. Each of these chapters is thus a *different* approach to *different* ways of knowing groundwater: not only in the forms of knowledge I discuss, but also in the ways in which my own *modes of access to these modes of access*, also vary through the thesis.

I posed the question in the methodological section of how to study groundwater as a dynamic materiality, how to bring it into the realm of research as an active participant. Here, the multi-modal design of this project has been vital in engaging with groundwater from multiple perspectives and in multiple ways. Drawing as method in this thesis has become increasingly multifaceted and significantly variegated beyond the way I set out drawing as method in the introduction: I mobilise drawings in many different ways including my own drawing processes alongside critique of others'.

As described in the introduction, the processual nature of drawing makes it absolutely suited to working with the processual nature of matter, in creating conditions of openness, collaboration, and hospitality to groundwater as an object of knowledge: drawing as a process of coming to know, trying to make sense of things. A lot of the understandings and knowledge gained through the course of the thesis has been generated by intra-active processes including sketches. Some of these drawings are invisible in the thesis, they do not appear as artefacts but inform how I am writing and understanding. Drawings that remained on the drawing board were not 'left out' of the thesis but developed forms of understanding that fed back into the writing. In the case of figure 59, for instance, the section produced an understanding of the elevation difference between the case study site and the beach, which could not have been derived by other means (since the section did not otherwise exist). This understanding was reincorporated into the text, and the drawing remained unfinished, in process, and provisional.

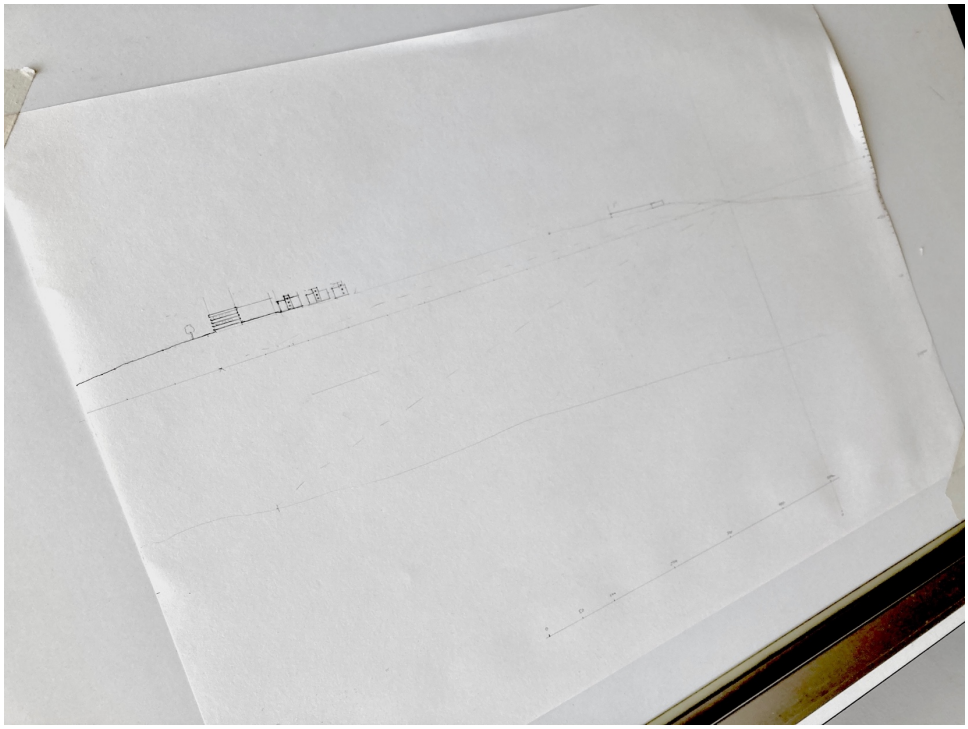

Figure 59. Unfinished drawing showing relation of Bay View apartments to Elliots Beach. Drawing and photograph by the author.

This example is not limited to drawing, but as described in chapter one (p. 110) this particular drawing process included relating conversations, scientific diagrams, field sketches, topographic data, and photographs. The methodology evolved throughout the thesis to develop ways of relating all these forms of information through drawing and writing, attempting not to synthesise a 'true' picture but to keep different ways of knowing in tension. In chapter one I explored groundwater primarily through ethnographic methods focussing on interviews, site visits (shadowing), and discourse analysis. In chapter two, responding to the relative lack of access to people working directly with the metro construction project, it was necessary to employ another method and focus on archival sources, relating these to contemporary accounts, my own observations, and scientific histories. In chapter three, I felt it necessary to combine ethnographic techniques (interviews, site visits) with a reading of reports and academic papers, in order to thicken my reading of those sources.

Having done this work, it is clear that a methodology for engagement with groundwater requires a plurality of media and to not privilege any one form of representation over another. Considering this, a research design based on even greater diversity of sources and analytical techniques might be productive for future engagements with groundwater knowledge.

Reflections and Limitations

As I have described in the introduction, I chose groundwater as a research topic both because it was unavoidable in the many narratives of the city of Chennai, and because it facilitated ways into thinking about correspondences between material and social worlds. I was personally drawn to groundwater as a set of material processes that had long disciplinary histories around them, but which nonetheless seemed insufficient to deal with what was happening: existing accounts of groundwater were unable to explain what was going on in particular moments. Here, I was not simply concerned with groundwater's socio-political dimensions—its circulations and inscriptions in the anthropocentric city (a thesis on groundwater could well have stayed above ground, examining its relations in terms of commercial exchanges)—but its movements and capacities beyond ways in which it is typically framed in individual disciplines.

This thesis has not attempted a comprehensive mapping of groundwater materials, processes, and knowledges, but rather has been primarily concerned with certain knowledge-production practices in order to develop a series of implications of thinking with groundwater from Chennai. Whilst far from universal, these conclusions are suggestive of modes of relational practice in situations where knowledge is (necessarily) incomplete, unfinished, and inconclusive.

Having done this work, I am left with profound personal consequences to the ways in which I understand urban materiality. As a recently-practicing architect with a strong interest in public space, pursuing a PhD which by necessity became an inter-disciplinary concern, I have invested myself in geology, chemistry, ecology, and ethnography. The interdisciplinary nature of this work is a continuation of groundwater producing an effect in the world—through me—which will continue to demand this plurality of approach to urban materiality in the future.

This thesis sits alongside and with great respect for research which has more precisely explored the practices of, for example, municipal engineers engaged in the management of water resources in Chennai.[640] The limitations in access that I have experienced through researching this thesis reflects the ways in which groundwater knowledge is socialised: once this knowledge is produced it circulates in certain forums, and is removed from others. The official reports which resulted from the investigations discussed in the first section of chapter three are unpublished, and are only accessible to me because their authors are situated within academic institutions and have published fragments in academic journals. Those authors also agreed to speak to me about them, though sometimes only due to connections made as part of the larger research project. Even

[640] Ramesh, 'Between Fragments and Ordering: Engineering Water Infrastructures in a Postcolonial City'.

then, I can only access them because I belong to a university that subscribes to the correct database. My choice of case study here is still limited to what I am able to access, and relies for instance on translators, and other kinds of interlocutors. Other methods of study are inaccessible to me for the same reason.

Implications, Positions, Future Research

This thesis has been written amongst a proliferation of papers, talks, and conferences in recent years on the theme of the underground, and which are variously concerned with predominantly human-made subterranean spaces.[641] As I conclude, the *Architectural Review* has just published 'The Underground issue' describing it as a 'the site of sedimented histories and power struggles, of politicised excavations and commodified infrastructures. […] A land rich with matter'.[642] This research supports such calls for (re-)engaging with the (under)ground.[643] Groundwater research is vital for the liveability of cities, and is concerned with major threats such as subsidence (as discussed in chapter three), flooding, and the intra-action of complex urban subterranea with changing climates. In general, I make the case in this thesis for the importance of groundwater research, in disciplines outside the natural sciences, in terms of everyday liveability, and forms of co-habitation that are not only concerned either with major events, or with anthropogenic structures.

I will dwell for a moment on the remarkable range of perspectives around access to and use of groundwater in this thesis, and the variety of very tight daily relationships with the dynamics of subterranean space. In Western European writing, at least, ideas about the underground are so often limited to either that which we (humans) can inhabit, that which we can extract (by hand, or machinery), or in which we can bury. These are all conceptualisations based upon movement, usually of bodies but also of minerals, and waste, from surface to 'below' and from 'below' to surface. Take, for example, the opening of Robert Macfarlane's *Underland* where the author lists his ways in via: grave, labyrinth, tomb, mine, cave, chamber, and dump (for nuclear waste).[644] Macfarlane thus categorises underground spaces as being either for 'shelter', 'yield', or 'dispose'. Perhaps it's the term 'space' which is the problem here, since, as mentioned earlier in relation to Ingold's use of Gibson's 'medium', this usually refers to an absence of any materials other than

[641] See e.g. Harriet Hawkins, 'Underground Imaginations, Environmental Crisis and Subterranean Cultural Geographies', *Cultural Geographies*, 27.1 (2020), 3–21.
[642] Manon Mollard and others, 'Underground', *Architectural Review*, 1480, 2021, 3.
[643] Melo Zurita, George Munro, and Houston.
[644] Robert Macfarlane, *Underland: A Deep Time Journey* (Hamish Hamilton, 2019).

air (despite that material's own complexities). In Chennai there is instead a constant umbilical connection to the subterranean environment, and its flows of groundwater and minerals.

Though not explicitly concerned with design (as a semi-formalised or professionalised process), this thesis is itself is a form of practice with groundwater, which demands a development of forms of spatial practice predicated on knowledge and control of situations, to instead develop ways to 'couple and co-evolve in a radically open ended aesthetics'.[645] I will be seeking to develop these concerns into implications for spatial practices through further research into the implications the ways in which Anthropocene ecologies challenges disciplines such as architecture. This thesis leaves me with questions about the possible forms that spatial practices might take, based upon the understanding developed through thinking with groundwater from Chennai. It also suggests a method for approaching these questions based not on thinking about futures at a distance, but by extrapolation from close readings of material conditions. I will therefore take up these questions in future research by bringing the ways of thinking that emerge from this thesis into conversation with scenarios that grow out of existing practices, following Papadopoulos:

> to explore the otherwise, the not yet fully materialized, the unknown from significant proximity […] getting as close as possible to something that is already there and yet has not fully emerged [and also] getting as close as possible to its past by unlocking its speculative potential in order to reconstruct promising alternative histories [646]

I will close this thesis with some brief additional reflections on the theoretical development of the introduction, in light of the material discussed through the chapters. The limitations and difficulties of existing theory in approaching groundwater in its multiple capacities and intra-active materiality has been shown throughout the thesis. In particular, theorists of correlationism knots themselves around questions of access, and determined efforts at escaping the problem of correlation in order to access things directly. This thesis instead embraces the complicity of observation in the production of groundwater as a material.

