

Reimagining the amphibious city:

FROM HEALTH DATA TO ECOLOGICAL DESIGN IN AN AMAZONIAN INFORMAL COMMUNITY

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University of Washington

Abstract

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Rebecca Anne Bachman

Chair of the Supervisory Committee:

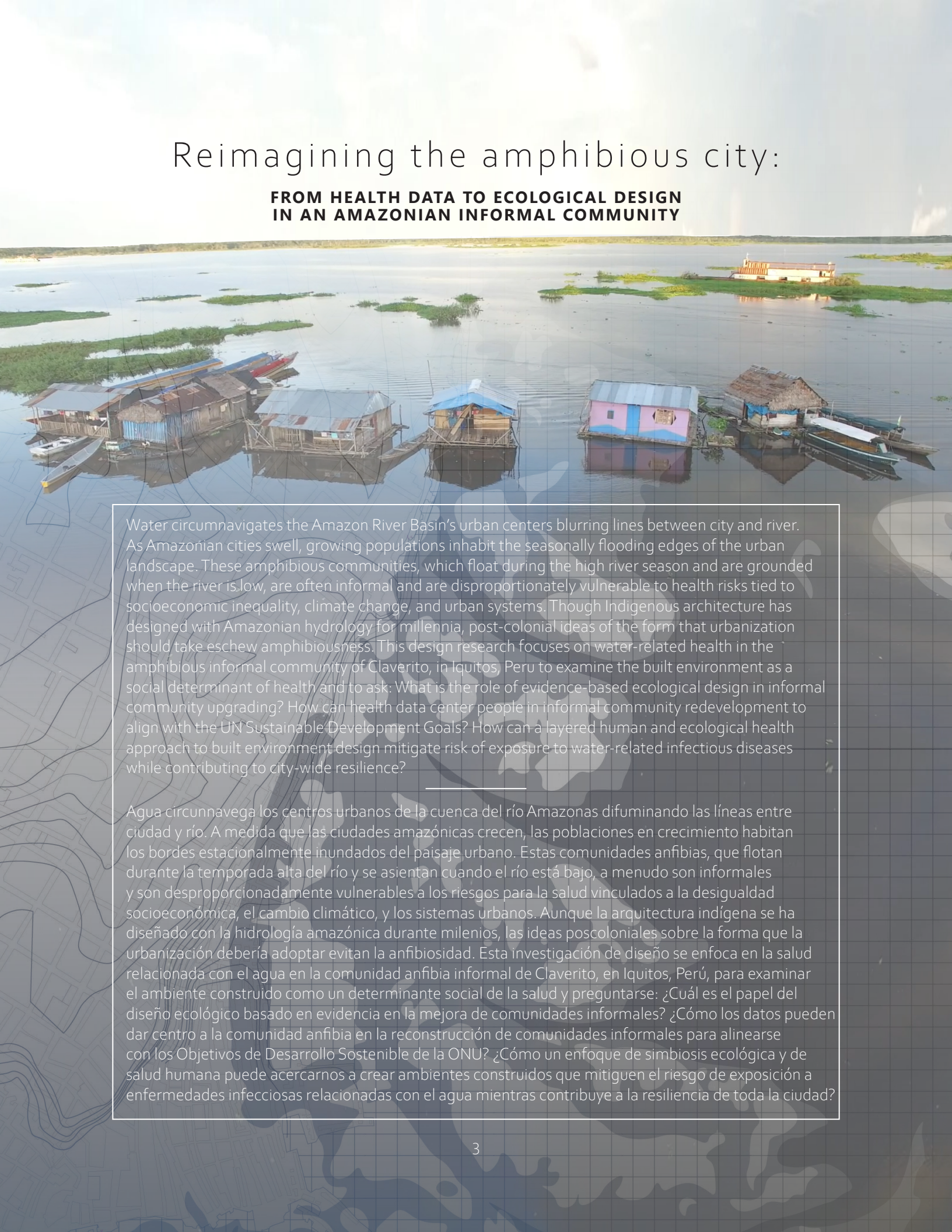
Nancy Rottle

Landscape Architecture

Water circumnavigates the Amazon River Basin's urban centers blurring lines between city and river. As Amazonian cities swell, growing populations inhabit the seasonally flooding edges of the urban landscape. These amphibious communities, which float during the high river season and are grounded when the river is low, are often informal and are disproportionately vulnerable to health risks tied to socioeconomic inequality, climate change, and urban systems. Though Indigenous architecture has designed with Amazonian hydrology for millennia, post-colonial ideas of the form that urbanization should take eschew amphibiousness. This design research focuses on water-related health in the amphibious informal community of Claverito, in Iquitos, Peru to examine the built environment as a social determinant of health and to ask: What is the role of evidence-based ecological design in informal community upgrading? How can health data center people in informal community redevelopment to align with the UN Sustainable Development Goals? How can a layered human and ecological health approach to built environment design mitigate risk of exposure to water-related infectious diseases while contributing to city-wide resilience?

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Agua circunnavega los centros urbanos de la cuenca del río Amazonas difuminando las líneas entre ciudad y río. A medida que las ciudades amazónicas crecen, las poblaciones en crecimiento habitan los bordes estacionalmente inundados del paisaje urbano. Estas comunidades anfibias, que flotan durante la temporada alta del río y se asientan cuando el río está bajo, a menudo son informales y son desproporcionadamente vulnerables a los riesgos para la salud vinculados a la desigualdad socioeconómica, el cambio climático, y los sistemas urbanos. Aunque la arquitectura indígena se ha diseñado con la hidrología amazónica durante milenios, las ideas poscoloniales sobre la forma que la urbanización debería adoptar evitan la anfibiosidad. Esta investigación de diseño se enfoca en la salud relacionada con el agua en la comunidad anfibia informal de Claverito, en Iquitos, Perú, para examinar el ambiente construido como un determinante social de la salud y preguntarse: ¿Cuál es el papel del diseño ecológico basado en evidencia en la mejora de comunidades informales? ¿Cómo los datos pueden dar centro a la comunidad anfibia en la reconstrucción de comunidades informales para alinearse con los Objetivos de Desarrollo Sostenible de la ONU? ¿Cómo un enfoque de simbiosis ecológica y de salud humana puede acercarnos a crear ambientes construidos que mitiguen el riesgo de exposición a enfermedades infecciosas relacionadas con el agua mientras contribuye a la resiliencia de toda la ciudad?

AUTHOR'S NOTE

My undergraduate degree from the University of California at Santa Barbara is in Global and International Studies with a regional focus on Latin America. I had the incredible opportunity during the course of that degree program to spend a year in Rio de Janeiro, Brazil, where I worked at a nongovernmental organization in an informal community, or favela, where I also lived, while studying at a local university on exchange. During that time, the street that I lived on in Rocinha was undergoing a major widening project as part of a public health campaign against tuberculosis, and, I would soon find out, as part of a larger effort to upgrade and pacify the community through public investment and a military dismantling of informal economy and governance.

This was a formative year that sowed in me a deep curiosity for public health, the intense socioeconomic inequality dividing people in cities all over the world, and how it all manifests in built environments, often in informal communities. In graduate school, I have pursued a dual education in landscape architecture and global health as well as opportunities to return to Iquitos, Peru through InterACTION Labs programming, all of which has provided opportunities to synthesize meaningful connections between design and issues I care about. That intersection between landscape architecture and global health is core to this thesis.

It is also necessary to point out that the major international forces that have caused and continue to perpetuate the problems central to this thesis stem from systems built and maintained by white people from high income countries such as myself. I believe that an exploration of methods that counter those classist, racist, non-inclusive forces is not only urgently needed, but also the responsibility of people of privilege, like myself, who have studied these issues, albeit from the outside, and aim to build conversations that advocate for informal community redevelopment that centers people and their environments.

ACKNOWLEDGMENTS

Thank you to the community of Claverito and Traction, whose collaboration through the InterACTION Labs program is foundational to this thesis. To Leann Andrews, Coco Alarcón, and so many team members in the field who have continued to work toward better futures year after year, thank you. I owe the greatest thank yous to Leann and Coco, who have trusted me with their data and encouraged me along the way, and especially to Leann, whose patient support at every step of the way has sustained this process. Further thank you to Nancy Rottle, for exposing me to floating wetlands and wetland ecology early on and for your continued support as committee chair.

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Thank you to my family—mom, dad, grandma, sister x 3, and the rest—your continued support through my unexpected life choices is not lost on me. And to Thor for your persistent support as I continually shift between being very much here and very much out of the country—thank you. Finally, thanks to my friends in this cohort; I've been enriched by each of you and look forward to years of friendship.

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Introduction

PROJECT OVERVIEW + LANGUAGE

Project overview + language

Claverito is an informal community along the eastern shore of the central district of Iquitos, Peru. Home to a fluctuating population of around 280 people in 52 homes, the amphibious community lives intimately with water: during seasonal floods, the community floats two to four meters (roughly six to 13 meters) over the floodplain floor, while the dry season grounds all structures. Community members are relatively recent migrants to the

continually urbanizing city of Iquitos; years lived in Claverito ranges from around one to 50 years, with an average of about 15 years. The community lacks access to clean water, sanitation, and waste management, among other infrastructure and improved conditions, exposing community members to a plethora of infectious diseases, among them dengue, malaria, and countless parasitic, viral, and bacterial infections.

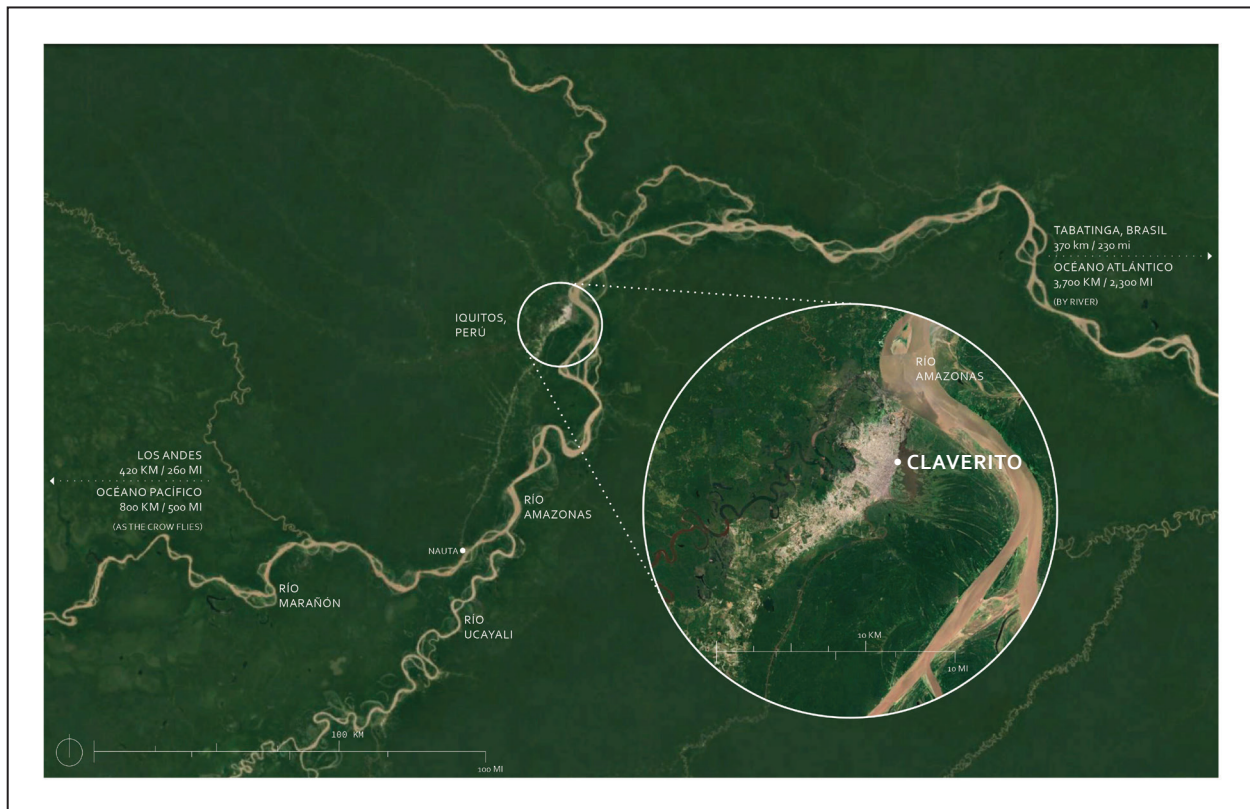


Figure - 1 - Claverito, Iquitos, Perú

Circumstances for Claverito are not unique. The waters of three rivers, Río Nanay, Río Itaya, and Río Amazonas surround Iquitos. Their floodplains are home to roughly 90,000 people—nearly 20 percent of the city’s population—living in communities with varying degrees of informality. Some have land rights. Some are connected to municipal plumbing. Some are on the electrical grid. Some may have improved public access to potable water. Yet all are disproportionately vulnerable to health risks tied to socioeconomic inequality, climate change, and urbanization.

Similar risks face growing urban populations throughout the Amazon, in cities from Iquitos to the delta city of Belém, Brazil and beyond. An effort to align with the UN’s Sustainable Development Goals (SDGs) shows that most if not all goals either directly or indirectly allude to conditions of urban Amazonian informal communities—goals like 1) no poverty; 3) good health and well-being; 6) clean water and sanitation; 9) industry, innovation and infrastructure; 10) reduced inequalities; 11)

sustainable cities and communities; 13) climate action; 14) life below water; 15) life on land; and 17) partnerships for the goals (United Nations, 2020).

Change is urgent. But “sustainable development” is easier said than done. The built environment is a social determinant of health, and is an important place to focus efforts toward achieving health equity (Marmot, 2007). This thesis explores how health data and a layered landscape systems approach can drive upgrading in place that works for human and ecological health and expand opportunities for sustainable development, building momentum toward attainment of SDGs.