Whilst the series of conclusions at the beginning of this chapter are consistent with key theoretical tools I have mobilised throughout the thesis, in particular Barad's work on knowledge production, the particular expression of intra-active materialism here in this thesis differs from

[645] Jon Goodbun, 'Gregory Bateson's Ecological Aesthetics - an Addendum to Urban Political Ecology', *Field*, 4.1 (2011), 35–46 (p. 43).
[646] Dimitris Papadopoulos, *Experimental Practice: Technoscience, Alterontologies, and More-than-Social Movements* (Durham, NC: Duke University Press, 2018), p. 6.

that work in that it is developed from a complex multi-modal and multi-disciplinary enquiry that moves between material and discursive forms of research.

In particular, this thesis is a determined counter to certain literatures discussed in the section on vital-materialist enquiry which revert to the separation of materials into categories. The processual and relational nature of groundwater undermines knowledge that is based upon division and classification, and as such exposes the limits of essentialist descriptions of materiality.

As I have said multiple times throughout this thesis, this has been an experiment with ways of knowing groundwater, as a way into thinking through some of the complex relational entanglements and feedbacks of urban habitats. Through these intra-active accounts of materiality and representation, I have, I hope, made the case for thinking with groundwater from Chennai.

List of Interviews

Interviews with different actors involved with groundwater in Chennai are a central research resource for the thesis. This appendix provides an annotated list of the interviews, including some details that help situate each of the interviewees. I had many other conversations, walks, and WhatsApp exchanges with interlocuters in Chennai—this list is limited to the sources that are referred to in the text, or directly influenced the writing.

Sekhar Raghavan, Chennai, 16 August 2017

This was my first meeting with Sekhar at the Rain Centre in Chennai, with Lindsay Bremner. I had gone to Chennai not for fieldwork as such, but for an initial visit to try and help me clarify a revised research proposal. I had become interested in groundwater by this point, and so Lindsay suggested I join this meeting, since the topic of rainwater harvesting might be interesting to me as a case study. Whilst not quoted in the text, it was a hugely important meeting where we discussed the rainwater harvesting programme, and were given a tour of drawings, models, and installations at the centre used to explain particular harvesting technologies. Sekhar spoke in particular about traditional methods of water management including the eri system, and made drawings as he spoke (figure 13).

Santha Sheela Nair, Chennai, 17 August 2017

Santha Sheela Nair is a retired Indian Administrative Service (IAS) officer who had been Vice-Chairperson of the Tamil Nadu State Planning Commission and Officer on Special Duty at the Chief Minister's Office, where she led the rainwater harvesting programme. This interview, conducted by Lindsay Bremner, is quoted in the thesis, and further reflects my debt to the wider fieldwork conducted by the *Monsoon Assemblages* team.

Indumathi M. Nambi, IIT Madras, Chennai, 23 January 2018

Indumathi is a Professor in the Environment and Water Resources Division at the Department of Civil Engineering, IIT Madras. I wanted to talk to her specifically about the many agencies involved in the management of groundwater resources in Chennai, and how her work intersected with them. The conversation informed a significant portion of chapter 3, and led me to other sources. This meeting was enabled by MONASS advisory board member Sudhir Chella Rajan at IIT Madras, who contacted Indumathi on my behalf and directed me to her office.

Indukanth S Ragade, Chennai, 24 January 2018

Indukanth was, alongside Sekhar Raghavan, instrumental in the early implementation of rainwater harvesting structure in Chennai. We spoke for over two hours in his apartment in T. Nagar in central Chennai, mostly about particular harvesting installations and methods for dealing with contaminated wastewater, including bioremediation.

L. Elango, Department of Geology, Anna University, Chennai, 25 January 2018

This was my first meeting with Elango Lakshmanan, Professor of Hydrogeology at the Department of Geology, Anna University. I had made the connection after reading a number of Elango's articles, and in addition to the conversation he shared with me some materials and offered ongoing help in my study of groundwater in Chennai. I gained an overall picture of the kinds of work he was doing, as well as that of his research students, and some insight into the different ways groundwater is known in Chennai.

Sekhar Raghavan, Chennai, 25 January 2018

During my second meeting with Sekhar, I asked more about how he thought about, and measured the quality of groundwater, particularly in relation to a drawing he had shown us on the previous meeting describing different strata at different levels (figure 21). As our conversation went on, Sekhar invited me to join him on a visit to a nearby school, which is recounted in detail in chapter 1.

L. Elango, Department of Geology, Anna University, Chennai, 22 June 2018

My second meeting with Elango, at the start of my second period of fieldwork. We talked about how I was going to conduct my work, and how I could intersect with work going on in his department. This led to the visit to Pulicat (figure 10), as well as making connections within the department that generated additional interviews and conversations.

Tom Herard, Auroville, 24 June 2018

A fellow researcher working on another project in Chennai suggested I speak to Tom, who was responsible for water management in Auroville, and we eventually met in the café at the Auroville Visitors Centre. We spoke about the programmes that had implemented to manage groundwater, as well as the difficulties and complexities they faced that had made it especially difficult to maintain as a reliable water source.

Phone call with an architect working for CMRL, 29 June 2018

This conversation, anonymised in relation to the interviewee's wishes, was the only exchange I managed to have with someone on the inside of the Chennai Metro construction project. We discussed the complexities of tunnelling in relation to water, and the processes of monitoring and management used during construction.

Veena Srinivasan, Ashoka Trust, Banagalore, 4 July 2018

Having read Veena's work on Chennai's water supply network, referred to in chapter 1, I wanted to meet to talk in more generally about how groundwater is measured and conceptualised. This also gave me the opportunity to visit the Ashoka Trust for Research in Ecology and the Environment in Banaglore, where I was able to read and collect a number of resources on historical water levels, piped networks, and wells.

Pooja Kumar, Urur Kuppam, Chennai, 5 July 2018

Pooja is a researcher and activist who, with Nityanand Jayaraman, runs The Coastal Resource Centre in Chennai. We met at their office in Urur Kuppam, and spoke about their work as well as the recent history of urbanization in and around the fishing village in which they are located.

Santha Sheela Nair, Besant Nagar, Chennai, 7 July 2018

I wanted to meet Santha Sheela Nair myself after reading Lindsay's interview, so that I could ask more questions about how rainwater harvesting was implemented, and how its success was measured. We met at her apartment in Besant Nagar and spoke about the history of the area, traditional water treatment practices, and discussed newspaper clippings relating to rainwater harvesting that she had saved.

Anandaruban P., Department of Geology, Anna University, Chennai, 17 July 2018

I had been spending a lot of time at the department and knew that I wanted to speak to Ruban about his work on groundwater modelling with SWAT and MODFLOW. I left this interview right to the end of my second period of fieldwork, so that I had as much knowledge as I could beforehand, and we had a very detailed conversation that informed the latter parts of chapter 1.

L. Elango, Department of Geology, Anna University, Chennai, 17 July 2018

Third and final formal meeting with Elango before departing Chennai. I asked additional questions about Elango's work in relation to what I had seen and learnt during the period of fieldwork, particularly in relation to the material that formed the basis of chapter 3 on industrial contamination. We also spoke about how I was going to structure and develop my thesis, and how we might collaborate in the future.

Parama Roy, IIT Madras, Chennai, 11 January 2019

During my final period of fieldwork in Chennai I attended a workshop for PhD students hosted by the Indian Institute for Human Settlements in Bangalore. There I met Ashwin Mahalingam from the Department of Civil Engineering at IIT Madras, and after speaking about my work, he had offered to give me a copy of the report that he and his colleagues had recently written, *Chennai: State of Water*. I arrived to IIT Madras the following week to collect the report and spoke to Parama about its scope, production, and findings.

List of Abbreviations

Organisations

BPCL	Bharat Petroleum Corporation Limited
CETP	Common Effluent Treatment Plant
CLC	Chrome Leather Company
CMRL	Chennai Metro Rail Limited
CMWSSB	Chennai Metropolitan Water Supply and Sewerage Board ('MetroWater')
CPCB	Central Pollution Control Board
EWRE	Environmental and Water Resources Engineering division (IIT Madras)
GSI	Geological Survey of India
IIT	Indian Institute of Technology
PWD	Government of Tamil Nadu Public Works Departments
PTIETC	Pallavaram Tanners Industrial Effluent Treatment Company
SWSM	Sustainable Water Security Misson (of CMWSSB)
TCCL	Tamil Nadu Chromates and Chemicals Limited
TNPCB	Tamil Nadu Pollution Control Board
TWAD	Tamil Nadu Water Supply and Drainage Board
USGS	United States Geological Survey
WHO	World Health Organisation

Processes

MAH	Managed Aquifer Recharge
RWH	Rainwater Harvesting

Measures

lps	Litres per Second
mld	Million Litres per Day
ppm	Parts per Million

Matters

NAPL	Non-Aqueous Phase Liquid
DNAPL	Dense Non-Aqueous Phase Liquid
LNAPL	Light Non-Aqueous Phase Liquid
PAH	Polycyclic Aromatic Hydrocarbon
TDH	Total Dissolved Solids
TPH	Total Petroleum Hydrocarbons

References

Acciavatti, Anthony, 'Re-Imagining the Indian Underground: A Biography of the Tubewell', in *Places of Nature in Ecologies of Urbanism*, ed. by Anne Rademacher and K. Sivaramakrishnan (Hong Kong: Hong Kong University Press, 2017), pp. 206–37

Achyuthan, Hema, and N. Fedoroff, 'Ferricretes in Tamil Nadu, Chennai, South-Eastern India: From Landscape to Micromorphology, Genesis, and Paleoenvironmental Significance', in *New Trends in Soil Micromorphology* (Berlin, Heidelberg, 2008), pp. 111–36

Adey, Peter, Ben Anderson, and Luis Lobo Guerrero, 'An Ash Cloud, Airspace and Environmental Threat', *Transactions of the Institute of British Geographers*, 36.3 (2011), 338–43

Ahuja, Neel, 'The Anthropocene Debate: On the Limits of Colonial Geology', 2016 <https://ahuja.sites.ucsc.edu/2016/09/09/the-anthropocene-debate-on-the-limits-of-colonial-geology/> [accessed 19 May 2020]

Alaimo, Stacy, *Bodily Natures: Science, Environment, and the Material Self* (Bloomington, IN: Indiana University Press, 2010)

———, *Exposed: Environmental Politics and Pleasures in Posthuman Times* (Minneapolis, MN: University of Minnesota Press, 2016)

Amit, Vered, and Nigel Rapport, *The Trouble with Community: Anthropological Reflections on Movement, Identity and Collectivity* (London: Pluto Press, 2002)

Amrith, Sunil, *Unruly Waters: How Mountain Rivers and Monsoons Have Shaped South Asia's History* (London: Allen Lane, 2018)

Anderson, Richard A, 'Chromium as an Essential Nutrient for Humans', *Regulatory Toxicology and Pharmacology*, 26.1 (1997), S35–41

Arabindoo, Pushpa, 'Unprecedented Natures?', *City*, 20.6 (2016), 800–821

Atkinson, Paul, and Sara Delamont, 'Analytic Perspectives', in *The SAGE Handbook of Qualitative Research*, ed. by Norman K. Denizen and Yvonna S. Lincoln, Third Edit (Thousand Oaks, CA: SAGE, 2005)

Auyero, Javier, and Debora Swistun, 'Confused Because Exposed: Towards an Ethnography of Environmental Suffering', *Ethnography*, 8.2 (2007), 123–44

Back, William, *Hydrochemical Facies and Ground-Water Flow Patterns in Northern Part of Atlantic Coastal Plain: Hydrology of Aquifer Systems*, Geological Survey Professional Paper (Washington, 1966)

Balakrishnan, T, *District Groundwater Brochure: Chennai District, Tamil Nadu* (Chennai: Central Ground Water Board, 2008)

Ballestero, Andrea, *A Future History of Water* (Durham, NC: Duke University Press, 2019)

———, 'Andrea Ballestero' <https://andreaballestero.com>

———, 'Aquifers (or, Hydrolithic Elemental Choreographies)', *Fieldsights*, Theorizing the

Contemporary, 2019 <https://culanth.org/fieldsights/aquifers-or-hydrolithic-elemental-choreographies> [accessed 20 August 2019]

———, 'Spongiform', *Fieldsights*, Theorizing the Contemporary, 2018 <https://culanth.org/fieldsights/spongiform> [accessed 20 August 2019]

———, 'The Underground as Infrastructure? Water, Figure/Ground Reversals, and Dissolution in Sardinal', in *Infrastructure, Environment, and Life in the Anthropocene*, ed. by Kregg Hetherington (Durham, NC: Duke University Press, 2019), pp. 17–44

———, 'Touching with Light, or, How Texture Recasts the Sensing of Underground Water', *Science Technology and Human Values*, 2019, 1–24

Ballukraya, P. N., and R. Ravi, 'Hydrogeology of Madras City Aquifers', *Journal of the Geological Society of India*, 45 (1995), 87–96

———, 'Natural Fresh-Water Ridge as Barrier Against Sea-Water Intrusion in Chennai City', *Journal of the Geological Society of India*, 52.3 (1998), 279–86

Banks, Leah D., Kelly L. Harris, Jane A. Mantey, Darryl B. Hood, Anthony E. Archibong, and Aramandla Ramesh, 'Polycyclic Aromatic Hydrocarbons', in *Biomarkers in Toxicology* (Elsevier, 2014), pp. 451–58

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

———, 'Meeting the Universe Halfway: Realism and Social Constructivism without Contradiction', in *Feminism, Science, and the Philosophy of Science*, ed. by Lynn Hankinson Nelson and Jack Nelson (Dordrecht: Kluwer Academic Publishers, 1996), pp. 161–94

———, 'No Small Matter: Mushroom Clouds, Ecologies of Nothingness, and Strange Topologies of Spacetimemattering', in *Arts of Living on a Damaged Planet*, ed. by Anna Lowenhaupt Tsing, Heather Anne Swanson, Elaine Gan, and Nils Bubandt (Minnesota: University of Minnesota Press, 2017), pp. G103–20

———, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter', *Signs: Journal of Women in Culture and Society*, 28.3 (2003), 801–31

Bastian, Michelle, Owain Jones, Niamh Moore, and Emma Roe, eds., *Participatory Research in More-than-Human Worlds* (London: Routledge, 2016)

BBC Newsnight, 'John Berger on Ways of Seeing, Being an Artist, and Marxism', 2011 <https://www.youtube.com/watch?v=b5y7QRt2bws> [accessed 12 January 2020]

Beauregard, Robert A, *Planning Matter: Acting with Things* (Chicago: The University of Chicago Press, 2015)

Bebbington, Anthony, 'Underground Political Ecologies: The Second Annual Lecture of the Cultural and Political Ecology Specialty Group of the Association of American Geographers', *Geoforum*, 43.6 (2012), 1152–62

Beech, Nick, 'Ground Exploration: Producing Everyday Life at the South Bank, 1948-1951', in *Urban Revolution Now: Henri Lefebvre in Social Research and Architecture*, ed. by Christian Schmid, Łukasz Stanek, and Ákos Moravánszky (Farnham: Ashgate, 2014), pp. 191–205

Bengsten, Peter, 'Toxic Chemicals Used for Leather Production Poisoning India's Tannery Workers', *The Ecologist*, 26 October 2012

Bennett, Jane, *Vibrant Matter: A Political Ecology Of Things* (Durham, N.C.: Duke University Press, 2010)

Berger, John, 'Branching Out', in *Berger on Drawing*, ed. by Jim Savage (Aghabullogue, Co. Cork, Ireland: Occasional Press, 2005), pp. 78–83

———, 'Drawing: Correspondence with Leon Kossoff', in *The Shape of a Pocket* (London: Bloomsbury, 2001)

———, 'Drawing on Paper', in *Keeping a Rendevous* (Granta, 1992)

———, 'Lobster and Three Fishes: A Dialogue between John and Yves Berger', in *Berger on Drawing*, ed. by Jim Savage (Aghabullogue, Co. Cork, Ireland: Occasional Press, 2005), pp. 119–45

———, 'Steps towards a Small Theory of the Visible', in *The Shape of a Pocket* (London: Bloomsbury, 2001)

———, *Ways of Seeing* (London: Penguin, 1972)

Berger, John, and Jean Mohr, *Another Way of Telling: A Possible Theory of Photography* (New York: Pantheon Books, 1982)

Bergson, Henri, *Creative Evolution*, trans. by Arthur Mitchell (New York: Henry Holt, 1911)

Bharath, Kaveri, 'Dr. Sekhar Raghavan: The Rain Man', in *Champions of Chennai*, 2018, pp. 28–30

Bhat, Harshavardhan, 'Stickiness in a Monsoon Air Methodology', in *Rubber Boots Methods for the Anthropocene*, ed. by Nils Bubandt, Astrid Anderson, and Rachel Cypher (Minneapolis, MN: University of Minnesota Press)

Bhattacharya, Saptarshi, 'Pallavaram Colony Residents Complain of Water Contamination', *The Hindu*, 21 May 2004

Biggs, Iain, 'Deep Mapping: A Partial View', 2014 <http://www.iainbiggs.co.uk/2014/10/deep-mapping-a-partial-view/> [accessed 23 April 2018]

———, 'Hybrid Texts and Academic Authority: The Wager in Creative Research', in *Thinking Through Art: Reflections on Art as Research*, ed. by Katy Macleod and Lin Holdridge (Abingdon: Routledge, 2006), pp. 190–200

Björkman, Lisa, *Pipe Politics, Contested Waters: Embedded Infrastructures of Millennial Mumbai* (Durham, NC: Duke University Press, 2015)

Bordeleau, Erik, 'The Care of the Possible: Isabelle Stengers Interviewed', *Scapegoat*, 1, 2011, 12–27

Bowen, Robert, *Groundwater*, 2nd edn (Barking, Essex: Elsevier Applied Science Publishers Ltd., 1986)

Bremner, Lindsay, Beth Cullen, Christina Leigh Geros, Harshavardhan Bhat, Anthony Powis, and John Cook, *Monsoon as Method* (Barcelona: Actar, 2021)

Bridge, Gavin, 'The Hole World: Scales and Spaces of Extraction', *New Geographies*, 2 (2009), 43–49

Brindha, K., and L. Elango, 'Assessing the Changes in Groundwater Quality around Tanneries: The Chennai Example (India)', in *Understanding Freshwater Quality Problems in a Changing World* (International Association of Hydrological Sciences, 2013)

———, 'Impact of Tanning Industries on Groundwater Quality near a Metropolitan City in India', *Water Resources Management*, 26.6 (2012), 1747–61

———, 'PAHs Contamination in Groundwater from a Part of Metropolitan City, India: A Study Based on Sampling over a 10-Year Period', *Environmental Earth Sciences*, 71.12 (2014), 5113–

Bryant, Levi R, 'Ruins and Post-Correlationist Thoughts', *Larval Subjects*, 2018 <https://larvalsubjects.wordpress.com/2018/08/10/ruins-and-post-correlationist-thought/> [accessed 28 August 2018]

———, *The Democracy of Objects*, ed. by Graham Harman and Bruno Latour, *New Metaphysics* (Ann Arbor: Open Humanities Press, 2011)

Calvino, Italo, *Invisible Cities*, 1974

Carse, Ashley, 'Nature as Infrastructure: Making and Managing the Panama Canal Watershed', *Social Studies of Science*, 42.4 (2012), 539–63

Casey, Edward S., *Getting Back Into Place: Toward a Renewed Understanding of the Place-World* (Bloomington, IN: Indiana University Press, 1993)

Causey, Andrew, *Drawn to See* (North York, Onatario: University of Toronto Press, 2017)

Chandler, David, and Jonathan Pugh, 'Anthropocene Islands: There Are Only Islands after the End of the World', *Dialogues in Human Geography*, 2021

'Chennai Takes to Streets, Demands Water', *Times of India*, 7 June 2019 <https://timesofindia.indiatimes.com/city/chennai/city-takes-to-streets-demands-water/articleshow/69682204.cms>

Chorley, Richard J., 'The Drainage Basin as the Fundamental Geomorphic Unit', in *Introduction to Physical Hydrology*, ed. by Richard J. Chorley (London: Methuen & Co Ltd, 1969), pp. 37–59

Clark, Nigel, *Inhuman Nature: Sociable Life on a Dynamic Planet* (London: Sage, 2011)

Clark, Nigel, and Bronislaw Szerszynski, *Planetary Social Thought : The Anthropocene Challenge to the Social Sciences* (London: Polity, 2020)

Clark, Nigel, and Kathryn Yusoff, 'Geosocial Formations and the Anthropocene', *Theory, Culture & Society*, 34.2–3 (2017), 3–23

CMRL, 'Closure Of Bore Wells Along Tunnel Alignment', 2011 <https://chennaimetrorail.org/wp-content/uploads/2015/11/pres16.pdf> [accessed 20 June 2017]

Coelho, Karen, 'Lines in the Mud: Tank Eco-Restoration and Boundary Contestations in Chennai', *Urbanisation*, 5.2 (2020), 121–39

Coelho, Karen, and Nithya V. Raman, 'From The Frying-Pan to the Floodplain: Negotiating Land, Water And Fire In Chennai's Development', in *Ecologies of Urbanism in India: Metropolitan Civility and Sustainability*, ed. by Anne Rademacher and K Sivaramakrishnan (Hong Kong: Hong Kong University Press, 2013), pp. 145–68