This design research begins by gathering contextual threads at a regional scale. It then zooms in on Claverito to examine the existing burden of infectious diseases and the built environment as a social determinant of health (SDH) by examining several survey questions and other instruments whose responses and measurements offer detailed windows into health and the built environment



Figure - 2 - The urban Amazon

in Claverito. This leads into a design exploration that reimagines possibilities for evidence-based ecological design. Water runs its course throughout, narrowing the focus to water-related infectious diseases, human behavioral relationships with water, water quality, water ecology, and perceptions of water in urban design. The built environment as more than a mere interface between humans and water, but a shaper of experience, of health, of ecology.

Foundational to the Claverito case study is data collected by the Seattle-based non-governmental organization (NGO) Traction over the span of 2016 to 2019. Traction's data collection is part of a Transdisciplinary Action Research (TDAR) approach, which provides a framework for collaboration between professional design teams and community members to "address complex societal and ecological issues across scales – from immediate community scale needs to broader societal goals of public health, social and environmental justice, and ecological sustainability" (Andrews, 2018). Part of Traction's mission is to collect data that can inform best practices for professionals working with marginalized communities. Though the ideal application for this data would be layered into a community participatory process, this thesis explores how evidence-based design that applies Traction's data might begin to take form.

Table 1 (right) includes an overview of this thesis project and the questions that drive it. Research begins in chapter 2 by engaging a literature review and geospatial analysis to answer the question: *What are the long histories behind and conditions of amphibious informal communities in Iquitos?* Chapter 3 then transitions to a review of literature and scientific studies, with a specific eye out for studies that focus on infectious diseases, informal communities, or living intimately with water, to answer the question: *How do the built environment and health connect?*

Chapter 4 follows with a site analysis of Claverito, before research culminates in Chapter 5 with a secondary analysis of Traction's data to answer the two-part question: *What are the water-related health problems in Claverito, and how do they connect to the built environment?* Chapter 6 responds to research with a design exploration that asks: *How can ecological design be a tool for mitigating risk of exposure to water-related infectious diseases in Claverito?* An overview of methods and findings accompanies research questions in table 1.

PROJECT OVERVIEW

Table 1 - Project overview

		Research		
		FROM HISTORY TO HYDROLOGY (CH. 2)	HEALTH + THE BUILT ENVIRONMENT (CH. 3)	WATER-RELATED HEALTH IN CLAVERITO (CH.5)
RESEARCH QUESTION		What are the long histories behind + conditions of amphibious informal communities in Iquitos?	How do the built environment + health connect (focus on infectious diseases, informal communities + living intimately with water)?	What are the water-related health problems in Claverito + how do they connect to the built environment?
METHOD		Literature review (sociopolitical + built environment history, climate change) + geospatial analysis (geography, hydrology)	Literature review including the review of scientific studies.	Secondary analysis of relevant Traction data
FINDING		Amphibious informal communities face challenges stemming from history, conventional design + climate change.	The built environment is an interface between people + water-related infectious diseases.	Built environment conditions + interactions support water-related pathogens that affect community health in Claverito.
Design exploration (CH. 6)				
DESIGN QUESTION		How can ecological design be a tool for mitigating risk of exposure to water-related infectious diseases in Claverito?		DESIGN OUTCOME
				Design concepts for rainwater harvesting, amphibious biodigestion outhouses, aquatic phytoremediation buffers, and more.

CONCEPTS + DEFINITIONS

The following describe the concepts and definitions that were influential to the perspective and approach formulated in this thesis.

THE BUILT ENVIRONMENT + GLOBAL HEALTH

The built environment is broad; any place that has endured some anthropogenic influence is arguably a part of it. The built environment is not only shaped by design professionals like landscape architects, planners, and architects, but also by agents at various scales (e.g. individuals, communities, economies), driven by mixed motives (e.g. pleasure, hunger, profit), and acting across a spectrum from abstract to felt. The built environments in which we exist reflect thick histories and help to shape human experiences and human health. Wrapped up in built environments are all of humanity's inequities.

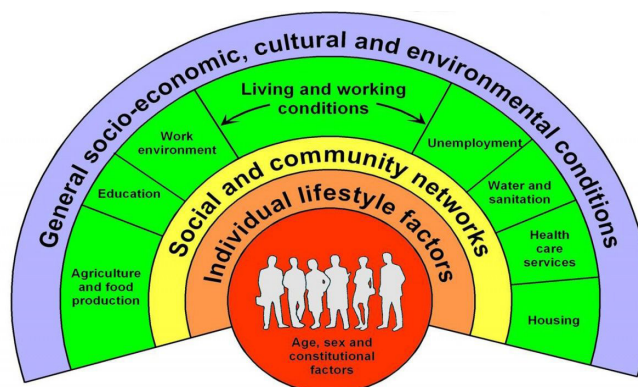
The field of global health examines population health within the global context and aims to achieve health equity for communities across the socioeconomic spectrum. Public health theory is foundational to global health research and practice, which engages efforts not only to address health outcomes but also to understand and mitigate upstream causes, or social determinants, of those health outcomes. Built environments

are core to those social determinants, and built environment design (often referred to as "environmental intervention" in the public health and global health worlds) has the potential to reduce and prevent adverse health outcomes (M. van den Bosch, 2017). This thesis marks an intersection between built environment and global health disciplines by examining the built environment as a social determinant of health (SDH) in a context where inequity is a major shaper of both.

THE SOCIAL DETERMINANTS OF HEALTH (SDH)

As described by the World Health Organization (WHO), the social determinants of health (SDH) are the "conditions in which people are born, grow, live, work, and age. These circumstances are shaped by the distribution of money, power and resources at global, national and local levels" (World Health Organization, 2020). SDH are wrapped up in long histories, globalization, urbanization, and built environments. They provide a framework through which to affect change toward equitable

ends (Marmot, 2007; Solar & Irwin, 2010). SDH further offer a framework for examining, understanding, and designing for relationships between built environments and human health—a framework that is integral to this thesis.



Source: Dahlgren and Whitehead, 1991

Figure - 3 - Dahlgren and Whitehead's SDH wheel

UN SUSTAINABLE DEVELOPMENT GOALS (SDGS)

Seventeen interconnected goals comprise the UN Sustainable Development Goals (SDGs). Signed by UN member states in 2015 with the goal of realization by year 2030, the SDGs “are a blueprint to achieve a better and more sustainable future for all. They address global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice” (United Nations, 2020). The SDGs are revised in name and content from their antecedent, the Millennium Development Goals (MDGs), eight priorities that member nations committed in year 2000 to working toward achieving by 2015 (Birn, Holtz, & Pillay, 2017).

Though this work does not explicitly adopt SDG indicators and targets, the informal community upgrading described in this work directly addresses many layers of SDGs including goals 1) no poverty; 3) good health and well-being; 6) clean water and sanitation; 9) industry, innovation, and infrastructure; 10) reduce Inequalities; 11) sustainable cities and communities; 13) climate action; 14) life below water; 15) life on land; and 17) partnerships for the goals. While most of the SDGs evoke a physical image, goal 17 is more abstract, calling in part for interdisciplinary efforts such as those central to this thesis.

NEGLECTED TROPICAL DISEASES (NTDS)

Neglected Tropical Diseases (NTDs) are important in global health, referring to a large group of communicable diseases that receive disproportionately low funding yet affect an extremely disproportionately low-income population globally, including informal communities. Frequently forgotten by high income countries (HICs) that see only rare cases, NTDs are often connected to vectors (e.g. mosquitoes, black flies), as in the case of dengue fever, and a lack of basic water and sanitation infrastructure, as in the case of soil-transmitted helminths and other parasites

(CDC, 2020). They are responsible for some of the highest numbers of annual deaths globally and, combined, lower life expectancy and quality of life for more than a billion people on the planet (WHO, 2015).

Many NTDs are preventable and treatable, but the

prevention and treatment of NTDs remains severely underfunded in research and development, or “neglected” (Philipsborn, Steinbeis, Bender, Regmi, & Tinnemann, 2015). Prioritizing mitigation of the impact of NTDs also aligns with the UN SDGs, for which the WHO laid out extensive guidelines for multi-sectoral approaches in 2015 (WHO, 2015). NTDs are not only a question of healthcare systems, but are also connected to built environments, suggesting possibilities for upstream approaches to NTD mitigation in design. This thesis focuses on water related NTDs.



Figure - 4 - The UN Sustainable Development Goals (SDGs)

ECOLOGICAL DESIGN

An ecological design approach in the context of this thesis expands the thinking behind conventional infrastructure to address complex design problems where conventional design has failed or left considerable room for improvement. The ecological design thinking in this thesis shuns a human-less understanding of ecology, acknowledging that landscapes are never wholly “natural” and never wholly cultural (Spirn, 2002). Rather, human and ecological elements are woven together in design thinking. Ecological design also has the potential to layer benefits that self-sustain and grow over time: “Ecological design is the process of actively shaping the form and operations of complex environments in such a way that composition and processes help to maintain and, if possible, increase the integrity of a region’s ecological relationships” (Rottle & Yocom, 2011).

Ecological design thinking is especially important in informal communities because of the often complex and difficult landscapes (e. g. swales, steep hillsides, wetlands) that pose challenges to conventional infrastructure (Werthmann, 2011). In these landscapes, conventional design may address one aspect of, say, sanitation, but in so doing compromise other aspects of human or ecological health. An example of the limitations of conventional infrastructure is sewerage in Iquitos, which during storms often backs up at low elevations, exposing people to more sewage during the high river season than they would have been exposed to without this infrastructure in the first place. Another example is paved pathways that achieve a design objective of improved access, but in doing so decrease permeability of a landscape adapted to infiltrate stormwater, instigating urban flooding.

WORD CHOICE

The nature of this discourse is semantically complex; the best word choice differs from one context to another, both across space and time. Because they are at the core of efforts to innovate both in ideology and method, semantics are tasked with holding nearly unbearable shifting weights. Thus, to haphazardly choose words without a discussion of why or why not is to dismiss the histories, controversies, and approaches to which certain word choices refer and which shape today's conversations (—which, in turn, are outdated by tomorrow—that is, if these conversations are fruitful). Pedantic parenthetics aside, it is important for clarity's sake to establish a glossary of terms that remains consistent throughout this thesis. It is my hope that while terms reflect current best judgment, the content can transcend shifting subtext as

sociopolitical circumstances evolve over time. Headings reflect the language used henceforth in this thesis.

SPANISH WORDS

For some concepts specific to amphibious urbanization, local language is used, always italicized:

Zonas inundables – flood zones

Tierra firme – non-flood zones (“firm land”)

Casas flotantes – floating homes

Casas sobre pilotes – stilted homes

Botes – wooden canoes with long-tail motors

In names of rivers, the Spanish name is used without italics: Río Amazonas – Amazon River



Figure - 5 - Iquitos' residential land use typologies



Figure - 6 - Casas sobre pilotes: stilted homes (low river season)



Figure - 7 - Casas flotantes: floating homes (low river season)

AMPHIBIOUS

Amphibious communities are situated on floodplains and are adapted to both high and low river seasons. In the urban Amazon, the two predominant amphibious housing typologies are *sobre pilotes*, or stilted, in which foundations of structures are fixed to the floodplain below on tall, usually wooden stilts, and *flotantes*, or floating, in which structures float when the river is high and are grounded when the river is low.

Traction has chosen to use the word amphibious to describe the community of Claverito because common language of “floating” does not sufficiently encompass the dynamic changing water levels of the floodplains, which render the community floating for at-most half of each year. Furthermore, amphibious allows the language to shift away from informal community terminology with institutionally negative connotations and toward a dialogue that acknowledges the complex and valuable ecology of the place.

HIGH RIVER + LOW RIVER SEASONS

The hundreds of thousands of cubic meters of water discharged from the Amazon basin’s network of rivers into the Atlantic Ocean per second make the river system the largest by volume in the

world. Annual flooding earns the basin another superlative as the largest riverine flooded forest system on planet Earth. But rainforest hydrology is defined by much more than rainy weather. Seasonal fluctuations in water levels throughout the Amazon basin do not only respond to precipitation but also reflect a complex array of inputs including shrinking glaciers and annual snowmelt from high in the Andes mountains, as well as factors affecting thousands of streams and tributaries from nine countries spanning the over six million square kilometer (three million square mile) watershed.

The rainforest is speckled with shifting microclimates; that evapotranspiration from the forest canopy creates its own rain cloud puffs that burst into acute showers during the low river season displays but one piece of a multi-scaled hydrological puzzle driving water levels in the Amazon basin (Marengo & Espinoza, 2015). On non-flooded *tierra firme*, anthropogenic forces like rainforest burning and clearing also have microclimatic precipitation effects that do not directly coincide with seasonal flooding (Laurance, 2006). For these reasons, rain and flood are not to be used interchangeably. Because this thesis is focused not on weather but on water levels, the terms *high river season* and *low river season* permeate the text.

LMIC + HIC

Because this project takes place in a low-income setting, a discussion of related terminology is important. By definition, *first world/third world* terminology is outdated: first applied in the 1950s with the French *tiers monde*, first, second, and third world refer to capitalist, communist, and non-affiliated nation-states, respectively, during the Cold War (Oxford Learner's Dictionaries, 2020). By 2020, its Cold War foundation is 30-years deteriorated, a welcome weathering to what was from the start an overtly biased ranking system.

The first issue with *developing/developed* rhetoric is that it claims to know what counts as *developed* and what does not—a threshold that is extremely subjective and whose exploitation effectively paves the way for neoliberal hegemony. A second problem with referring to a country or economy as *developing* is that it implies that these countries

are simply slower to develop, when in fact their conditions have been actively and systemically stunted by the very *developed* countries setting the standards of so-called *development*. A third issue with *developed/developing* comes down to grammar: the two are past and present participles, respectively, of the verb, to develop. Their very tense refers to an unchanging state, disregarding not only the constant flux inherent to change but also that development exists on multi-dimensional spectra. Conditions do not only vary from one country to another, but also within countries, regions, and cities; from rural to urban, from one ecoregion to

the next. *Developed/developing* rhetoric ignores this complexity.