Cohen, Jeffrey Jerome, *Stone: An Ecology of the Inhuman* (Minneapolis: University of Minnesota Press, 2015)

Colebrook, Claire, *Death of the PostHuman: Essays on Extinction, Vol. 1* (Ann Arbor: Open Humanities Press, 2014)

Cook, Ian, 'Follow the Thing: Papaya', *Antipode*, 36.4 (2004), 642–64

Coole, Diana, and Samantha Frost, 'Introducing the New Materialisms', in *New Materialisms: Ontology, Agency, and Politics*, ed. by Diana Coole and Samantha Frost (Durham, NC: Duke University Press, 2010), pp. 1–43

Creuzé des Châtelliers, M., D. Poinsart, and J. -P. Bravard, 'Geomorphology of Alluvial

Groundwater Systems', in *Groundwater Ecology*, ed. by Janine Gilbert, Dan L. Danielopol, and Jack A. Stanford (London: Academic Press, 1994), pp. 157–85

Crossland, Zoë, 'Evidential Regimes of Forensic Archaeology', *Annual Review of Anthropology*, 42 (2013), 121–37

Crotty, Michael, *The Foundations of Social Research: Meaning and Merspective in the Research Process* (London: SAGE, 1998)

Cruikshank, Julie, *Do Glaciers Listen? Local Knowledge, Colonial Encounters, & Social Imagination* (Vancouver, BC: UBC Press, 2005)

Cullen, Beth, and Christina Leigh Geros, 'Constructing the Monsoon: Colonial Meteorological Cartography , 1844-1944', *History of Meteorology*, 9 (2020)

Cunha, Dilip da, *The Invention of Rivers: Alexander's Eye and Ganga's Descent* (Philadelphia, PA: University of Pennsylvania Press, 2019)

Cushing, Sumner W., 'The East Coast of India', *Bulletin of the American Geographical Society*, 45.2 (1913), 81–92

Dalin, Carole, Yoshihide Wada, Thomas Kastner, and Michael J. Puma, 'Groundwater Depletion Embedded in International Food Trade', *Nature*, 543.7647 (2017), 700–704

Darcy, Henry, *Les Fontaines Publiques de La Ville de Dijon* (Paris: Dalmont, 1856)

Davies, Thom, 'Slow Violence and Toxic Geographies: "Out of Sight" to Whom?', *Environment and Planning C: Politics and Space*, 2019

Davis, Heather, 'Molecular Intimacy', in *Climates : Architecture and the Planetary Imaginary*, ed. by James Graham (Zurich: Lars Müller Publishers, 2016), pp. 205–11

Debaise, Didier, 'The Emergence of a Speculative Empiricism: Whitehead Reading Bergson', in *Deleuze, Whitehead, Bergson: Rhizomatic Connections*, ed. by Keith Robinson (Basingstoke: Palgrave Macmillan, 2009), pp. 77–88

DeLanda, Manuel, *A Comparison of Deleuze's Assemblage Theory and the New Materialist Approach*, *Assemblage Thinking Symposium 2017, University of the Aegean*, 2017

———, *A Thousand Years of Nonlinear History* (New York: Zone Books, 1997)

———, 'Nonorganic Life', *Zone 6: Incorporations*, 1992, 129–67

Deleuze, Gilles, *Bergsonism* (New York: Zone Books, 1991)

———, *Foucault*, trans. by Seán Hand (Minneapolis, MN: University of Minnesota Press, 1988)

Deleuze, Gilles, and Félix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. by Brian Massumi (Minneapolis, MN: University of Minnesota Press, 1987)

Denizen, Seth, 'Three Holes in the Geological Present', in *Architecture in the Anthropocene: Encounters Among Design, Deep Time, Science and Philosophy*, ed. by Etienne Turpin (Open Humanities Press, 2013), pp. 29–46

Descola, Phillipe, *The Ecology of Others*, trans. by Geneviève Godbout and Benjamin P. Luley (Chicago: Prickly Paradigm Press, 2013)

Desmond, Matthew, 'Relational Ethnography', *Theory and Society*, 43.5 (2014), 547–79

Dewsbury, John-David, 'Performative, Non-Representational, and Affect-Based Research: Seven Injunctions', in *The SAGE Handbook of Qualitative Geography*, ed. by Dydia DeLyser, Steve Herbert, Stuart Aitken, Mike Crang, and Linda McDowell (London: SAGE Publications Ltd, 2010), pp. 321–34

———, 'Witnessing Space: "Knowledge without Contemplation"', *Environment and Planning A*, 35 (2003), 1907–32

Douglas, Mary, *Purity and Danger: An Analysis of Concepts of Pollution and Taboo* (New York: Routledge, 1966)

Dubey, C. S., B. K. Sahoo, and N. R. Nayak, 'Chromium (VI) in Waters in Parts of Sukinda Chromite Valley and Health Hazards, Orissa, India', *Bulletin of Environmental Contamination and Toxicology*, 67.4 (2001), 541–48

Edgeworth, Matt, 'On the Agency of Rivers', *Archaeological Dialogues*, 21.2 (2014), 157–59

EFSA Panel on Dietetic Products Nutrition and Allergies (NDA), 'Scientific Opinion on Dietary Reference Values for Chromium', *EFSA Journal*, 12.10 (2014), 3845

Ehlen, Judy, 'Above the Weathering Front: Contrasting Approaches to the Study and Classification of Weathered Mantle', *Geomorphology*, 67.1–2 (2005), 7–21

Elango, S., *Health Status and Epidemiological Study Around 5 Km Radius of Sterlite Industries (India) Limited, Thoothukudi* (Tirunelveli: Department of Community Medicine, Tirunelveli Medical College, 2008)

'Experts Collect Water Samples at Tondiarpet', *The Hindu*, 26 July 2013 <https://www.thehindu.com/news/cities/chennai/experts-collect-water-samples-at-tondiarpet/article4953534.ece#>

Express News Service, 'Rs 233 Crore Set aside to Tide over Chennai Water Crisis', *New Indian Express*, 1 June 2019 <https://www.newindianexpress.com/cities/chennai/2019/jun/01/rs-233-crore-set-aside-to-tide-over-chennai-water-crisis-1984457.html>

'Falling Palar Water Table Sparks Concern', *The Hindu*, 26 March 2013 <https://www.thehindu.com/news/cities/chennai/falling-palar-water-table-sparks-concern/article4548317.ece>

Finn, Geraldine, 'The Politics of Spirituality: The Spirituality of Politics', in *Shadow of Spirit: Postmodernism and Religion* (London: Routledge, 1992)

Foote, R. B., 'On the Distribution of Stone Implements in Southern India', *Quarterly Journal of the Geological Society*, 24.1–2 (1868), 484–95

Foucault, Michel, *Discipline and Punish* (London: Pantheon, 1977)

Fox, Nick J., and Pam Alldred, 'New Materialist Social Inquiry: Designs , Methods and the Research-Assemblage', *International Journal of Social Research Methodology*, 18.4 (2015), 399–414

Freeze, R. Allan, and John A. Cherry, *Groundwater* (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1979)

'Fresh Cracks Emerge on Anna Salai near Gemini Flyover Sparking Fears of Another Cave-In', *The News Minute*, 2017 <https://www.thenewsminute.com/article/fresh-cracks-emerge-anna-salai-near-gemini-flyover-sparking-fears-another-cave-60159> [accessed 10 May 2019]

Gallagher, Sean, 'India: The Toxic Price of Leather', *Pulitzer Center*, 2014 <https://pulitzercenter.org/stories/india-toxic-price-leather-0>

Gandy, Matthew, 'Liquid City', 2007 <https://www.youtube.com/watch?v=u2UPPjlgb9k> [accessed 18 October 2016]

Gassman, P. W., M. R. Reyes, C. H. Green, and J. G. Arnold, 'The Soil And Water Assessment Tool: Historical Development, Applications, And Future Research Directions', *Transactions*

Of The ASABE, 50.4 (2007), 1211–50

Gautham, Komal, 'Chennai: Getting Your Bubble-Top Cans May Become Harder', *Times of India*, 16 June 2019 <http://timesofindia.indiatimes.com/articleshow/69808535.cms>

———, 'Concerns Arise over Quality of Tanker Water in Chennai', *Times of India*, 10 June 2019 <https://timesofindia.indiatimes.com/city/chennai/concerns-arise-over-quality-of-tanker-water-in-chennai/articleshow/69718267.cms>

Geological Survey of India, 'Survey of India: Madras Quadrangle' (Calcutta: Geological Survey of India, 1999)

Ghosn, Rania, and El Hadi Jazairy, *Geostories: Another Architecture for the Environment* (ACTAR, 2018)

Gibert, Janine, Dan L. Danielopol, and Jack A. Stanford, *Groundwater Ecology* (London: Academic Press, 1994)

Gibson, James J., *The Ecological Approach to Visual Perception* (Boston: Houghton Mifflin, 1979)

Goodbun, Jon, 'Gregory Bateson's Ecological Aesthetics - an Addendum to Urban Political Ecology', *Field*, 4.1 (2011), 35–46

Government of India (Ministry of Water Resources), 'Cauvery Water Disputes Tribunal', 2007

Government of Tamil Nadu, *State Action Plan on Climate Change of Tamil Nadu State: Towards Balanced Growth and Resilience*, 2014

Gowrisankar, G., Ramachandran Chelliah, Sudha Rani Ramakrishnan, Vetrimurugan Elumalai, Saravanan Dhanamadhavan, Karthikeyan Brindha, and others, 'Data Descriptor: Chemical, Microbial and Antibiotic Susceptibility Analyses of Groundwater after a Major Flood Event in Chennai', *Nature*, 2017

Graft, Auralice, Ashwin Mahalingam, A. Ramachandran, Akshaya Ayyangar, O. Hemasree, Devashish Mankar, and others, *Chennai: State of Water* (Chennai: Tamil Nadu State Land Use Board, 2019)

Grosz, Elizabeth, 'Bodies-Cities', in *Sexuality and Space*, ed. by Beatriz Colomina (New York: Princeton Architectural Press, 1992), pp. 241–54

Le Guin, Ursula K., 'Keynote (Arts of Living on a Damaged Planet)', 2014 <https://vimeo.com/97364872> [accessed 6 September 2018]

Gustafson, Chloe, Kerry Key, and Rob L. Evans, 'Aquifer Systems Extending Far Offshore on the U.S. Atlantic Margin', *Scientific Reports*, 9.1 (2019), 8709

Haack, Sheridan K., and Barbara A. Bekins, 'Microbial Populations in Contaminant Plumes', *Hydrogeology Journal*, 8.1 (2000), 63–76

Halperin, Ilana, 'Integrating Catastrophe: A Talk on Drawing', 2003 <http://www.ilanahalperin.com/new/drawing_talk.html> [accessed 12 January 2020]

Hantush, Mahdi S., 'Modification of the Theory of Leaky Aquifers', *Journal of Geophysical Research*, 65.11 (1960), 3713–25