Related alternatives like *underdeveloped country* and *least developed countries (LDCs)* center development without—at least superficially—subscribing to a rigid dichotomy. This language stems from United Nations terminology from the 1960s based on their Human Development Index (HDI), which is comprised of three major indicators of socioeconomic development: gross national income (GNI) per capita, the Human Assets Index (HAI), and the Economic Vulnerability Index (EVI)

(United Nations Department of Economic and Social Affairs, 2020). While this system does add dimension to *development* by taking into account metrics like education, life expectancy, and quality of life, it leaves no room for Indigenous ways of knowing, superimposing a colonial value system on all of human civilization (Hesse-Biber, 2014). Built into

the terminology is potential for “graduation”—at once a useful acknowledgment of flux and a gross perpetuation of development dichotomy.

More recent rhetoric often describes the world in terms of *global south/global north*. Defined in 1980 by the Brandt Commission's famous Brandt Line, which attempted to draw a line between rich and poor countries not only in another attempt to provide a framework for understanding global inequality, but also to inspire collaboration between members of the so-called *global south* (Wionczek, 1981). From west, the line neatly skirts the top of

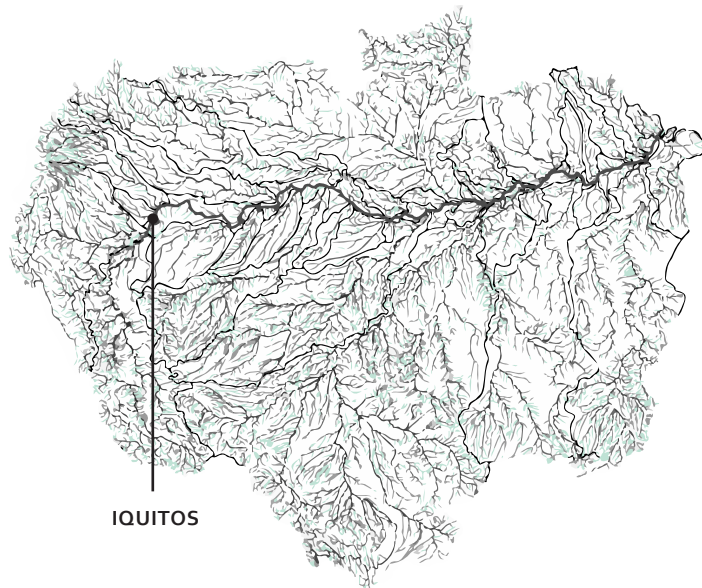


Figure - 8 - The largest watershed on Earth

Mexico, Africa and the Arabian Peninsula before haphazardly ploughing across northern India, Nepal and China. It emerges in the Pacific just north of Shanghai, circumvents Indonesia, and plummets south to pull Australia, New Zealand, and the rest of Polynesia into the *north* (Royal Geographical Society, 2013).

Never mind the fact that the equator runs roughly 20 degrees south of the large part of the Brandt Line; a literal subscription to south/north semantics was abandoned decades ago. Its proponents champion it for “mark[ing] a shift from a central focus on development or cultural difference toward an emphasis on geopolitical relations of power” (Dados & Connell, 2012). But *north/south* imposes a different kind of hierarchy—one that overtly alludes to subordination and that silences so many geopolitical exceptions to *north/south* organization. In keeping with Dados and Connell’s call for a more decolonized categorization system, the language should not privilege some data over others (Hesse-Biber, 2014).

Another recent language system makes use of *high-income countries (HICs)/low- and middle-income countries (LMICs)/low-income countries (LICs)*. Limitations of this system are that it fails to traverse geographic scale, ignoring income gaps within countries across the *HIC* to *LIC* spectrum, and that it takes an oversimplified view by putting income front and center. Histories of hegemony—imperialism, colonialism, disinvestment from structural adjustment, neoliberalism—contribute far more to differences between countries than point-in-time income. *LMIC/HIC* language does, however, shift blame and stigma away from people and toward root causes or social determinants, while providing room for a spectrum from one extreme to another. It asks not which one, but where on a scale.

The ideals behind this work hope to address socioeconomic inequality rather than overall national income. But because geopolitical history is important background for this work, and because that history affects *LMICs* very differently from *HICs*, the distinction is relevant; the language used in this thesis is *LMIC/HIC*.

INFORMAL COMMUNITIES

Defined by the Merriam Webster Dictionary as “a densely populated usually urban area marked by crowding, run-down housing, poverty, and social disorganization” (Merriam-Webster, 2020), *slum* is probably the most widely used term. UN-Habitat defines *slum* as living conditions experiencing any number of the following five “deprivations”: lack of safe water, access to sanitation, durability of housing, overcrowding, and security of tenure (UN-Habitat, 2016). Use of the word *slum* spreads across a variety of understandings and positionalities, from respectful to derogatory. Of the terminology discussed in this overview, *slum* is of those most likely to appear in conversations that lack empathy and ignore the complex web of circumstances that lead to and describe them.

Referring not only to people but also to the built environment, *informal settlement* is a more sensitive way of saying *slum* that also starts to get at physical characteristics: informal utilities set up by community members to meet their needs, lack of access to publicly-funded infrastructure like sanitation, roads, public transportation, waste management, and healthcare systems. The word *informal* is limiting in that it runs the risk of implying that its opposite, *formal*, which alludes to colonial urban developmental forms like the urban grid, is superior or more proper for its organization (Gouverneur, 2015). It also invites acknowledgment of the landscapes that often host informal urban growth: places hitherto deemed undesirable for building due to exposure to hazards like urban waste, extreme terrain, and risk of landslide or flooding (Werthmann, 2011). *Informal community* goes a step further by bringing humans into the picture. It gets at the social fabric of an informal settlement—a layer that should be central to redevelopment.

Squatter settlement directly alludes both to people and the built environment, but its subtext centers in on landlessness or lack of land tenure—a top priority for communities in some regions and a topic that has been widely debated for decades (Davis, 2006). Use of the word *squatter* is also problematic, as it highlights illegal activity out of context. Even if land

tenure were a primary focus of this thesis, this would not be the chosen terminology.

Shanty town is another term that points to the built environment, originally used to refer to temporary housing by laborers or military. In an urban context, *shanty town* recalls cheap materiality in building: use of corrugated metal, plastic, and plywood, without mention of people or sociopolitical context.

It is important to acknowledge that extreme socioeconomic inequality is not only a thing of LMICs. The United States has one of the highest income gaps in the world and is not without its landless citizens and informal communities and settlements. A 2017 point-in-time estimate recorded over half a million people (roughly 0.17 percent of the US population) experiencing homelessness on a January night (National Alliance to End Homelessness, 2019). Differences between HIC homelessness and LMIC informal communities is part semantics and part policy. In the former, informal settlement is strictly policed and people experiencing homelessness are often uprooted no less than daily. In the latter, people are generally better able to build longer-term informal housing. This topic warrants further research and discussion but is beyond the scope of this thesis.

A long list of regionally specific terms exists: *asentamientos humanos*, *invasiones*, *pueblos jóvenes*, *favelas*, *sukumbasi*, *ranchos*, *zopadpatti*, *colonias*, and so on. Subtext varies depending on the speaker and many other circumstances. Terminology for floating informal communities in Spanish is *asentamiento humano flotantes*, and people in Claverito sometimes refer to their community as a *pueblo*. For the purposes of this work, *informal community* is the preferred terminology.

INFORMAL COMMUNITY UPGRADING

Slum redevelopment is an umbrella term encompassing a wide range of phrases that allude to a need for addressing informal communities from *eradication* to *upgrading in place*. In the former, *eradication*, the most extreme of redevelopment methods, communities can face destruction with no warning, as in countless cases worldwide where bulldozers were hired in an attempt to erase informal settlements. *Relocation* can be less violent and is characterized by the movement of people from an informal settlement to another place or places. Within *slum relocation* exist perhaps as many different approaches as there have been attempts at relocation. Community participation, economic viability, maintained social cohesion, and housing conditions are all areas where relocation has been evaluated and criticized. Eradication and relocation have often resulted in failure, where community members reject displacement and return.

Often used in the context of organized crime in the favelas of Rio de Janeiro and other informal communities with armed informal governance, *pacification* refers to the usually forceful overtaking by a government of its informal counterpart. This method is often accompanied by efforts toward land tenure and upgrading in place, however, because it is accompanied by a dismantling of well-established social and economic systems, it shares some negative side effects with relocation.

An emerging term is *reinvigoration*, which initially feels promising for its positivity, though it may ignore existing robust community strength and vigor, and is not widespread. *Slum upgrading* is the preferred language of UN Habitat and the WHO, and it refers to in-situ investment in informal communities to improve conditions (UN-Habitat, 2016). Degrees of community participation vary greatly from one *slum upgrading* project to the next, as do funding inputs, design priorities, scale, and other factors. Nearly synonymous terms include *formalization* and *incorporation*, though their subtext is land tenure and governmental approval, rather than built environments. This work zeroes in on *slum upgrading* and uses the language, *informal community upgrading*.

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U.S. GEOLOGICAL SURVEY, 1969

5 km

From history to hydrology

THE URBAN AMAZONIAN AMPHIBIOUS INFORMAL COMMUNITY

The urban Amazonian amphibious informal community

RESEARCH QUESTION #1

What are the long histories behind and conditions of amphibious informal communities in Iquitos?

The so-called pristine, biodiverse land- and waterscapes for which the Amazon rainforest is famed has always included humans. The amount of time that humans Indigenous to the region have lived with Amazon basin landscapes dwarfs the period since European influence began in the 16th century. This analysis of history and context utilizes methods of literature review (of sociopolitical history, built environment history, and climate change) and geospatial analysis (of geography and hydrology) to examine how colonization and genocide of Indigenous people, boom and bust extraction industries of rubber and oil, and structural adjustment and neoliberal policy have driven urbanization and the growth of informal communities in Iquitos, through a landscape lens.

Concerned with the post-colonial landscape, the historical context for this thesis acknowledges millennia of Indigenous history, and skips over a couple of centuries of European and American mapmaking, seeking of profitable resources (cinnamon, gold), and missionary efforts, to 19th century resource extraction as a starting point for understanding current conditions of amphibious informal communities in Iquitos.

RESOURCE EXTRACTION

Coinciding with the industrial revolution, demand for rubber exploded in the 19th century. At the time, the Amazon basin was the only place to find it. Rubber barons enslaved a horrendous, unknowable number of Indigenous people—a side of resource extraction whose effects are felt to this day. As people were treated as disposable laborers, generations of Indigenous knowing were lost (Leonardo Tello Imaina & Fraser, 2016).



Figure - 9 - Extraction of latex from *Hevea brasiliensis*: the rubber tree [Wikimedia Commons]



Figure - 11 - Oil drilling in the Peruvian Amazon [Diario Correo Perú]



Figure - 10 - Gold mining in the Peruvian Amazon [Globe Red]

"On the one hand, the first explosion of informal areas was in the 1950s and 1960s. And it was strongly correlated with the agrarian and colonization reforms. We wanted to destroy latifundia, these huge land holdings. We wanted to be modern, go beyond the feudal system that we inherited from the colonial times. But the problem that this created is that it forgot that Indigenous cultures had collective property regimes. And when it was not replaced by a private property regime, the land was fragmented into nuclear family units that could not [support] even one family... Even very simple agriculture, just for one family, sustenance was not possible. ... There was huge migration.

But there are also issues of structural adjustment programs from the 1980s and 1990s that privatized, reduced public spending, opened borders, and reduced regulation and so forth... What's interesting about this is that most of the disinvestment [in Latin America from] the reduction of public spending occurred in the rural areas, in the hinterlands. So people suddenly had to use a strategy of multi-sited households where they would have some members of the families in the hinterland, some members of the family in the forest, some members of the family in the informal areas of the city, and hopefully some members abroad so that they could benefit from remittances. This becomes an informal strategy of survival. And it's all caused by... the political economy, and that is important to discuss because it impacts the way we design.

Our economies depend mainly on ... extraction of raw materials, mining, oil, and food—agribusiness. All those industries expelled people from the hinterlands. There's a lot of displacement. But on the other hand, they do offer jobs. What do you do? You try to profit from all the possible economies that you have. We don't have... the case of Europe or the States where cities industrialized and became poles that attract people because there are jobs in the city. What we have is the opposite. People come to the cities in search of services—public education, health[care], eventually services like potable water—but our economies are totally in the hinterlands. So we become this dislocated society and our slums exploded. ... This condition... has marked us as designers as much as archaeology [and] geography. That's what defines us."

Ana María Durán, 2017

subsequent waves of rubber have been central to local economies.

Another extractive industry whose story is woven throughout the Peruvian Amazon and Indigenous ways of life is that of hydrocarbon oil. The northern Pacific coast of Peru is home to the first oil well in South America, drilled in 1863, and Peru remained a principal oil producer globally through the 1930s (Mogollón, 2008). However, white oil mongers did not take exploitation to the Peruvian Amazon until 1939, spurring series of economic boom and bust cycles that were punctuated by an extreme oil boom between 1979 and 1985 (Finer & Orta-Martínez,

2010). Some symptoms of this boom and waves of others have been rash ecosystem destruction, exploitation of Indigenous laborers, severed ties with Indigenous ways of life, and migration to cities (Orta-Martínez & Finer, 2010). Like rubber booms, periods of disinvestment that have followed oil booms have complicated urbanization, reinforcing socioeconomic inequality along colonial-Indigenous heritage, and propelling growth of informal urban communities.

STRUCTURAL ADJUSTMENT + NEOLIBERALISM

Meanwhile, on a global scale, other forces were at play. Structural adjustment programs (SAPs) set up by the World Bank and funded by HICs in Europe and North America established short-term loans for post-colonial LMICs to help bolster economic and other development. Changes made as part of SAPs include privatization, reduced trade regulations, and major cuts to public spending (Durán, 2017). Their short-term nature as well as high interest rates ultimately made it impossible for LMICs across the globe to pay them back (McGregor, 2005).

Much of the “underdevelopment” that LMICs are known for today stems from the austerity measures that indebted national governments were forced to impose. Suddenly all income earned had to go toward paying loans back to the World Bank, rather than local needs such as maintenance of civic infrastructure, healthcare, education (Birn, Holtz, & Pillay, 2017). The long-term effects of the SAPs have been contradictory to their original supposed intent. This is often referred to as structural violence, along with subsequent contemporary neoliberal international trade systems that are criticized for similarly reinforcing gaps in income and local investment. The effects of SAPs in Latin America are further explained in Durán’s pull quote on the previous page.

INFORMAL URBAN GROWTH

How have these histories shaped Latin American cities and informal communities? The growth of informal communities in Latin America as understood for this work is described perfectly by Ana María Durán, an Ecuadorian architectural

theorist whose work focuses on ecological urbanism in Latin America and Amazonian urbanism. She emphasizes that the degree of informality in Latin American cities cannot be underestimated, acknowledging the complexity of the possible causes, before offering a synthesis of historical theory, featured in the pull quote on the previous page.

Durán’s explanation is not to oversimplify or detract from regional specificities, yet her overview does a good job of weaving different threads of history, as well as grounding the story in landscape and urbanization. In Iquitos, the end of the rubber boom, as well as boom cycles in the oil extraction industry, led directly to the growth of informal amphibious communities. Other factors have been desires among people living rurally for improved access to education and healthcare, as punctuated by prevalence of unfamiliar diseases whose treatment in the jungle is insufficient.

Systemic land use practices have also displaced people from the jungle to the city, including rainforest fires and continued growth of extractive industries of oil and mining, for which the national government has allowed for scoping on Indigenous land (Finer & Orta-Martínez, 2010). Climate change has also been and will continue to be a major driver for Amazonian urbanization and the growth of informal communities, with reduced productivity of agroforestry and fishing resulting from increasingly extreme flood and drought events (J. A. Marengo, Nobre, Sampaio, Salazar, & Borma, 2011; United Nations Department of Economic and Social Affairs, 2008). Population data for Iquitos are inexact, but experts estimate that nearly 20 percent of Iquitos’

URBANIZATION IN LATIN AMERICA

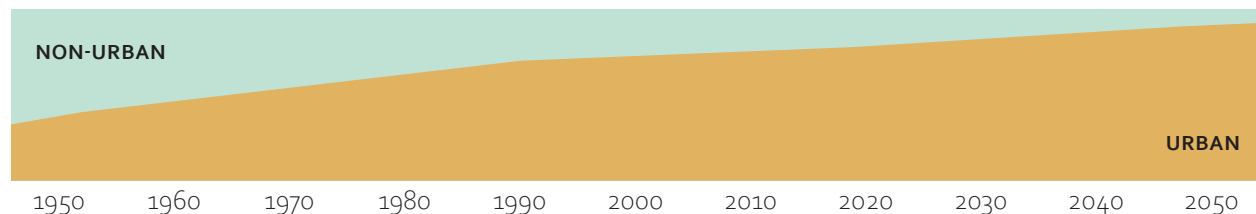


Figure - 13 - Urbanization in Latin America (created from UN-Habitat data)

"Today, the line that calls out a river is part of everyday experience. When historians and archaeologists speak of early civilizations on rivers, they invoke this line. When geographers describe a landmass drained by rivers, they draw this line. When engineers devise embankments, dams, barrages, drains, diversions, and bridges, they work with this line on the drawing board where such interventions are more easily conceived and tested. When urban designers envision cities on rivers, they conceive this line as a riverfront or waterfront. When ecologists speak of a river basin, they see this line gathering from multiple points like branches of a tree and dispersing like roots into the sea, and when they speak of a riparian zone, they thicken this line to indicate an interface between land and river. When scholars translate ancient texts or the spoken word, they tend to be already disposed to seeing a terrain marked by the line of riverbanks. When social and environmental activists in their drive against dam projects speak of lifelines to which so many disempowered people and wildlife are bound, they are referring to the line of riverbanks. When people see flood, which is becoming an increasingly common event around the world, they see water transgressing this line. And when authorities keep people from encroaching on rivers, they enforce this line."

Dilip da Cunha, 2019

population of roughly half a million people—approximately 90,000 people—live in amphibious communities.

HYDROLOGY, SOILS + INDIGENOUS ARCHITECTURE

Globally, questions of informal communities and their redevelopment have been debated for as long as informal communities have existed, and there is no one-size fits all approach to redevelopment. Perhaps no better way to illustrate the impossibility of a one-size-fits-all approach to informal community redevelopment exists than to examine informal communities through a landscape lens. We know that informal communities are often left to occupy urban areas that were regarded unfit for or inconvenient to formal development. But subscribing to a narrow view of architecture and planning can frame the entire Amazon basin as unsuitable to building.

Let us consider Amazonian soils. Geologically speaking, no part of the basin below a certain elevation is fit for building structures using methods imported from Europe or North America. Architects and designers know that bearing capacity of soils must be able to support a proposed load or structure; if the soils' bearing capacity does not,

then other engineering measures must be added. Increased moisture content in soil both decreases strength and increases stress (Steven Strom, Kurt Nathan, & Woland, 2013). Despite some three thousand kilometers (nearly ten thousand feet) of distance between Iquitos and the Atlantic, the elevation of the *tierra firme* center of the city is only 104 meters (341 feet) above sea level. Thin, sandy soils with extremely high seasonal moisture content comprise the Amazon basin.

According to Iquitos architecture professor Jorge Tapullima, it is extremely expensive and difficult to build heavy buildings even on Iquitos' firmest of *tierra firme*. That is why so few buildings over two or three stories exist in the city, and why one failed investment of a 20 story hospital building in the historic center of Iquitos was abandoned before completion: it started to sink (Tapullima, 2019). Urbanization in the Amazon basin can benefit from a shift in the way we think about water and land. Da Cunha puts it best, in his writing on the use of lines in representing rivers (da Cunha, 2019). (See pull quote above.)

There must be more than one way for cities to grow sustainably in the Amazon basin; not against water, but with it. Indigenous architecture has

been designing with water all along. Throughout the Amazon basin, humans have been living with water in *casas flotantes* (floating houses) and *casas sobre pilotes* (stilted homes) for thousands of years (Olórtegui del Castillo de Rummenhoeller, 2008). Yet Indigenous architecture is being ignored in contemporary urban design and investment (Olórtegui del Castillo de Rummenhoeller, 2019; Tapullima, 2019). On (perhaps one corner of) the global stage, Indigenous inclusion is an increasingly important topic. In 2019, the United Nations Environment Programme hosted a Global

Landscapes Forum in which Indigenous leaders from around the world discussed Indigenous rights as a solution to climate change, and subsequently published the story as an international call to action (United Nations Environment Programme, 2019). (See pull quote.)

"Indigenous peoples do not just face problems—they also hold solutions. They possess knowledge useful to restoring ecosystems and retain practices that have worked alongside thriving ecosystems for years. Key to securing their rights is inclusion; incorporating them in decision-making and governance allows for the usage of their much ignored and sometimes maligned skills and expertise."

UN Environment Programme (UNEP), 2019

The overwhelming majority of Iquitos' population, whether residing on *tierra firme* or in *zonas inundables*, have Indigenous roots. But Colonial influence has imposed an idea of what urban design should look

like, and in it there is no room for amphibiousness.

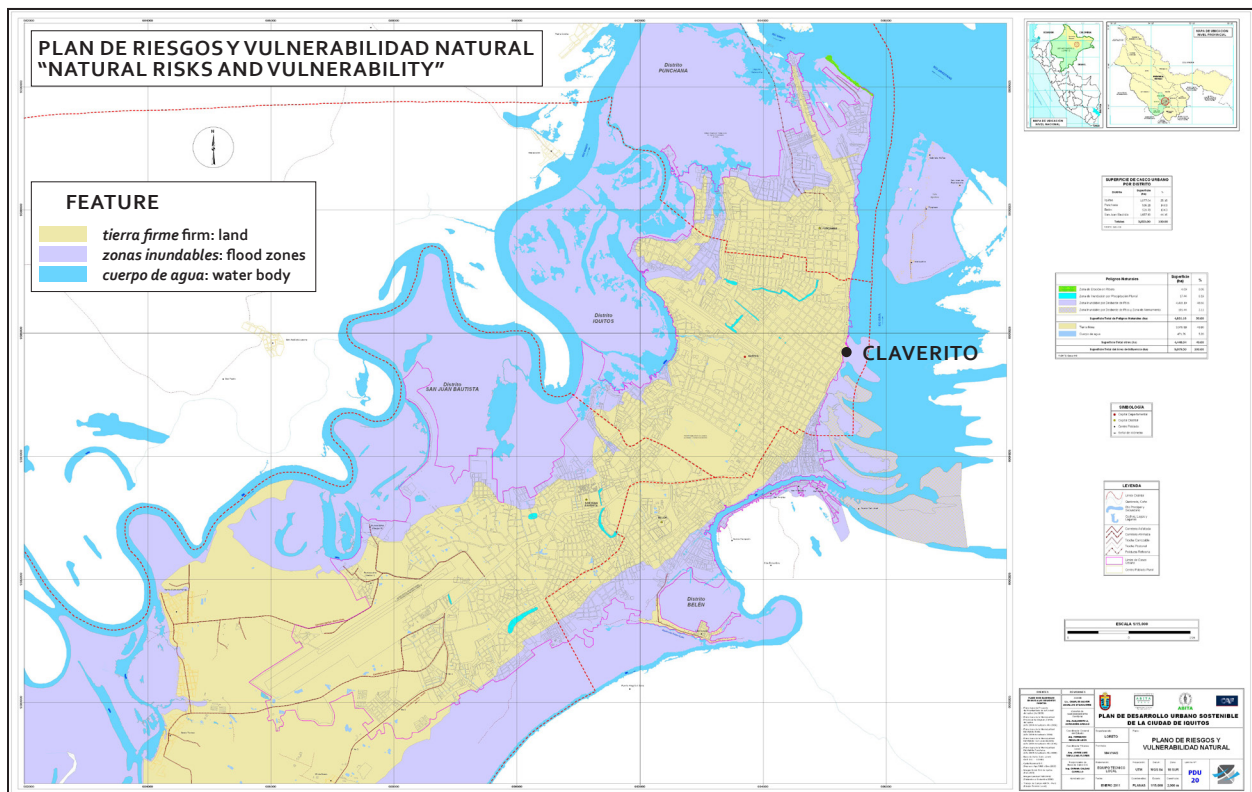


Figure - 14 - Iquitos' tierra firme + zonas inundables



Figure - 17 - Sobre pilotes: stilted + informal amphibious community



Figure - 15 - Sobre pilotes: stilted + formalized amphibious community



Figure - 16 - Belén, Iquitos, high river season [The Telegraph]

INFORMAL URBANIZATION, REDEVELOPMENT POLICY + CLIMATE CHANGE

Despite these factors, there has always been room for informality. The vast majority of urbanization in Iquitos has been informal—that is, considerable construction of buildings, roads, and other infrastructure were to some degree unplanned and designed to react to immediate needs. This urbanization did not adhere to policy either because it preceded policy or because it has simply never been practical or possible for Iquitos (or any city) to urbanize in an entirely formal way. In times of rapid urbanization worldwide, throughout history, in both HICs and LMICs, cities simply cannot formally keep up with the demands of rapid migration to urban centers (Gouverneur, 2015). When faced with survival, people take planning and construction into their own hands and adapt to their immediate circumstances.

As was the case in European and North American cities in the wake of industrial revolutions, formalization often happens retroactively (and it coincides with displacement of Indigenous people, people of color, and other systemically marginalized communities). Over the course of Iquitos' history, the vast majority of what are now Iquitos' formal areas are so thanks to retroactive formalization processes (Tapullima, 2019). The central district of Iquitos was founded back in the 19th century, but its other three districts were not incorporated until relatively recently: Punchana in 1987, and San Juan Bautista and Belén in 1999 (Vildósola, 2019).

Those districts are also the most recently settled, but significant populations preceded their formal incorporation into the municipality of Iquitos.

The question of informal community redevelopment is at its core another question of retroactive formalization. But it is hidden under cloaks of other issues: stigma against newcomers; stigma against poverty; stigma against traditional practices; racism; classism; xenophobia. In Iquitos, policy is currently structured such that buildings must be fixed to the land underneath year-round for its owner to secure land rights. Some amphibious homes—*casas sobre pilotes*—have indeed gained formal status through use of stilts.

That amphibious homes *sobre pilotes* have been able to formalize and, ultimately, stay, suggests possibilities for further upgrading in place for informal communities in Iquitos, but stilted amphibiousness is in some ways more vulnerable to changing hydraulic cycles due to climate change than floating amphibiousness. Increasing intensity of both draught and flood seasons has in recent decades lead to several instances of extreme water levels—a trend that will increase in severity over time (Jose A. Marengo et al., 2013; J. A. Marengo et al., 2011; Tomasella et al., 2011). In Iquitos, because *casas sobre pilotes* are fixed at heights that cannot not predict the effects of climate change on hydraulic systems, severe floods have inundated and destroyed them (Valdivia, 2012).

Casas sobre pilotes also pose access challenges that may be more easily avoided in *casas flotantes*. The usually wooden foundations of amphibious homes cycle through replacement on a five- to 10-year cycle (Vildósola, 2018). This maintenance of *casas sobre pilotes* may be more intensive and technical than that of *casas flotantes*, which conveniently ground each year. Furthermore, the scale of *casas flotantes* is colossal in Iquitos; stiling each of them would be extremely costly both at the onset and through maintenance.

Because *casas sobre pilotes* are stilted high above the floodplain, sets of wooden stairs, which are often steep and unstable, are needed to access the floodplain below, and sometimes to access main pathways and homes, often rendering the stilted amphibious community non-inclusive of people experiencing difficulty walking and people who rely on wheels to get around. The floating typology does not necessarily solve issues of access; where stilts can maintain a community closer to the elevation of *tierra firme* through use of bridges, floating communities rest well below that elevation both during high and low river seasons. While pathways are more likely to be level or ramped within a community, community entrances sit at the bottom of steep hillsides—as is typically the case for both typologies.