Haraway, Donna, 'Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective', *Feminist Studies*, 14.3 (1988), 575–99

———, 'The Promises of Monsters: A Regenerative Politics for Inappropriate/d Others', in *Cultural Studies*, ed. by Lawrence Grossberg, Cary Nelson, and Paula A. Treichler (New York: Routledge, 1992), pp. 295–336

Harding, Sandra, *Whose Science? Whose Knowledge?: Thinking From Women's Lives* (Milton Keynes: Open University Press, 1991)

Harman, Graham, 'I Am Also of the Opinion That Materialism Must Be Destroyed', *Environment and Planning D: Society and Space*, 28.5 (2010), 772–90

Harmsen, Joop, and René P.J.J. Rietra, '25 Years Monitoring of PAHs and Petroleum Hydrocarbons Biodegradation in Soil', *Chemosphere*, 207 (2018), 229–38

Harvey, David, 'Space as a Key Word', in *Marx and Philosophy Conference*, 2004

Hawkins, Harriet, 'Underground Imaginations, Environmental Crisis and Subterranean Cultural Geographies', *Cultural Geographies*, 27.1 (2020), 3–21

Heeks, Richard, and Satyarupa Shekhar, *An Applied Data Justice Framework: Analysing Datafication and Marginalised Communities in Cities of the Global South*, Development Informatics, 2018

Hird, Myra J., and Kathryn Yusoff, 'Subtending Relations : Bacteria , Geology , and the Possible', in *Geneaologies of Speculation*, ed. by Suhail Malik and Armen Avanessian (Continuum Press, 2014)

Holbraad, Martin, *Can the Thing Speak?*, *OAC Press Working Papers Series*, 2011

Holbraad, Martin, and Morten Axel Pedersen, *The Ontological Turn: An Anthropological Exposition* (Cambridge: Cambridge University Press, 2017)

Hubbert, M. King, 'The Theory of Ground-Water Motion', *Journal of Geology*, 48 (1940), 785–944

Humphreys, W. F., 'Hydrogeology and Groundwater Ecology: Does Each Inform the Other?', *Hydrogeology Journal*, 17.1 (2009), 5–21

Hylland, Ketil, 'Polycyclic Aromatic Hydrocarbon (PAH) Ecotoxicology in Marine Ecosystems', *Journal of Toxicology and Environmental Health, Part A*, 69.1–2 (2006), 109–23

Hynes, H. B. N., 'The Stream and Its Valley', *SIL Proceedings, 1922-2010*, 19.1 (1975), 1–15

Indian Geotechnical Services, *Geotechnical Investigation Report for DDC-101 - Chennai Metro Rail Project Phase-1 Extension from Washeranpet to Wimco Nagar: Proposed Underground Section* (New Delhi: Indian Geotechnical Services, 2015)

Ingold, Tim, 'Earth, Sky, Wind, and Weather', *Journal of the Royal Anthropological Institute*, 13.S1 (2007), S19–38

———, 'Ground', *Society and Space*, 2019 <http://societyandspace.org/2019/03/03/ground/>

———, 'Materials Against Materiality', *Archeological Dialogues*, 14.1 (2007), 1–16

———, 'Toward an Ecology of Materials', *Annual Review of Anthropology*, 41.1 (2012), 427–42

Invisible Photographer Asia, 'Extending The Materiality And Dimensionality Of Photography – Harikrishna Katragadda', 2018 <https://invisiblephotographer.asia/2018/08/03/harikrishnakatragadda-awardsinterview/>

Jacobus, Mary, *Romantic Things* (Chicago: University of Chicago Press, 2012)

James, William, 'Varieties of Religious Experience: A Study in Human Nature' (New York: Longmans, Green, and Co., 1902)

Jayaraman, Nityanand, 'Unfit for Habitation: Life in Chennai's Industrial Badlands', *Carboncopy*, 2020 <https://carboncopy.info/unfit-for-habitation-living-amid-chennais-industrial-badlands/> [accessed 6 January 2021]

Jensen, Casper Bruun, 'Continuous Variations: The Conceptual and the Empirical in STS', *Science, Technology & Human Values*, 39.2 (2013), 192–213

Jouhki, Jukka, 'Imagining the Other: Orientalism and Occidentalism in Tamil-European Relations in South India' (University of Jyväskylä, 2006)

Jullien, François, *Living off Landscape: Or the Unthought-of in Reason*, trans. by Pedro Rodriguez (London: Rowman & Littlefield, 2018)

Kaika, Maria, *City of Flows: Modernity, Nature, and the City* (London: Routledge, 2005)

Kaliraj, S., N. Chandrasekar, and N. S. Magesh, 'Impacts of Wave Energy and Littoral Currents on Shoreline Erosion/Accretion along the South-West Coast of Kanyakumari, Tamil Nadu Using DSAS and Geospatial Technology', *Environmental Earth Sciences*, 71.10 (2014), 4523–42

Kampf, Stephanie K., and Stephen J. Burges, 'Parameter Estimation for a Physics-Based Distributed Hydrologic Model Using Measured Outflow Fluxes and Internal Moisture States', *Water Resources Research*, 43.12 (2007)

Karpagam, V, and K Ramesh, 'Assessment of Groundwater Quality of Chrompet Industrial Area by Water Quality Index Method', 3.7 (2015), 123–32

Katragadda, Harikrishna, 'You Can't Step into the Same River Twice', 2018 <https://harikatragadda.wixsite.com/ganga/ganga-river-pollution>

Keller, Susanne B., 'Sections and Views: Visual Representation in Eighteenth-Century Earthquake Studies', *BJHS*, 31, 1998, 129–59

Khakbaz, Behnaz, Bisher Imam, Kuolin Hsu, and Soroosh Sorooshian, 'From Lumped to Distributed via Semi-Distributed: Calibration Strategies for Semi-Distributed Hydrologic Models', *Journal of Hydrology*, 418–419 (2012), 61–77

Kinchy, Abby J., Roopali Phadke, and Jessica M. Smith, 'Engaging the Underground: An STS Field in Formation', *Engaging Science, Technology, and Society*, 4 (2018), 22–42

Koleli, N., and A. Demir, 'Chromite', *Environmental Materials and Waste: Resource Recovery and Pollution Prevention*, December, 2016, 245–63

Koskinen, Ilpo, 'Throwing the Baby Out or Taking Practice Seriously', in *Reflections and Connections: On the Relationship between Production and Academic Research*, ed. by Nithikul Nimkulrat and Tim O'Riley (Helsinki: University of Art and Design Helsinki, 2009), pp. 11–17

Kotaś, J., and Z. Stasicka, 'Chromium Occurrence in the Environment and Methods of Its Speciation', *Environmental Pollution*, 107 (2000), 263–83

Kovats, Tania, *The Drawing Book—a Survey of Drawing: The Primary Means of Expression* (London: Black Dog, 2005)

Kramrisch, Stella, *The Hindu Temple* (Calcutta: University of Calcutta, 1946)

Krishna Chaitanya, S.V., 'Tondiarpet Oil Leak: BPCL Told to Pay Another Rs 3 Lakh in Damages', *New Indian Express*, 24 February 2019 <https://www.newindianexpress.com/states/tamil-nadu/2019/feb/24/tondiarpet-oil-leak-bpcl-told-to-pay-another-3l-in-damages-1942864.html>

Krishnan, M. S., *Geology of India and Burma* (Madras: Higginbothams, 1956)

Kueper, B.H., G.P. Wealthall, J.W.N. Smith, S.A. Leharne, and D.N. Lerner, *An Illustrated Handbook of DNAPL Transport and Fate in the Subsurface*, R&D Publications, 2003

Kumar, A. Ramesh, and P. Riyazuddin, 'Chromium Speciation in Groundwater of a Tannery Polluted Area of Chennai City, India', *Environmental Monitoring and Assessment*, 160.1–4 (2010), 579–91

Kumar, M. Senthil, and L. Elango, 'Numerical Simulation of Groundwater Flow Regime in a Part of The Lower Palar River Basin, Southern India', in *Modelling in Hydrogeology*, ed. by L. Elango and R. Jayakumar (UNESCO-IHP, 2001), pp. 115–26

de la Bellacasa, Maria Puig, *Matters of Care: Speculative Ethics in More Than Human Worlds* (Minneapolis: University of Minnesota Press, 2017)

Lakshmi, Geeta, and S. Janakarajan, *Intricacies of Chennai Metropolitan Water Laws*, 2005

Landström, Catharina, and Sarah J. Whatmore, 'Virtually Expert: Modes of Environmental Computer Simulation Modeling', *Science in Context*, 27.4 (2014), 579–603

Landström, Catharina, Sarah J. Whatmore, and Stuart N. Lane, 'Learning through Computer Model Improvisations', *Science Technology and Human Values*, 38.5 (2013), 678–700

Latour, Bruno, 'From Realpolitik to Dingpolitik or How to Make Things Public', in *Making Things Public: Atmospheres of Democracy*, ed. by Bruno Latour and Peter Weibel (Cambridge, MA: MIT Press, 2005), pp. 2–34

———, *The Pasteurization of France*, trans. by Alan Sheridan and John Law (Cambridge, MA: Harvard University Press, 1988)

Latour, Bruno, and Albena Yaneva, '"Give Me a Gun and I Will Make All Buildings Move": An ANT's View of Architecture', in *Explorations in Architecture: Teaching, Design, Research*, ed. by Reto Geiser (Basel: Birkhäuser, 2008), pp. 80–89

Law, John, *After Method: Mess in Social Science Research* (Abingdon: Routledge, 2004)

Lee, David Robert, 'A Device for Measuring Seepage Flux in Lakes and Estuaries', *Limnology and Oceanography*, 22.1 (1977), 140–47

Lefebvre, Henri, *Rhythmanalysis: Space, Time and Everyday Life*, trans. by Stuart Elden and Gerald Moore (London: Continuum, 2004)

Leviton, Alan E, and Michele L Aldrich, 'The Impact of Travels on Scientific Knowledge : William Thomas Blanford , Henry Francis Blanford , and the Geological Survey of India , 1851-1889', 55.9 (2004), 117–37

Liboiron, Max, 'Toxins or Toxicants? Why the Difference Matters', *Discard Studies*, 2017 <https://discardstudies.com/2017/09/11/toxins-or-toxicants-why-the-difference-matters/>

Liboiron, Max, Manuel Tironi, and Nerea Calvillo, 'Toxic Politics: Acting in a Permanently Polluted World', *Social Studies of Science*, 48.3 (2018), 331–49

Linton, Jamie, 'Is the Hydrologic Cycle Sustainable? A Historical-Geographical Critique of a Modern Concept', *Annals of the Association of American Geographers*, 98.3 (2008), 630–49

Lorimer, Hayden, 'Cultural Geography: The Busyness of Being "More-than-Representational"', *Progress in Human Geography*, 29.1 (2005), 83–94