URGENCY + ECOLOGY

Built environment designers, planners, and policy makers must expand the way we think about urban design in a landscape so intimately interwoven with water as the urban Amazon. Paradoxically,

floating communities are a thing of prestige in many HICs: floating houseboat communities in the likes of Seattle, London, and Denmark house some of the highest income people in the world's highest income cities. High-end designs for floating utopian communities are trending in architecture design competitions worldwide, and the United Nations has suggested that floating cities could help to ease global housing shortages in the face of continued urbanization, sea level rise, and climate change (United Nations, 2019).

And while ecologists criticize overwater structures as detrimental to nearshore habitat (Thom, Williams, & Diefenderfer, 2005), amphibious communities can act as ecological buffers and increase resiliency for cities surrounded by floodplains—buffers with the potential to dull wave action, prevent erosion, and combat urban heat island effect while promoting biodiversity, improving water quality, and offering housing solutions. This concept is further explored in the following chapter, which zooms in on a site analysis of the amphibious community of Claverito.

In Iquitos, challenges stemming from history, conventional design, and climate change do not only shape amphibious informal communities, but also the urban condition at large. Projected urban growth and climate change implications are likely to augment these challenges. Amphibious informal communities, which reflect Indigenous architecture and house nearly one in five Iquitos residents, are adapted to the floodplain ecosystem and, if embraced, can increase resiliency for Iquitos as a whole.



Figure - 18 - Mixed *casas sobre pilotes* + *flotantes* at high-low river transition, Belén [Rádio e Televisão de Portugal]

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Health + the built environment

TROPICAL DISEASE + THE AMPHIBIOUS COMMUNITY

Tropical disease + the amphibious community

RESEARCH QUESTION #2

How do the built environment and health connect (with a focus on water-related health and informal communities)?

WHAT IS WATER-RELATED HEALTH?

Water-related health problems are defined in this thesis as infectious diseases whose transmission is closely related to human relationships with water. The scope of infectious diseases is quite broad because they all connect through water and the built environment in similar ways. The major categories of water-related health problems for the purposes of this work are as follow:

1. mosquito-borne diseases
2. rat-related diseases
3. water-borne parasitic infections + intestinal worms
4. water-borne bacterial + viral infections

Many studies have explored and demonstrated relationships between the built environment and human health, especially regarding water-

related diseases. The following narrative briefly introduces the epidemiology of diseases within each subcategory of water-related health before drawing on literature from these studies to explore how each subcategory relates to water and the built environment, and how built environment design can be leveraged to mitigate risk of infection.

Subcategories that define water-related health for the purposes of this thesis are not mutually exclusive. Flaviviruses, for example, is a group of viruses transmitted by arthropods like mosquitoes and ticks that includes dengue, Zika, and yellow fever. Thus, flaviviruses are described in the mosquito subsection, while a larger group of bacteria and viruses transmitted through water are the focus of the “other bacterial and viral infection” subcategory. Malaria—a parasite transmitted by mosquitoes—is another example; it is in the mosquito-subcategory, while a large group of parasites or intestinal worms whose transmission is related to water are the focus of the parasite subcategory.



MOSQUITO-BORNE DISEASES

Epidemiology of mosquitoes

People become infected with dengue, yellow fever, Zika, and chikungunya when bit by disease carrying *Aedes aegypti* and *Aedes albopictus* mosquitoes; *Anopheles* mosquitoes transmit malaria.

Dengue fever is one of the most prevalent mosquito-borne diseases worldwide; about half of the world's population is at risk, an estimated 390 million infections occur each year, and, in some countries, it is one of the leading causes of death among children and adults (World Health Organization, 2019a). It is most prevalent in urban and semi-urban tropical and sub-tropical areas, and Iquitos is no exception. In February of 2020, the Peruvian government declared a state of emergency in three districts, including Iquitos' district of Loreto, not only requiring that health departments carry out relief efforts, but also calling out connections between sanitation infrastructure and the spread of dengue (El Peruano, 2020). The *Ae. aegypti* and *Ae. anopheles* mosquitoes that transmit dengue find habitat near human habitation.

Other diseases transmitted by *Ae. aegypti* and *Ae. albopictus* mosquitoes include yellow fever, Zika, and chikungunya. Yellow fever has been around for at least a century and a half and has caused major epidemics including in the United States. An effective vaccine has existed for yellow fever for nearly 100 years, but barriers to vaccination including cost impede access for health care systems in LMICs and for people living in poverty. It is endemic to many countries on the African and South American continents where just under half of people are vaccinated (World Health Organization, 2019b). Diagnostics and response systems for Zika, which gained notoriety in a 2015-2016 epidemic, remain underdeveloped, and no vaccine exists (World Health Organization, 2019c). The Amazon rainforest has hosted Zika hotspots, and prevalence remains underrepresented in data.

Malaria is another mosquito-borne disease that is prevalent throughout the Amazon and Iquitos despite the preference of its vector—mosquitoes in the *Anopheles* genus—for rural landscapes.

Malaria has no cure and can be prevented with prophylaxis taken daily or bi-weekly. Their intensive regimens, cost, and side effects render malaria prophylaxis unrealistic long-term solutions for residents of malaria areas. The Peruvian national combined burdens of disease for malaria, dengue, and yellow fever was 1.61 percent of deaths in 2017 (IHME, 2017). Considering that their vectors thrive in tropical and subtropical climates, most of those cases likely occurred in the Amazonian region of Peru, where rates of diagnoses are also likely lower than reality.

Mosquitoes, water + the built environment

Mosquito-borne diseases exist where there is mosquito habitat: standing water at warm temperatures. Burdens of *Ae. aegypti*- and *Ae. albopictus*-borne diseases will likely be defined more by those mosquitoes' domestic nature than by climate and weather in coming decades, as they find ideal habitat in urban environments that offer human hosts and the artificial containers inside of which these mosquitoes preferentially lay their eggs and larva develop (Jansen & Beebe, 2010).

Fumigation has been shown to reduce rates of dengue temporarily, if conducted early in dengue prevalence season, in Iquitos (Stoddard et al., 2014), but studies have also shown that mosquitoes are adapting to pesticides (Perea, León, Salcedo, Brogdon, & Devine, 2009; Perich, Davila, Turner, Garcia, & Nelson, 2000). This adaptation renders the long-term efficacy of fumigation ineffective at best, and lethally counterproductive at worst. A study in a Puerto Rican city that looked at mosquito behavior as it relates to both weather and human behavior found that most *Ae. aegypti* pupae were produced in containers managed by people—especially trash—which explained why mosquitoes were so prevalent during the drought period (Barrera, Amador, & MacKay, 2011).

Water supply and storage systems are also known to provide habitat for mosquitoes, methods for control of which could include sealing storage containers as well as draining puddles and establishment of habitat for mosquito predators (Alarcón, 2016). Further mitigation strategies include stormwater

management that avoids standing water either through grade change that keeps water moving, infiltration of water into the ground, or uptake by plants (Metzger, 2005), and planting design that avoids plant species that collect standing water, such as bromeliads (Cardoso, Lourenço-de-Oliveira, Codeço, & Motta, 2015).

The preference of malaria’s vectors, mosquitoes in the *Anopheles* genus, for rural areas has not stopped malaria from spreading in the urban Amazon. In fact, research has suggested that their prevalence has gone up with Amazonian deforestation, demonstrating their propensity to sunlit puddles in rural and urban clearings alike (Laurance, 2006). The threat of puddles and other standing water in which all mosquitoes proliferate is increasing across the rural to urban spectrum with more frequent, more extreme flooding and longer periods of warmer temperatures (Cimons, 2019).

The WHO acknowledges the role of the built environment in mosquito-borne disease prevalence

and has called for efforts to control *Ae. aegypti* through design (Lindsay, Wilson, Golding, Scott, & Takkend, 2017). Methods of mosquito habitat mitigation will be increasingly important in years to come, as risk of exposure to the likes of dengue is projected to increase with urbanization and climate change (Gubler, 2011; Jansen & Beebe, 2010; Ryan, Carlson, Mordecai, & Johnson, 2019).

RAT-RELATED DISEASES

Epidemiology of rats

Rats are not unique among mammals for acting as reservoirs for diseases including leptospirosis, hantavirus, plague, and South American arenaviruses. Other reservoirs include mice and canine species. The prevalence of rats especially in relationship to solid waste has earned rats the title for this subsection of water-related health, but this discussion speaks for other disease carrying mammals as well. The most common rat-related disease in Iquitos is leptospirosis, a bacterial infection. It infects people across spectra from rural to urban, and from amphibious to *tierra firme*.

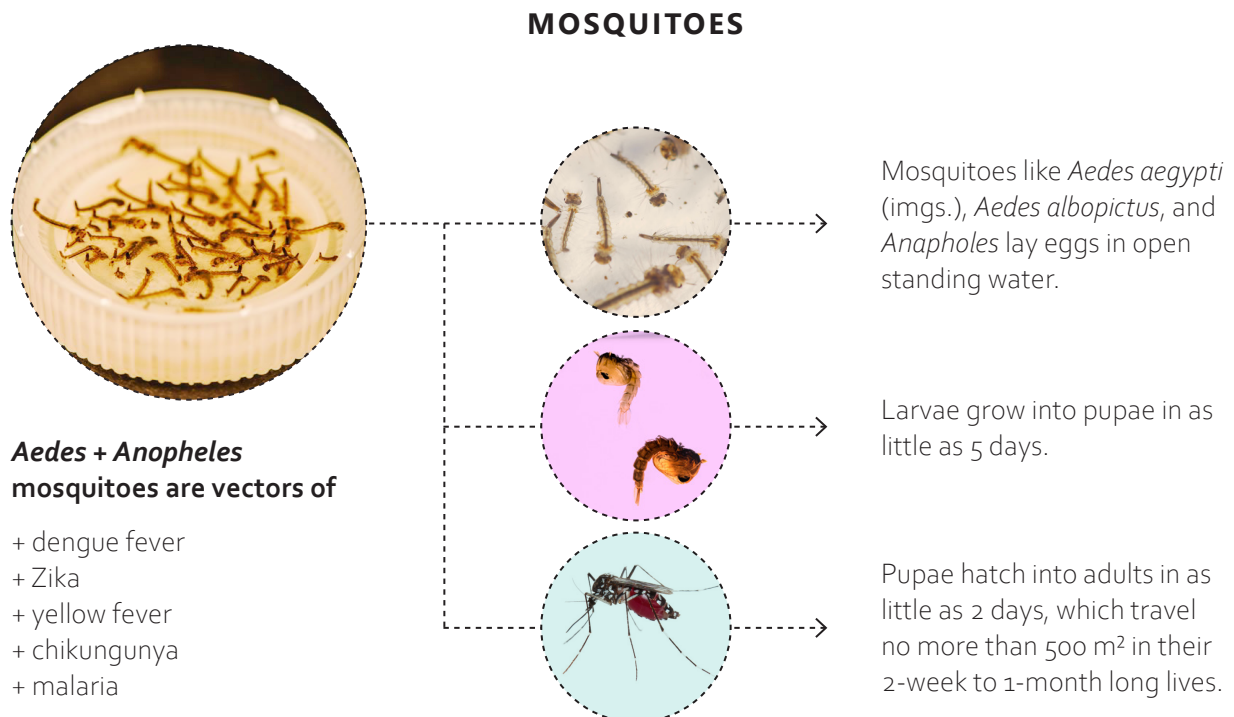


Figure - 19 - Mosquito-borne diseases

Rats, water + the built environment

People who come into contact with the urine or feces of rats infected with the *Leptospira* genus of bacteria are at high risk of leptospirosis infection. Rats find habitat in and around exposed and mismanaged solid waste, around which their infected urine and feces can collect, exposing people to pathogens in infected rats' excrement (Lau, Smythe, Craig, & Weinstein, 2010). Rats have been found breeding, burrowing, and feeding on trash. The lack of effective solid waste management disproportionately occurs in poor communities experiencing public disinvestment, exposing them to infection and disease (Krystosik et al., 2020).

Diseases transmitted by rats have also been connected to floods, swimming, and bare footedness (Centers for Disease Control and Prevention, 2019). Urine and feces collect near rat habitat with poor drainage and that lack water quality controls, suggesting opportunities for lowering the risk of exposure through solid waste management, drainage, and sanitation infrastructure.

WATER-BORNE PARASITIC INFECTIONS + INTESTINAL WORMS

Epidemiology of water-borne parasites

A long list of water-borne parasitic infections and intestinal worms affect the health of people and non-human species in the urban Amazon. No single parasite is singled out in this study because an extensive list of parasites connects to water and puts populations at risk in similar ways. Parasites including soil-transmitted helminths, the three categories of which are roundworms, tapeworms, and flukes, are prominent in Peru. Cases may disproportionately affect people living in tropical climates like Iquitos, where a significant number of cases also likely goes uncounted.

Other parasites closely connected to water are those in the *Giardia* genus, which cause giardiasis diarrheal disease by colonizing the small intestines of human and other animal species. *Giardia* is extremely common and has infected nearly one in three people in LMICs (CDC, 2015).

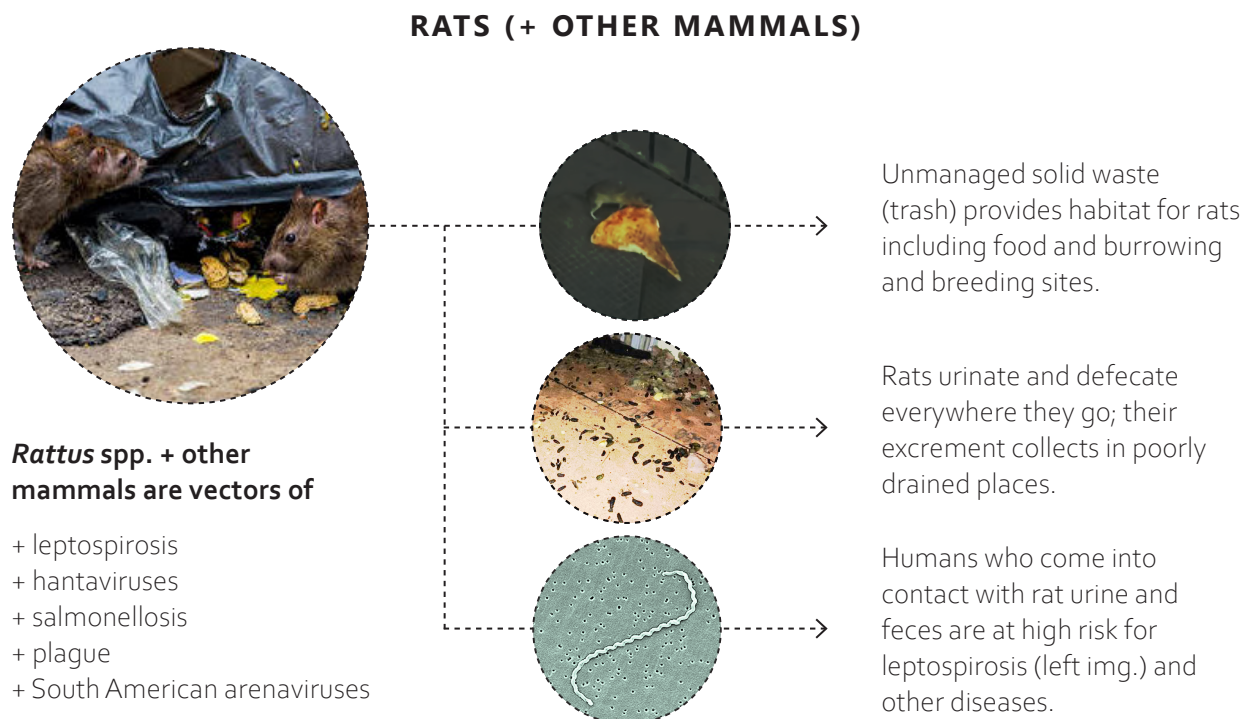


Figure - 20 - Rat-related diseases

Countless water-borne parasites cause infection in humans, and common symptoms are diarrhea, abdominal pain, anemia, and dehydration. Co-infection between parasites/intestinal worms and other diseases as well as compounding conditions like malnutrition put people at risk for severe symptoms and can cause developmental stunting in children, as well as lower quality of life and life expectancy.

Parasites, water + the built environment

The parasites with which this thesis is concerned live in water and on moist surfaces. Strong correlations have been identified between parasitic infection and drinking water. This discussion is focused on the two examples mentioned above.

As their name suggests, soil-transmitted helminths live in soil and on surfaces that are moist and unsanitary; they infect people through contact with exposed skin (WHO, 2019). Prevention of helminth infection does not end with use of shoes; they re-enter the environment through untreated stools of infected individuals, and thrive in environments with

poor drainage, wet surfaces, and lack of wastewater infrastructure.

In revisiting giardiasis, a connection to wastewater treatment comes into focus. People are infected with *Giardia* when they consume *Giardia* cysts in food or water; the cysts are extremely infectious and come from feces of infected people, who shed one to ten billion *Giardia* cysts per day while infected—consumption of less than ten cysts can cause infection (CDC, 2015). Countless other parasites are spread through the same mechanism of infected feces contaminating water for drinking, bathing, and household needs.

WATER-BORNE BACTERIAL + VIRAL INFECTIONS

Epidemiology of water-borne bacteria + viruses

This last subsection of water-related health is broad by design and is focused on pathogens that relate to sanitation infrastructure. It includes bacteria in the Salmonella genus such as Salmonella Typhi, Salmonella enterica and others which cause typhoid fever and other salmonella infections, as

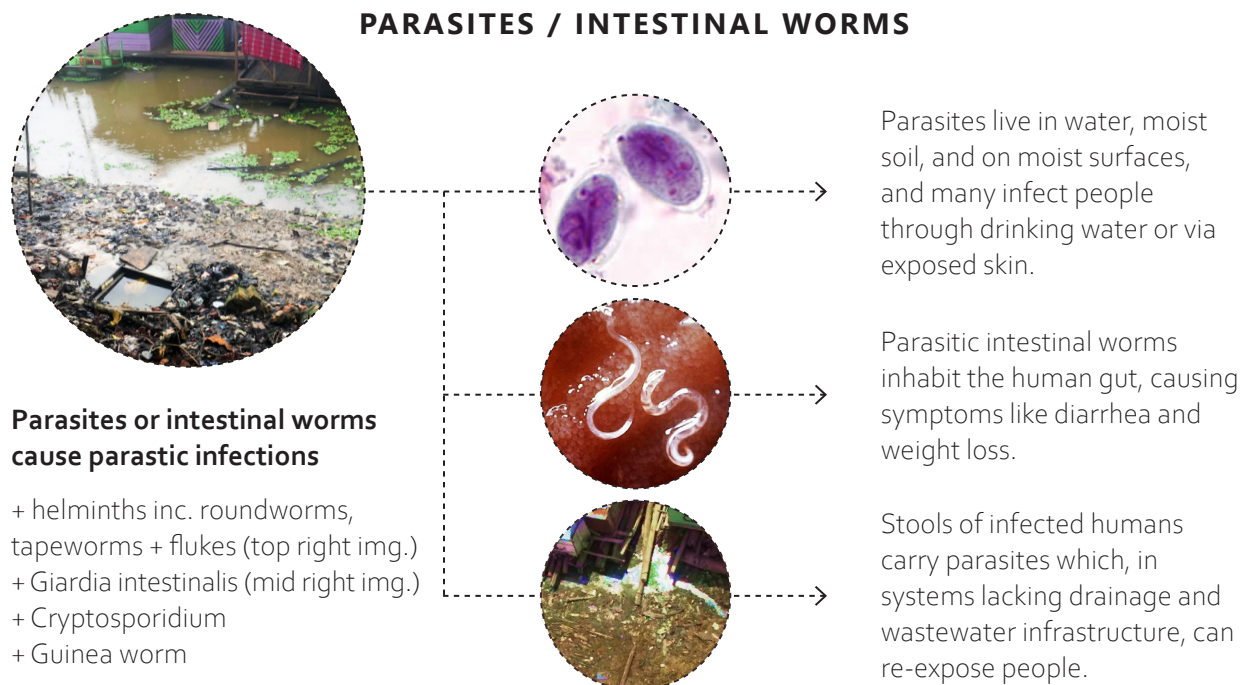


Figure - 21 - Water-borne parasitic infections/intestinal worms

well as *Escherichia coli*, or *E. coli*, which causes *E. coli* infection. Other fecal coliforms also cause gastrointestinal infection. Another extremely infectious bacterial infection is Cholera, the most recent Latin American epidemic of which began in Peru and spread throughout the continent, causing 9,000 deaths between 1991 and 1993 (Guthmann, 1995). Common symptoms of each of these bacterial infections include diarrhea, stomach pain, weakness, and sometimes fever.

Viruses of particular concern for this category of water-related health include those connected to sanitation systems, including adenovirus, astrovirus, hepatitis A and E, rotavirus, and many more. (Worth noting is a sited potential risk of coronaviruses (Gall, Mariñas, Lu, & Shisler, 2015), though no evidence has shown that the COVID-19 we have all come to know in 2020 is water-borne.) Globally, rotavirus is the leading cause of severe acute diarrhea in children under five, and people at especially high risk of water-borne viral infection are children, pregnant women, people experiencing malnutrition, and people with underlying health problems, such

as unmanaged HIV, while water-transmitted viral infections are often self-limiting in healthy adults (Gall et al., 2015).

Bacteria + viruses, water + the built environment

Connections between pathogens, water, and the built environment are well-known. A connection between an unsanitary water pump and a cholera epidemic in mid-19th century London earned John Snow a prominent place in epidemiology history and transformed the role of public water systems designers in public health. Despite the nearly two-centuries passed discovery of this connection between drinking water and infectious disease, the basic sanitation infrastructure required to prevent water-borne infections lacks in communities worldwide.

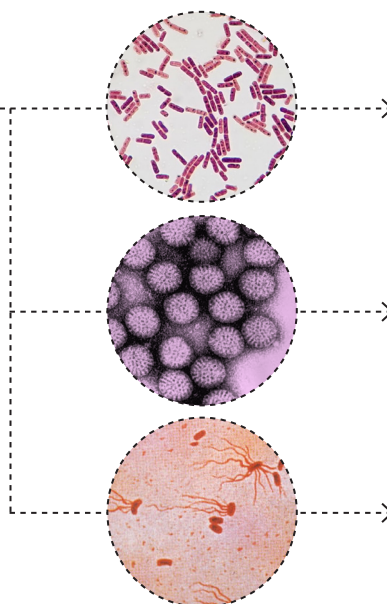
Infections from bacteria in the *Salmonella* genus occur when people ingest contaminated water or food. Like other bacteria that cause infections, *Salmonella* is connected to handwashing, cooking, wastewater infrastructure, access to clean water, and water storage. Viruses are also a threat through

WATER-BORNE BACTERIA + VIRUSES



Other bacteria + viruses cause infections thru water

- + *E. coli* (top right img.)
- + fecal coliforms
- + rotavirus (mid right img.)
- + *Salmonella* (low right img.)
- + hepatitis A + E viruses



Other bacteria + viruses live in water contaminated by human and animal feces and other contaminants.

They cause gastroenteritis and other infections through water for drinking, household needs + swimming causing diarrhea, fever + other symptoms.

Lack of access to clean water, clean water storage + wastewater infrastructure drive continued risk of infection.

Figure - 22 - Water-borne bacterial + viral infections

wastewater, as infected people with viruses shed high viral loads in their stools, which, if entering the environment untreated, expose people using water to the same viruses (Gall et al., 2015).

Vaccines for viral infections like poliovirus and hepatitis A have been around for decades, and others, such as vaccines for rotavirus, are new. People at high risk of exposure to these viruses disproportionately face barriers to vaccination access, while antivirals do not exist for most (Gall et al., 2015). Implementation of effective wastewater infrastructure, safe water storage systems, and improved access to clean water have repeatedly shown that built environment interventions are extremely effective upstream solutions to high burdens of bacterial, viral, (and parasitic) infections (Bartram & Cairncross, 2010; "Cholera in the Americas," 1991; USAID, 2019; WHO technical staff, 2011).

Infrastructure for drinking water and water for household uses is often contaminated in populated places without potable water or with ineffective

wastewater infrastructure, and thus improved access to drinking water supplies, low-cost strategies to treat and safely store drinking water at point of use (e.g. filters, chlorine, safe storage), safe toilets, in-situ treatment, handwashing, and other washing (e.g. food, dishes) can reduce burdens of infectious disease (WHO, 2019).

Unsafe water, sanitation and handwashing put people at risk for diarrhea; according to IHME, 80 percent of chronic diarrhea cases in Peru are caused by this risk factor (IHME, 2017). People living in informal urban communities are at disproportionate risk for infectious diseases (National Academies of Sciences, 2018). These studies show that primary strategies for positively impacting health through built environment intervention boil down to sanitation, solid waste, and vector control. In populations that are disproportionately vulnerable to water-related health problems, such as informal communities and especially those living amphibiously, these built environment interventions can have major positive impacts on burdens of disease and community health and well-being.

THE SD[WATER-RELATED]H WHEEL

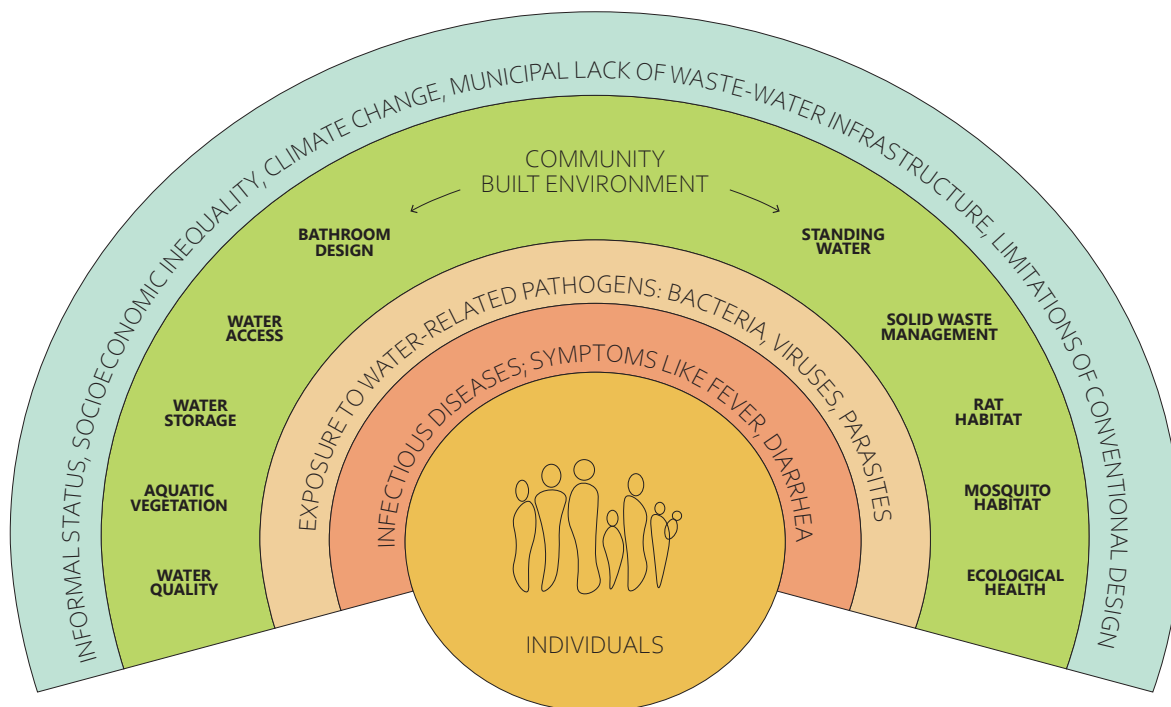


Figure - 23 - The social determinants of water-related health, adapted from Dahlgren + Whitehead, 1991

THE SOCIAL DETERMINANTS OF WATER-RELATED HEALTH

Figure 23, adapted from Dahlgren and Whitehead's classic 1991 Social Determinants of Health (SDH) Wheel, summarizes the ways that water-related health and the built environment connect.