Lutsky, Karen, and Sean Burkholder, 'Curious Methods', *Places Journal*, 2017

Macfarlane, Robert, *Underland: A Deep Time Journey* (Hamish Hamilton, 2019)

Manivannan, V., and L. Elango, 'Leather Processing and Its Possible Impact on Groundwater Quality in Silk Road Sites: A Case Study from Chennai, India', *Environmental Earth Sciences*, 76.1 (2017), 1–8

Mariappan, Julie, 'City May Get 25 Million Litres per Day of Water a Day from Vellore via Wagons', *Times of India*, 4 June 2019 <https://timesofindia.indiatimes.com/city/chennai/city-may-get-25mld-of-water-a-day-from-vellore-via-wagons/articleshow/69640925.cms>

Mathew, Pheba, and Soumya Chatterjee, 'Chennai Street Flooded with Sewage Sludge, Blamegame between Residents and Metro Officials', *The News Minute*, 2017 <https://www.thenewsminute.com/article/chennai-street-flooded-sewage-sludge-blamegame-between-residents-and-metro-officials-60668> [accessed 10 May 2019]

Mattern, Shannon, 'Maintenance and Care', *Places Journal*, November 2018 <https://placesjournal.org/article/maintenance-and-care/> [accessed 21 June 2019]

———, 'The Big Data of Ice, Rocks, Soils, and Sediments', *Places Journal*, November 2017 <https://placesjournal.org/article/the-big-data-of-ice-rocks-soils-and-sediments/> [accessed 5 December 2017]

McDonnell, Jeffrey J., and Mary P. Anderson, eds., *Groundwater (Benchmark Papers in Hydrology)* (Wallingford: International Association of Hydrological Sciences, 2008)

McFarlane, Colin, 'Sanitation in Mumbai's Informal Settlements: State, `slum', and Infrastructure', *Environment and Planning A*, 40 (2008), 88–107

Medlicott, H. B., and W. T. Blanford, *A Manual of The Geology Of India, Part I* (Calcutta: Government of India, 1879)

van der Meer, Douwe G., Douwe J.J. van Hinsbergen, and Wim Spakman, 'Atlas of the Underworld: Slab Remnants in the Mantle, Their Sinking History, and a New Outlook on Lower Mantle Viscosity', *Tectonophysics*, 2017

Meillassoux, Quentin, *After Finitude: An Essay on the Necessity of Contingency*, trans. by Ray Brassier (London: Continuum, 2008)

Meinzer, Oscar Edward, 'Compressibility and Elasticity of Artesian Aquifers', *Economic Geology*, 23.3 (1928), 263–91

———, *Plants as Indicators of Ground Water*, Water-Supply Paper, 1927

Melo Zurita, María de Lourdes, Paul George Munro, and Donna Houston, 'Un-Earthing the Subterranean Anthropocene', *Area*, 50.3 (2018), 298–305

Merck KGaA, 'Diluted, Certified Standard Solutions (CRM) for Water and Wastewater Analysis' <https://www.merckmillipore.com/GB/en/analytics-sample-preparation/certified-standard-solutions/4qib.qB.BRMAAAFTnc8fGO_i,nav> [accessed 29 May 2019]

Miles-Watson, Jonathan, Hugo Reinert, and Helen Sooväli-Sepping, 'Introduction—Ruptured Landscapes', in *Ruptured Landscapes: Landscape, Identity and Social Change*, ed. by Jonathan Miles-Watson, Hugo Reinert, and Helen Sooväli-Sepping (Dordrecht: Springer Netherlands, 2015), pp. 1–7

Mishra, Haripriya, and Himanshu Bhusan Sahu, 'Environmental Scenario of Chromite Mining at Sukinda Valley – A Review', *International Journal of Environmental Engineering and Management*, 4.4 (2013), 287–92

Mishra, Vimal, Amar Deep Tiwari, Saran Aadhar, Reepal Shah, Mu Xiao, and Dennis Lettenmaier, 'Drought and Famine in India , 1870 – 2016', *Geophysical Research Letters*, 2019

Mollard, Manon, Eleanor Beaumont, Lili Zarzycki, and Ellen Peirson, 'Underground', *Architectural Review*, 1480, 2021, 3

Murton, Brian J., 'Monsoons in Agricultural Proverbs in Tamil Nadu', in *Monsoons*, ed. by J.S.

Fein and P.L. Stephens (New York: John Wiley & Sons, 1987), pp. 77–102

Myers, Natasha, 'Conversations on Plant Sensing : Notes from the Field', *Natureculture*, 3, 2015, 35–66

Namakkal, Jessica, 'European Dreams, Tamil Land: Auroville and the Paradox of a Postcolonial Utopia', *Journal of the Study of Radicalism*, 6.1 (2012), 59–88

Nambi, Indumathi M., 'Inland Petroleum Spills – Environmental Issues and Cleanup', in *Oil Spills India*, 2014

Nambi, Indumathi M., Bokam Rajasekhar, Vijay Loganathan, and R. RaviKrishna, 'An Assessment of Subsurface Contamination of an Urban Coastal Aquifer Due to Oil Spill', *Environmental Monitoring and Assessment*, 189.148 (2017)

Nambi, Indumathi M., R. Ravikrishna, and Vijay Loganathan, *Environmental Site Assessment of Tondiarpet Oil Spill Site* (Chennai, 2014)

Narasimhan, Balaji, S. Murty Bhallamudi, Arpita Mondal, Subimal Ghosh, and Pradeep Mujumdar, *Chennai Floods 2015: A Rapid Assessment* (Bangalore, 2016)

Narasimhan, T. N., 'Hydraulic Characterization of Aquifers, Reservoir Rocks, and Soils: A History of Ideas', *Water Resources Research*, 34.1 (1998), 33–46

Nayak, Suman, Rangabhashiyam S., Balasubramanian P., and Paresh Kale, 'A Review of Chromite Mining in Sukinda Valley of India: Impact and Potential Remediation Measures', *International Journal of Phytoremediation*, 22.8 (2020), 804–18

Neild, Susan M., 'Colonial Urbanism: The Development of Madras City in the Eighteenth and Nineteenth Centuries', *Modern Asian Studies*, 13.02 (1979), 217

Neuman, Shlomo P., 'Theory of Flow in Unconfined Aquifers Considering Delayed Response of the Water Table', *Water Resources Research*, 8.4 (1972), 1031–45

Nilekani, Rohini, 'Rohini Nilekani Dreams of Making Invisible Water Visible', *Livemint*, 10 August 2018 <https://www.livemint.com/Leisure/7ztndZVQNjFd9HVtfn9vnI/Rohini-Nilekani--Making-invisible-water-visible.html> [accessed 6 September 2018]

NITI Aayog, *Composite Water Management Index: A Tool for Water Management*, 2018

Nwankwoala, H.O, 'Towards a Conceptual Understanding of Groundwater Ecology', *European Journal of Sustainable Development*, 1.3 (2012), 493–508

Oppili, P., 'Heavy Rainfall Last Monsoon Cleaned up Groundwater', *Times of India*, 2016 <http://timesofindia.indiatimes.com/city/chennai/Heavy-rainfall-last-monsoon-cleanedup-groundwater/articleshow/51786030.cms> [accessed 15 February 2017]

———, 'Monsoon Ends, Level of Groundwater up in Chennai', *Times of India*, 4 January 2020 <https://timesofindia.indiatimes.com/city/chennai/monsoon-ends-level-of-groundwater-up-in-chennai/articleshow/73092749.cms> [accessed 15 July 2020]

Padma, V., N. N. Anand, R. Karthikeyan, K. Madhumidha, M. S.A. Javi, and Rudach Mituldevan, 'Occupational Health Hazards among the Workers in Leather Tanneries near Chromepet', *Biomedicine (India)*, 36.4 (2016), 109–12

Palmer, Joni, and Joern Langhorst, 'Landscape Forensics 2.0', in *AAG Annual Meeting* (Washington, DC, 2019) <https://aag.secure-abstracts.com/AAG Annual Meeting 2019/sessions-gallery/24395>

Pankow, James F., and John A. Cherry, *Dense Chlorinated Solvents and Other DNAPLs in Groundwater: History, Behavior, and Remediation* (Portland, Oregon: Waterloo Press, 1996)

Papadopoulos, Dimitris, *Experimental Practice: Technoscience, Alterontologies, and More-than-Social Movements* (Durham, NC: Duke University Press, 2018)

Pappu, Shanti, 'Changing Trends in the Study of a Paleolithic Site in India: A Century of Research at Attirampakkam', in *The Evolution and History of Human Populations in South Asia*, ed. by Michael D. Petraglia and Bridget Allchin (Dordrecht: Springer, 2007), pp. 121–35

Parameswari, K., and B. V. Mudgal, 'Assessment of Contaminant Migration in an Unconfined Aquifer around an Open Dumping Yard: Perungudi a Case Study', *Environmental Earth Sciences*, 74.7 (2015), 6111–22

———, 'Geochemical Investigation of Groundwater Contamination in Perungudi Dumpsite, South India', *Arabian Journal of Geosciences*, 7.4 (2014), 1363–71

Parikka, Jussi, 'Deep Times of Planetary Trouble', *Cultural Politics*, 12.3 (2016), 279–92

Parletta, Natalie, 'The Importance Of Groundwater And Of Predicting Human Impacts On It', *Forbes*, 2019 <https://www.forbes.com/sites/natalieparletta/2019/07/17/the-importance-of-groundwater-and-of-predicting-human-impacts-on-it/>

'Parts of Chromepet Get Contaminated Water', *The Hindu*, 16 July 2019 <https://www.thehindu.com/news/cities/chennai/parts-of-chromepet-get-contaminated-water/article28455470.ece>

Perrone, Debra, and Scott Jasechko, 'Deeper Well Drilling an Unsustainable Stopgap to Groundwater Depletion', *Nature Sustainability*, 2.8 (2019), 773–82

Pétursdóttir, Thóra, 'Small Things Forgotten Now Included, or What Else Do Things Deserve?', *International Journal of Historical Archaeology*, 16.3 (2012), 577–603

Pezzulo, Phaedra Carmen, *Toxic Tourism: Rhetorics of Pollution, Travel, and Environmental Justice* (Tuscaloosa: University of Alabama Press, 2007)

Pink, Sarah, *Doing Sensory Ethnography* (London: SAGE Publications Ltd, 2009)

Poland, Joe F., and George H. Davis, 'Land Subsidence Due to Withdrawal of Fluids', *Reviews in Engineering Geology*, 2 (1969), 187–268

Povinelli, Elizabeth, *Geontologies: A Requiem to Late Liberalism* (Durham, NC: Duke University Press, 2016)

———, 'Geontologies: The Figures and the Tactics', *E-Flux*, 2016 <http://www.e-flux.com/journal/78/81514/geontologies-the-figures-and-the-tactics/> [accessed 10 May 2017]

———, 'The Aesthetic Mark and the Cultic Difference [Talk]', *Showroom Gallery* (London, 30 October 2017)

Povinelli, Elizabeth, Mathew Coleman, and Kathryn Yusoff, 'An Interview with Elizabeth Povinelli: Geontopower, Biopolitics and the Anthropocene', *Theory, Culture & Society*, 34.2–3 (2017), 169–85

Powers, Richard, *The Overstory* (New York: W. W. Norton & Company, 2018)

Powis, Anthony, 'Acts of Drawing Something You Cannot See', in *Monsoon [+ other] Grounds*, ed. by Lindsay Bremner and John Cook (London: Monsoon Assemblages, 2020), pp. 89–95.