Individuals are at the center, with cases of infectious disease, water-related disease symptoms, and exposure to the pathogens that cause them—bacteria, viruses, parasites—stemming out from there.

The thick green section, community built environment, or the built environment of a community, is where this thesis is focused: the upstream, built environment aspects that provide preferred environments for those pathogens, where humans then become at risk for exposure. Standing water, solid waste, and mosquito habitat are all part of risk of exposure to mosquito-borne diseases like dengue and malaria, while rat habitat and solid waste management connect to diseases for which rats and other mammals act as reservoirs.

Aquatic vegetation and overall ecological health help to improve water quality, with the added benefit of providing habitat for mosquito predators including amphibians, fish, birds, and insects. Ecological health, as defined for this thesis, is the functioning of ecological systems to mitigate water-related health problems. In addition to functions like plants improving water quality and mosquito predators controlling mosquito populations, overall ecological health reflects balance and biodiversity. For example, an ecologically healthy amphibious

community system would keep rat populations in check and maintain pathogen levels in water that are safer for human contact.

The outermost ring of the circle includes systemic, scaled up determinants—issues like informal status, socioeconomic inequality, climate change, and municipal lack of waste-water infrastructure, which, in Iquitos and globally, exposes amphibious communities not only to pathogens in their own sewage, but also to that of populations living on *tierra firme*. Another important piece of the outer ring is the limitations of conventional design, which refers to systems like municipal solid waste, wastewater treatment, potable water, and other basic amenities and their lack of adaptation to an amphibious environment (or other landscape typologies where informal communities reside).

Effectively addressing the built environment may help to address those scaled up systemic determinants both by improving overall health and through more inadvertent, incremental steps toward achieving formal status, socioeconomic opportunity, and expanded design ideas for formalized development.

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Claverito

A SITE ANALYSIS OF THE INFORMAL AMPHIBIOUS COMMUNITY

Claverito

Claverito is located on a floodplain about five blocks north of Iquitos' city center. The shore is east facing, with water from the Río Itaya, a floodplain of the Río Amazonas, overall running northeast toward confluence with the Río Amazonas just a few kilometers north of Claverito. The community of Claverito shares its name with the Plaza Clavero, a plaza on the edge of the incorporated city's *tierra firme* (dry land) at an elevation of about six

meters (20 feet) above Claverito during the low river season. Stairs at either end of Plaza Clavero, as well as two other sets south of the plaza offer access from the *tierra firme* to the floodplain, where 52 homes are laid out along three parallel streets, Calle Charles Zevallos, Calle Washington, and Calle Miraflores.

The 52 houses in Claverito are home to about 280 people, and the number of people living in each household ranges from two to 10, with an average of between five and six. In a 2016 survey in which 44 households participated, residents had lived in Claverito ranging from one to 45 years, with a median of nine years and an average of 11.6 years. Over the course of four years (2016-2019), for all surveys that asked the age of community members, the median age was 18 and the average age was 24. Thirty percent of community members are 10 and younger, and a little over half of those children are under five. Babies are continually being born, with three to five newborns represented in each survey.

Claverito is undergoing constant change with the seasons and looks completely different from the low river season to the high river season. During the high river season, roughly January through June, water levels



Figure - 25 - Claverito floating, looking south, 2017 February



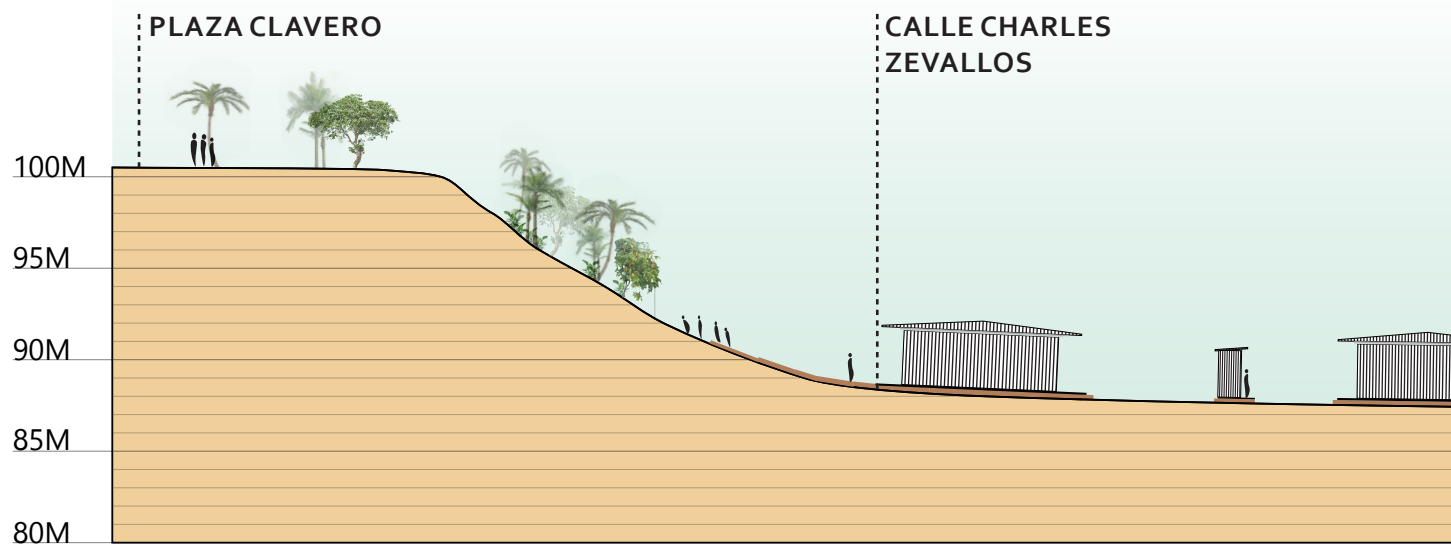
Figure - 24 - Claverito grounded, looking south, 2016 October



Figure - 26 - Plan view map of Claverito, low river season

CLAVERITO SECTION AA

Low river season: roughly August - November



High river season: roughly January - June

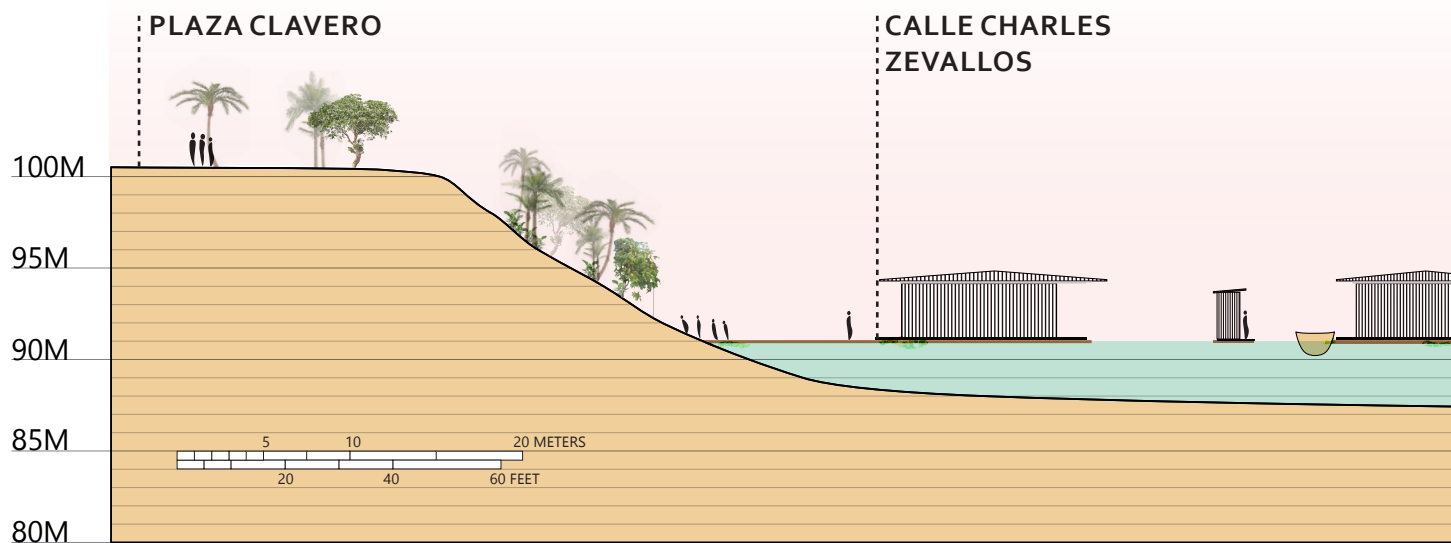
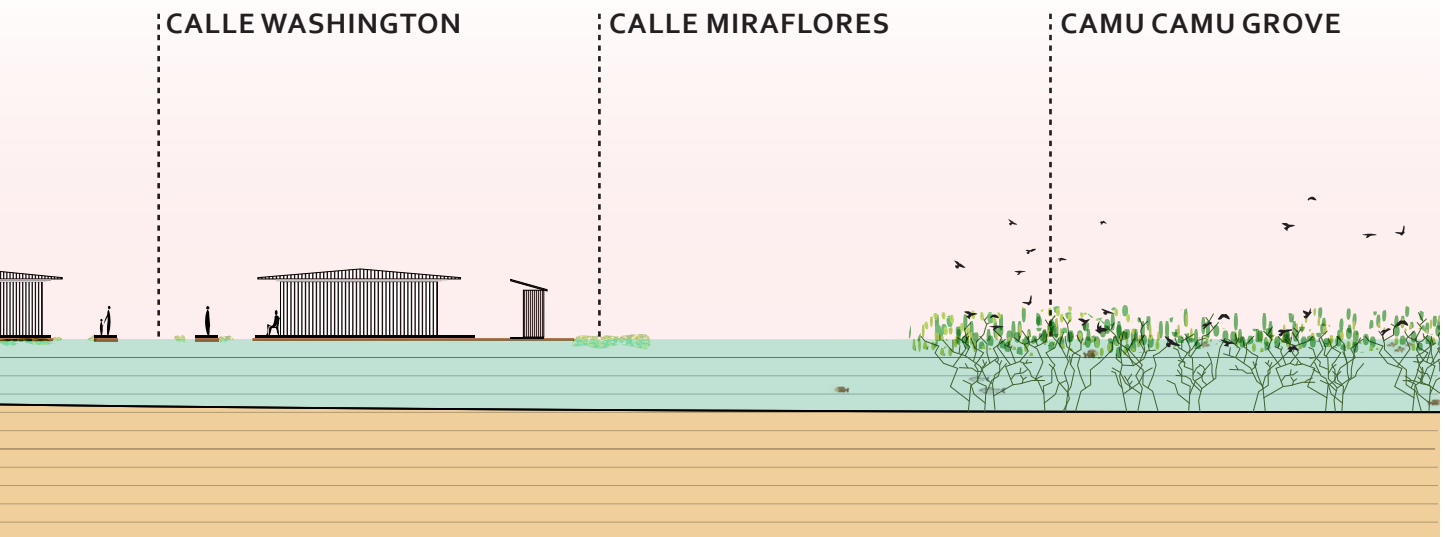
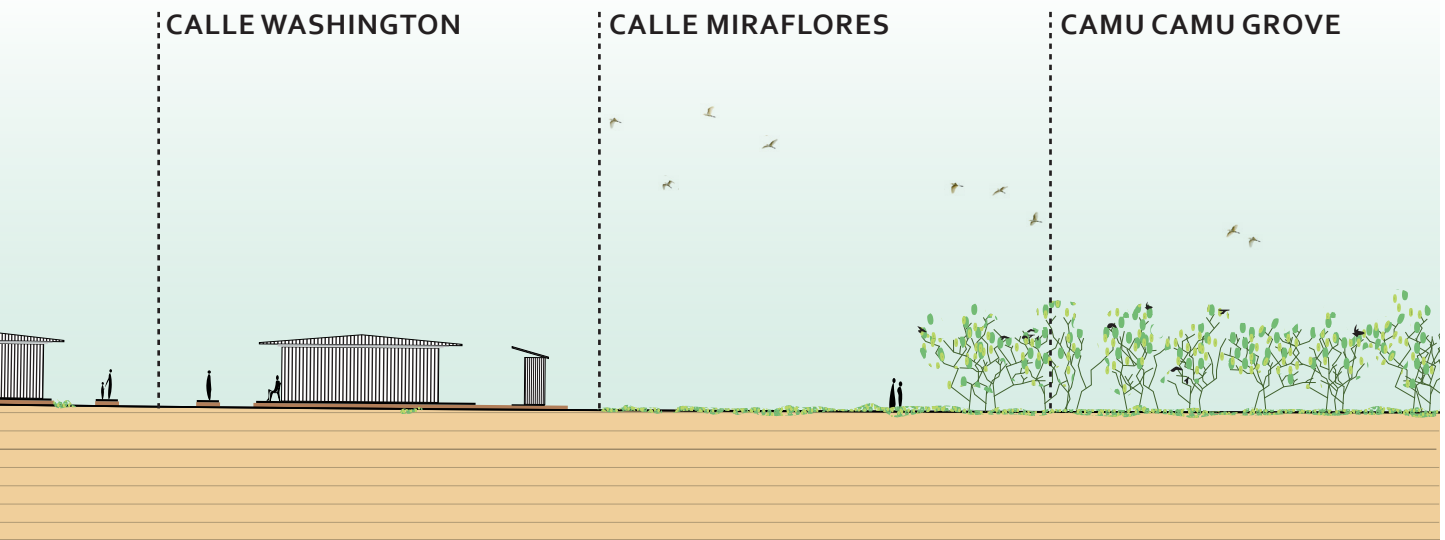


Figure - 27 - Sections AA: high + low river seasons



rise throughout the Amazon basin. As discussed in chapter 2, the seasons have not been consistently predictable in recent years, and climate change has led to increased severity and frequency of extreme levels of both flood and drought—a trend that is projected to continue throughout the Amazon basin (Barichivich et al., 2018; Jose A. Marengo et al., 2013; J. A. Marengo & Espinoza, 2015; Sorribas et al., 2016; Tomasella et al., 2011). The landscape in Claverito during flooding both mild and extreme is such that all structures float: homes, bathrooms, gardens, and all connecting pathways.