———, 'The Relational Materiality of Groundwater', *GeoHumanities*, 7.1 (2021), 89-112.

Prakash, Pavithra, and Indumathi M. Nambi, 'Dissolution and Contaminant Transport in Aquifers with Spatially and Temporally Variable Hydraulic Properties', *Special Topics and Reviews in Porous Media*, 3.4 (2012), 353–69

Radhakrishna, B. P., 'Man-Made Drought and the Looming Water Crisis', *Geological Society of India*, 63.5 (2004), 477–81

Rahder, Micha, *An Ecology of Knowledges: Fear, Love, and Technoscience in Guatemalan Forest Conservation* (Durham, NC: Duke University Press, 2020)

Raicy, M. C, S. Parimala Renganayaki, K. Brindha, and L. Elango, 'Mitigation of Seawater Intrusion by Managed Aquifer Recharge', in *Managed Aquifer Recharge: Methods, Hydrogeological Requirements, Pre and Post Treatment Systems*, ed. by L. Elango, V. C. Goyal, and W. Thomas, 2012, pp. 83–99

Ramakrishnan, Deepa H., 'Clean-up Time in Tondiarpet', *The Hindu*, 14 May 2015 <https://www.thehindu.com/news/cities/chennai/phase-ii-of-oil-clean-up-in-tondiarpet-commences/article7204465.ece> [accessed 30 June 2018]

Ramalingam, B. Jothi, 'A Thirsty Chennai Waits', *The Hindu*, 1 June 2019 <https://www.thehindu.com/news/cities/chennai/a-thirsty-chennai-waits/article27401259.ece>

Ramasamy, S. M., 'Remote Sensing and Active Tectonics of South India', *International Journal of Remote Sensing*, 27.20 (2006), 4397–4431

Ramesh, K, and V Thirumangai, 'Impacts of Tanneries on Quality of Groundwater in Pallavaram, Chennai Metropolitan City', 4.1 (2014), 63–70

Ramesh, Niranjana, 'A Tank Half Full: Water in the Socio-Ecological Imagination of Chennai', 2013

———, 'Between Fragments and Ordering: Engineering Water Infrastructures in a Postcolonial City', *Geoforum*, 119 (2021)

Rattenbury, Kester, *This Is Not Architecture: Media Constructions* (Abingdon: Routledge, 2002)

Reinert, Hugo, 'About a Stone: Some Notes on Geological Conviviality', *Environmental Humanities*, 8.1 (2016), 95–117

———, 'Entanglements: Intimacy and Nonhuman Ethics', *Society & Animals*, 2 (2014), 42–56

———, 'On the Shore: Thinking Water at a Prospective Mining Site in Northern Norway', *Society & Natural Resources*, 29.6 (2016), 711–24

Rivett, M., J. Drewes, M. Barrett, J. Chilton, S. Appleyard, H. Dieter, and others, 'Chemicals: Health Relevance, Transport and Attenuation', in *Protecting Groundwater for Health: Managing the Quality of Drinking-Water Sources*, ed. by O. Schmoll, G. Howard, J. Chilton, and I. Chorus (London: IWA Publishing, 2006)

Robinson, Keith, 'Glossary of 25 Key Terms', in *Deleuze, Whitehead, Bergson: Rhizomatic Connections*, ed. by Keith Robinson (Basingstoke: Palgrave Macmillan, 2009), pp. 220–34

———, 'Introduction', in *Deleuze, Whitehead, Bergson: Rhizomatic Connections*, ed. by Keith Robinson (Basingstoke: Palgrave Macmillan, 2009), pp. 1–27

Robson, Colin, *Real World Research: A Resource for Social Scientists and Practitioner-Researchers*, Second Edi (Oxford: Blackwell, 2002)

Roul, Avilash, 'Who Will Provide Water Security to Chennai?', *Down to Earth*, 2019 <https://www.downtoearth.org.in/blog/water/who-will-provide-water-security-to-chennai--64855>

Roumeau, Samuel, Aicha Seifelislam, Shazade Jameson, and Loraine Kennedy, *Water Governance and Climate Change Issues in Chennai*, Working Papers Series, 2015

Rouse, Joseph, *Knowledge and Power: Toward a Political Philosophy of Science* (Ithaca, NY: Cornell University Press, 1987)

Roy, Ananya, *City Requiem, Calcutta : Gender and the Politics of Poverty* (University of Minnesota Press, 2003)

Rubio, Fernando Domínguez, 'On the Discrepancy between Objects and Things: An Ecological Approach', *Journal of Material Culture*, 21.1 (2016), 59–86

Sahasranaman, A., and K. V. Emmanuel, *Common Effluent Treatment Plant: Pallavaram, Chennai, India*, 2001

Saravanan, Sukkampatti Palanisamy, Marc Desmet, Ambujam Neelakanta Pillai Kanniperumal, Saravanan Ramasamy, Nikita Shumskikh, and Cécile Grosbois, 'Geochemical Footprint of Megacities on River Sediments: A Case Study of the Fourth Most Populous Area in India, Chennai', *Minerals*, 9.11 (2019)

Saravanavel, J., and S. M. Ramasamy, 'Active Tectonics and Its Impacts over Groundwater Systems in the Parts of Tamil Nadu, India', *Arabian Journal of Geosciences*, 9.6 (2016), 429

Sathish, S., and L. Elango, 'An Integrated Study on the Characterization of Freshwater Lens in a Coastal Aquifer of Southern India', *Arabian Journal of Geosciences*, 9.14 (2016)

———, 'Groundwater Quality and Vulnerability Mapping of an Unconfined Coastal Aquifer', *Journal of Spatial Hydrology*, 11.1 (2011)

Scarpino, Philip V, 'Anthropocene World / Anthropocene Waters: A Historical Examination of Ideas and Agency', in *Rivers of the Anthropocene*, ed. by Jason M. Kelly, Philip V. Scarpino, Helen Berry, James Syvitski, and Michel Meybeck (Oakland, CA: University of California Press, 2018), pp. 101–15

Schuppli, Susan, *Material Witness: Media, Forensics, Evidence* (Cambridge, MA: MIT Press, 2020)

Sekar, Sunitha, 'Chennai Metro Tunnels near Completion', *The Hindu*, 5 November 2016 <https://www.thehindu.com/news/cities/chennai/Chennai-Metro-tunnels-near-completion/article16437160.ece>

Şen, Zekâi, *Practical and Applied Hydrology* (Amsterdam: Elsevier, 2015)

Senior, Kerry, 'Standards and Use Limitations for Chemicals in Leather Production', *Nothing to Hide* <http://nothing-to-hide.org/LeatherFacts/Chemistry:_not_all_bad>

Senthalir, S, 'As Lakes Dry up, Chennai Will Stop Receiving Water from Its Three Main Sources by June', *Scroll.In*, 2019 <https://scroll.in/article/922884/as-lakes-dry-up-chennai-will-stop-receiving-water-from-its-three-main-sources-by-june>

Shapiro, Nicholas, 'Attuning to the Chemosphere: Domestic Formaldehyde, Bodily Reasoning, and the Chemical Sublime', *Cultural Anthropology*, 30.3 (2015), 368–93

Shaviro, Steven, *The Universe of Things: On Speculative Realism* (Minnesota: University of Minnesota Press, 2014)

———, *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics* (Cambridge, MA: MIT Press, 2009)

Shekhar, Laasya, 'Flowing Water Bodies Become Parched Lands: Where Did the Water Go?', *Citizen Matters, Chennai*, 2019 <https://chennai.citizenmatters.in/lakes-encroachment-pallavaram-periya-keezhkattalai-eri-chennai-8926>

———, 'Where Is the Water to Wash Our Hands Frequently, Ask Residents of Ambattur and Chrompet', *Citizen Matters, Chennai*, 2020 <https://chennai.citizenmatters.in/water-crisis-

and-lockdown-in-chennai-suburbs-ambattur-chrompet-15471>

Shekhar, Satyarupa, 'Does Technology Reinforce Real-World Inequities?', *Transparent Chennai*, 2013 <http://www.transparentchennai.com/does-technology-reinforce-real-world-inequities/> [accessed 2 September 2019]

Shiklomanov, Igor, 'World Fresh Water Resources', *Water in Crisis a Guide to the World's Fresh Water Resources*, 1993, pp. 13–24

Sivakumar, R, '25 Years after Factory Downing Shutters, Chromium Sludge Causes Groundwater Contamination in Chennai', *New Indian Express*, 1 March 2020 <https://www.newindianexpress.com/cities/chennai/2020/mar/01/25-years-after-factory-downing-shutters-chromium-sludge-causes-groundwater-contamination-in-chennais-ranipet-2110455.html> [accessed 10 March 2020]

Sivaraman, K.R., and S. Thillaigovindarajan, *Micro-Level Status Report of Chennai River Basin* (New Delhi)

Sivaraman, R., 'Murky Waters in Tondiarpet', *The Hindu*, 3 April 2014 <https://www.thehindu.com/news/cities/chennai/chen-infra/murky-waters-in-tondiarpet/article5864195.ece>

de Sousa Santos, Boaventura, *The End of the Cognitive Empire* (Durham, NC: Duke University Press, 2018)

Srinivasachari, C. S., *History of the City of Madras* (Madras: P. Varadachary & Co., 1939)

Srinivasan, Veena, 'An Integrated Framework for Analysis of Water Supply Strategies in a Developing City: Chennai, India' (Stanford University, 2008)

———, 'Wake up, There's No Water!', *Deccan Herald*, 23 June 2019

Srinivasan, Veena, and Seema Kulkarni, 'Examining the Emerging Role of Groundwater in Water Inequity in India', *Water International*, 39.2 (2014), 172–86

Sriram, V., 'Lost Landmarks of Chennai #39', *Madras Musings*, 2018 <http://www.madrasmusings.com/vol-28-no-14/lost-landmarks-of-chennai-39/#> [accessed 10 March 2020]

Stalin, J Sam Daniel, 'Chennai Residents Blame Metro Tunnel For Groundwater Depletion', *NDTV*, 2019 <https://www.ndtv.com/tamil-nadu-news/chennai-residents-blame-metro-tunnel-for-groundwater-depletion-2035543> [accessed 10 May 2019]

Steinberg, Philip, and Kimberley Peters, 'Wet Ontologies, Fluid Spaces: Giving Depth to Volume through Oceanic Thinking', *Environment and Planning D: Society and Space*, 33.2 (2015), 247–64

Stengers, Isabelle, *The Invention of Modern Science* (Minneapolis, MN: University of Minnesota Press, 2000)

———, 'Thinking with Deleuze and Whitehead: A Double Test', in *Deleuze, Whitehead, Bergson: Rhizomatic Connections*, ed. by Keith Robinson (Basingstoke: Palgrave Macmillan, 2009), pp. 28–44

———, *Thinking with Whitehead: A Free and Wild Creation of Concepts*, trans. by Michael Chase (Cambridge, MA: Harvard University Press, 2014)

Strang, Veronica, 'Fluid Consistencies. Material Relationality in Human Engagements with Water', *Archaeological Dialogues*, 21.2 (2014), 133–50

Subramanian, Annamalai, Masako Ohtake, Tatsuya Kunisue, and Shinsuke Tanabe, 'High Levels

of Organochlorines in Mothers' Milk from Chennai (Madras) City, India', *Chemosphere*, 68.5 (2007), 928–39

Sudhakar, P, 'Ecological Heritage Sites of Chennai', *International Educational Scientific Research Journal*, 2.9 (2016), 15–17

Suganthi, S, L. Elango, and S K Subramanian, 'Groundwater Potential Zonation by Remote Sensing and GIS Techniques and Its Relation to the Groundwater Level in the Coastal Part of the Arani and Koratalai River Basin, Southern India', *Earth Sciences Research Journal*, 17.2 (2013), 87–95

Swaminathan, T.S.Atul, 'Residents of Chromepet, Surrounding Areas Complain of Erratic Water Supply', *The Hindu*, 25 July 2020 <https://www.thehindu.com/news/cities/chennai/residents-of-chromepet-surrounding-areas-complain-of-erratic-water-supply/article32192438.ece>

Swarup, Shubhangi, *Latitudes of Longing* (Noida, UP: HarperCollins India, 2018)

Swyngedouw, Erik, 'Modernity and Hybridity: Nature, Regeneracionismo, and the Production of the Spanish Waterscape, 1890–1930', *Annals of the Association of American Geographers*, 89.3 (1999), 443–65

Tamil Nadu State Ground and Surface Water Resources Data Centre, *Water Quality Information Guide* <http://www.groundwatertnpwd.org.in/report.htm> [accessed 10 March 2020]

Taylor, Jr., George C., *Historical Review of the International Water-Resources Program of the U.S. Geological Survey 1940-70* (Washington, DC: United States Government Printing Office, 1976)

Taylor, Marcus, *The Political Ecology of Climate Change Adaptation: Livelihoods, Agrarian Change and the Conflicts of Development*, *Routledge Explorations in Development Studies* (Abingdon: Routledge, 2015)

Tejonmayam, U, 'Monsoon Replenishes Groundwater, but Renders It Unfit for Consumption', *Times of India*, 6 March 2018 <https://timesofindia.indiatimes.com/city/chennai/monsoon-replenishes-groundwater-but-renders-it-unfit-for-consumption/articleshow/63177305.cms> [accessed 23 July 2020]

Terrain Guide of Chennai City <http://www.rainwaterharvesting.org/downloads/chennai_terrain.pdf> [accessed 17 February 2017]

The Hindu, 'Chennai Suffers with No Water' <https://www.youtube.com/watch?v=iaG7kRcSxwA>

Thomas, Brian F., 'How Deep Can the Straw Go?', *Nature Sustainability*, 2.8 (2019), 659–60

Thrift, Nigel, 'Intensities of Feeling: Towards a Spatial Politics of Affect', *Geografiska Annaler, Series B: Human Geography*, 86.1 (2004), 57–78

———, *Non-Representational Theory: Space, Politics, Affect* (Abingdon: Routledge, 2008)

———, *Spatial Formations* (London: SAGE, 1996)

Tironi, Manuel, and Nerea Calvillo, 'Water and Air: Territories, Tactics and the Elemental Textility of Urban Cosmopolitics', in *Urban Cosmopolitics: Agencements, Assemblies, Atmospheres*, ed. by Anders Blok and Ignacio Farias (Abingdon: Routledge, 2016), pp. 207–24

Tobiszewski, Marek, and Jacek Namie, 'PAH Diagnostic Ratios for the Identification of Pollution Emission Sources', 162 (2012), 110–19

Trentmann, Frank, 'Materiality in the Future of History: Things, Practices, and Politics', *The Journal of British Studies*, 48.02 (2009), 283–307

Tsing, Anna Lowenhaupt, 'Contaminated Diversity in "Slow Disturbance": Potential Collaborators for a Liveable Earth', in *Why Do We Value Diversity? Biocultural Diversity in a Global Context*, ed. by Gary Martin, Diana Mincyte, and Ursula Münster (Munich: Rachel Carson Centre, 2012), pp. 95–97

———, 'More-than-Human Sociality: A Call for Critical Description', in *Anthropology and Nature*, ed. by Kirsten Hastrup (New York: Routledge, 2013), pp. 27–42

———, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins* (Princeton: Princeton University Press, 2015)

———, 'When the Things We Study Respond to Each Other: Tools for Unpacking "The Material"', in *Anthropos and the Material*, ed. by Penny Harvey, Christian Krohn-Hansen, and Knut G. Nustad (Durham, NC: Duke University Press, 2019), pp. 221–44

Ugochukwu, Uzochukwu Cornelius, and Alfred Ochonogor, 'Groundwater Contamination by Polycyclic Aromatic Hydrocarbon Due to Diesel Spill from a Telecom Base Station in a Nigerian City: Assessment of Human Health Risk Exposure', *Environmental Monitoring and Assessment*, 190.249 (2018)

Ulmer, Jasmine B., 'Posthumanism as Research Methodology: Inquiry in the Anthropocene', *International Journal of Qualitative Studies in Education*, 30.9 (2017), 832–48

Urban Design Collective, and The Madras Office for Architects and Designers, *Urur Olcott Kuppam Model*, 2017

USDA Agricultural Research Service, 'SWAT - Soil and Water Assessment Tool', 2018 <https://data.nal.usda.gov/dataset/swat-soil-and-water-assessment-tool> [accessed 2 September 2019]

USGS, *2017 Minerals Yearbook: Chromium*, 2020

Vannini, Phillip, 'Non-Representational Ethnography: New Ways of Animating Lifeworlds', *Cultural Geographies*, 22.2 (2015), 317–27

Varkey, M. J., V. S. N. Murthy, and A. Suryanarayana, 'Physical Oceanography of the Bay of Bengal', *Oceanography and Marine Biology: An Annual Review*, 34 (1996), 1–70

Vasudevan, M., Indumathi M. Nambi, and G. Suresh Kumar, 'Scenario-Based Modelling of Mass Transfer Mechanisms at a Petroleum Contaminated Field Site-Numerical Implications', *Journal of Environmental Management*, 175 (2016), 9–19

de Vries, Franciska T., Rob I. Griffiths, Mark Bailey, Hayley Craig, Mariangela Girlanda, Hyun Soon Gweon, and others, 'Soil Bacterial Networks Are Less Stable under Drought than Fungal Networks', *Nature Communications*, 9.1 (2018)

Vutla, Bhoga Mandala Sayana, and S. Ravichandran, 'Groundwater Quality and Role of the Monsoon in Chennai City, South India', *Asian Journal of Chemistry*, 23.10 (2011), 4659–64

Wadia, D. N., *Geology of India* (London: Macmillan and Co., Limited, 1919)

Walsh, Bryan, 'The World's Most Polluted Places', *TIME*, 2007 <http://content.time.com/time/specials/2007/article/0,28804,1661031_1661028_1661016,00.html>

Walton, Brett, 'The Next Urban Water Crisis? Inadequate Data Clouds the Forecast', *Circle of Blue*, 2019 <https://www.circleofblue.org/2019/wef/the-next-urban-water-crisis-inadequate-data-clouds-the-forecast/>

Waltz, J. P., 'Ground Water', in *Introduction to Physical Hydrology*, ed. by Richard J. Chorley (London: Methuen & Co Ltd, 1969), pp. 122–30

Whatmore, Sarah, 'Earthly Powers and Affective Environments: An Ontological Politics of Flood Risk', *Theory, Culture & Society*, 30.7–8 (2013), 33–50

———, *Hybrid Geographies: Natures, Cultures, Spaces* (London: SAGE, 2002)

White, Richard, 'Discovering Nature in North America', *The Journal of American History*, 79.3 (1992), 874–91

———, *The Organic Machine: The Remaking of the Columbia River* (New York: Hill and Wang, 1995)

Whitehead, Alfred North, *Process and Reality: An Essay in Cosmology* (Cambridge: Cambridge University Press, 1929)

———, *Science and the Modern World* (Cambridge: Cambridge University Press, 1925)

———, *The Concept of Nature* (Cambridge: Cambridge University Press, 1920)

WHO, 'Chromium in Drinking-Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality', in *Guidelines for Drinking-Water Quality*, 2nd edn (Geneva: World Health Organisation, 1996), II

Williams, Rosalind, *Notes of the Underground: An Essay on Technology, Society, and the Imagination* (Cambridge, MA: MIT Press, 1990)

Wilson, Matthew W., 'New Lines? Enacting a Social History of GIS', *Canadian Geographer*, 59.1 (2015), 29–34

World Health Organization, *Guidelines for Drinking-Water Quality*, Fourth Edi, 2011

World Resources Institute, 'Aqueduct Water Risk Atlas' <https://www.wri.org/applications/aqueduct/water-risk-atlas>

Yokel, Robert A., Stephen M. Lasley, and David C. Dorman, 'The Speciation of Metals in Mammals Influences Their Toxicokinetics and Toxicodynamics and Therefore Human Health Risk Assessment', *Journal of Toxicology and Environmental Health - Part B: Critical Reviews*, 9.1 (2006), 63–85

Yusoff, Kathryn, 'Geologic Life: Prehistory, Climate, Futures in the Anthropocene', *Environment and Planning D: Society and Space*, 31.5 (2013), 779–95

———, 'Geosocial Strata', *Theory, Culture & Society*, 34.2–3 (2017), 105–27

Zeiderman, Austin, Sobia Ahmad Kaker, Jonathan Silver, and Astrid Wood, 'Uncertainty and Urban Life', *Public Culture*, 27.2 (2015), 281–304

Zhou, Dengen, Leslie A. Dillard, and Martin J. Blunt, 'A Physically Based Model of Dissolution of Nonaqueous Phase Liquids in the Saturated Zone', *Transport in Porous Media*, 39.2 (2000), 227–55