Floating is made possible by foundational *topas*, floating logs, which community members routinely harvest from the jungle or obtain from lumber mill scrapyards and float back to the community with the help of *botes*, or wooden canoes with long-tail motors. A few different species work well for floating foundations because they are buoyant, and they decompose slowly relative to other hardwoods.

Topas are also foundational to the pathways that connect homes to *tierra firme* and to one another. These layered floating pathways usually have flat planks on top but are uneven surfaces that can be unstable, slippery, and sometimes host standing

water; they undergo constant maintenance. During the high river season, several houses are connected by one or two relatively narrow paths; community members must pass across their neighbors' front porches when leaving or returning home by foot. About half of households also maintain amphibious gardens that were initiated in a Traction Transdisciplinary Action Research (TDAR) project in 2017 and 2018. Among plants growing in gardens are edible and medicinal species. Pots and garden beds separate plants from the river.

The materiality of floating communities supports biodiversity. Floating communities—the foundations of homes and the pathways in between—mimic large woody debris build-ups that are an important part of braided river systems. Among aquatic plant life characteristic to Claverito are huama (*Pistia stratiotes*, water cabbage, water lettuce) and putu putu (*Eichornia crassipes*, water hyacinth). Both are native or naturalized species to the Amazon region and are widespread in calm streams, tributaries, and *cochas*, the seasonal lakes formed when water levels go down (IIAP, 2019).

A series of studies conducted by Traction during the 2017 high river season in Claverito examined



Figure - 28 - Huama, putu putu + gramalote, high river season

water near huama, putu putu, gramalote (described below), and other aquatic species that collect and grow between homes and pathways, and found that levels of *E. coli* and fecal coliforms were often lower in areas with aquatic vegetation than in open water (Traction, 2017). They are among countless aquatic plant species that play important roles in their plant communities and biodiverse ecosystems, forming floating wetlands that cycle nutrients and provide habitat for non-plant species above and below the water's surface.

Other plant life that is important to Claverito is camu camu (*Myrciaria dubia*). A grove of camu camu trees is cultivated and maintained at the edge of the community. Like other trees native to the Amazon, camu camu is adapted to seasonal flooding; when the water is high, it is submerged, its tallest branches reaching green leaves above the surface of the water. Like Claverito's built elements, these trees capture debris and aquatic vegetation floating down the Río Itaya toward the Río Amazonas, building critical habitat for nesting birds, fish, amphibians, and countless insects. Renowned for its tasty fruit with high contents of vitamin C and other antioxidants and for its traditional medicine applications in treating arthritis, other inflammatory

diseases, and a long list of other health problems, camu camu is a valuable plant species in Amazonian ethnobotany and agroforestry (IIAP, 2019).

The origins of this camu camu grove are debated, but the community of Claverito is credited with maintaining the traditional practice of floodplain agroforestry in the city and contributing to urban biodiversity and water quality control that benefits Iquitos as a whole. The grove surrounding Claverito also acts as a buffer between the community and wave and current action, while Claverito and other amphibious communities, in turn, act as buffers between the *tierra firme* city and wave and current action, mitigating risk of erosion along the city's edges. Because urban shorelines in the Amazon and elsewhere tend to clear or dredge nearshore areas in ways that remove large woody debris and destroy nearshore habitat, amphibious communities like Claverito can play an important role in inviting robust ecosystem services back to the city by mimicking conditions found in the jungle. Floodplain nutrient cycling is an especially important ecosystem service for Iquitos, considering the city-wide lack of wastewater infrastructure.



Figure - 29 - Gramalote + camu camu, low river season



Figure - 31 - Low river season sewage swale



Figure - 30 - Groundwater during transition



Figure - 32 - Outhouses during transition

During the low river season, the landscape is different. Paused input from glaciers and seasonal snowpacks in the Andes Mountains as well as other highland precipitation roughly spanning the months of August through November means that the volume of water draining through the Amazon basin is much lower during this time. Throughout the rainforest, ponds and oxbow lakes form, tree trunks and forest floors taste air, and stretches of smaller tributaries dry up, thwarting passage of aquatic species and *botes*—forcing people to walk. An astounding diversity of endemic species is adapted to and relies on these hydrologic cycles.

In the city, the narrative contrasts. When the water level around Iquitos lowers, it exposes surrounding floodplains and grounds floating communities onto their muddy bottoms. Within a few weeks of exposure, the muddy plains sprout up with bright green grassy groundcovers including amphibious gramalote (*Leptochloa scabra*, rough sprangletop), which blankets floodplains during the low river season but floats in masses when water is high. Camu camu groves that shed their leaves while submerged begin to leaf out with the seasonal exposure to sun and air, all part of the cycle that includes their late-low river season fruiting period and their symbiotic relationship with native bees (Delgado, 2019).

It is during these first few weeks of exposed ground that urban floodplains put people at highest risk of exposure to disease. The water-borne bacteria, viruses, and parasites that come with a complete

Iquitos-wide lack of wastewater treatment settle on the ground's top layer. Much of the floating vegetation left with the water, while grounded huama, putu putu, and gramalote continue to grow, and are joined in-turn by annual groundcovers. As the moisture leaves mud, pathogens die. Puddles that emerge with receding water levels are mosquito habitat—the first seasonal round of them hatches all at once with a spike in exposure to mosquito-borne illness.

Foundations of homes settle onto the ground. Pathways offer raised routes over the floodplain surface but are no longer essential to foot access. Everything shifts. It was more level floating. As the landscape dries up and grass fills in, the seasonal soccer and volleyball fields are ready for use. While Claverito's community spaces are contained, surrounding floodplains that reach east from Iquitos' *tierra firme* edge come alive as people who live in informal and formal communities alike carve their annual desire lines through groundcovers and camu camu groves to access the waterfront, now much farther away.

The amphibious way of life, biannually alternating between living on water and living on land, is labor intensive. The partially submerged biodegradable materials that support communities both *flotante* (floating) and *sobre pilotes* (stilted) require relatively frequent replacement. Their owners recycle materials as needed, on a continual five to 10 year cycle (Vildósola, 2018). Wood—both raw logs from the jungle and lumber, often painted—is the most

common building material in Claverito. Most roofs are constructed from corrugated metal; other materials include plant-based thatch, tarp, and other plastics. The low river season is the time for building and maintenance.

Outhouses and in-home restrooms that during the high river season floated, delivering excrement straight into the river, rest on the ground during the low river season. People build shallow, narrow swales that collect wastewater and groundwater. They run exposed near homes, and often fail to drain or infiltrate due to flat topography and a high water table. Pathogens and mosquito vectors thrive in this standing water. People also maintain low water season pools, which serve as wells and for some as bathtubs.

An important part of Claverito is *el monte* ("the

mountain"), or the hillside adjacent to the community. Community members must descend and ascend this steep, often slippery hillside to move between *tierra firme* and the *zona inundable*. Two out of four of the stairways between the high land and Claverito's stretch of floodplain, as well as gardens and a community center are the subject of other TDAR projects initiated by Traction. *El monte* is a part of the amphibious community, acting as a threshold between the Claverito and the rest of Iquitos while hosting community green space.

Claverito's relationship with water is complex. Chapter 5 dives into an analysis of Claverito community data to understand what water-related health problems exist in the community, how they connect to built environment design, and to identify water-related health priorities that are then explored in chapter 6.



Figure - 33 - Bote, pedestrians, camu camu + gramalote on the floodplain, low river season

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Water-related health in Claverito

A SECONDARY DATA ANALYSIS

A secondary data analysis

RESEARCH QUESTION #3

What are the water-related health problems in Claverito and how do they connect to the built environment?

METHODS

This data analysis quantifiably examines both direct data and perceptions of water-related health. The purpose of this data analysis is multi-dimensional. Not only does it provide strong foundations for evidence-based design, but the data offers windows into the lived experiences of Claverito community members, shedding light on priorities and concerns that, if centered in a design exploration, can foster and sustain built environment changes for human and ecological health outcomes. Furthermore, the data provides baseline information against which the efficacy of design interventions can be measured, setting up the circumstances not only for measurable change in Claverito but also for design research that could inform amphibious informal community design elsewhere in Iquitos and the urban Amazon.

Because the data analysis portion of this project is a secondary analysis working off of the InterACTION Labs program led by Traction, methods are divided into two sections: an overview of Traction's data collection precedes an overview of the secondary analysis methods for this thesis.

TRACTION'S METHODS

The data informing this project was collected as part of the InterACTION Labs program led by Traction from 2016 to 2019 through various methods including 1) household surveys conducted verbally, 2) individual surveys conducted verbally, 3) individual physical exams conducted by nurses, and 4) physical environmental measures conducted by biologists.

The overall intention of the InterACTION Labs program is to improve environmental conditions through design interventions and follow human and ecological health in Claverito over time. Measures varied from year to year for a number of reasons: for some questions, no intervention was implemented so there was no reasonable expectation for the results to change; some research instruments are resource intensive (such as physical examinations requiring a lab); and excessive data measurement could pose an unnecessary burden on the community.

SECONDARY ANALYSIS METHODS

In the included tables, all instruments were designed by Traction, and methods describe the secondary analysis conducted as part of this thesis. Most of the data analyzed comes from a series of six household surveys, which had nearly full capture and offered a broad overview of water-related health at the community scale (see table 2). Each data set is described in more detail in the accompanying tables 5, 6 and 7 and in the findings section.

Part 1: What are the water-related health problems in Claverito?

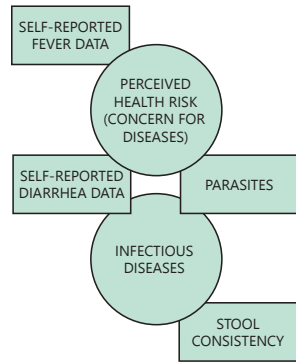
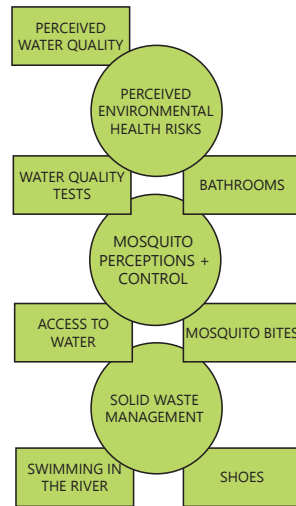


Figure - 34 - Research question + data overview

The secondary analysis began with a scan of available data. Elements connected to water-related health as defined in this project were highlighted and analyzed further. For any relevant survey question, data from each instance of that question over the course of four years of data analysis were used (rather than including only the data sets that yielded the most extreme results.) Most of the data analyzed came from the series of six household surveys (see table 2).

Because the research question takes a broad view on water-related health, relevant data varied widely.

Part 2: How do they connect to the built environment?




Eighteen relevant data sets were organized into the two-part research question: 1) What are the water-related health problems in Claverito? 2) How do they connect to the built environment? Part one examines indicators of water-related health problems including concern for diseases, self-reported fever and diarrhea data, stool consistency surveys, parasite tests, and cases of infectious diseases. Part two examines questions that capture perceived environmental health risks, mosquito perceptions, control, and bites, rat sightings, bathrooms, water quality satisfaction, sources of water for drinking and household needs, solid waste management, and behavior related to swimming and shoes.

Because participants were welcome to pass on any question that they did not feel comfortable answering, several instances of participants leaving a question blank existed. N values vary widely and are included throughout findings. For questions that were included in multiple surveys conducted during different seasons, low river season, high river season, or transition months are layered into data representation through color coding.


Table 2 - Household survey sample sizes + capture

	HOUSEHOLD SURVEY SAMPLE SIZES + CAPTURE					
	2016 AUGUST	2017 APRIL	2017 OCTOBER	2018 FEBRU.	2018 JULY	2019 AUGUST
Participating households	44	38	41	43	41	47
No. of people represented	238	222	220	214	210	250
Average household size	5.41	5.84	5.37	4.98	5.12	5.32
Total households in community	48	48	48	50	50	52
Percent capture	92%	79%	85%	86%	82%	90%



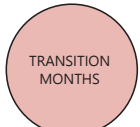
LOW RIVER SEASON

August - November



HIGH RIVER SEASON

January - June



TRANSITION MONTHS

July + December

ADDITIONAL CODING

For analysis of data sets that included additional coding due to open-ended answers, those methods are included here in detail. Two data sets in particular include substantial additional analysis and coding: the first question in part one, and the first question in part two, both of which focus on community perceptions as starting points for answering the research question. Neither question was designed specifically to focus on water-related health, but because responses to the open-ended questions overwhelmingly alluded to water in some way, they were coded as such. They were also excellent starting points for identifying community priorities. An overview of coding to extract water-related responses follows, as well as waste management data analysis methods and information about the Bristol stool consistency scale included in presented data.

Question: Are you worried about contracting any diseases? If yes, what diseases?

This question was asked in the first two household surveys: 2016 August (low river season) and 2017 April (high river season). An overview of the coding process used in analyzing responses to the open-ended follow-up question shows that diseases mentioned were broadly categorized as mosquito-borne, rat/rodent-related, other infectious, and non-infectious. The categories were drawn according to the most common responses. (See table 3.)

Question: Do you know of anything in your community that could harm you or make you sick? If yes, what?

This question was asked in the first three household surveys: 2016 August (low river season), 2017 April (high river season), and 2017 October (low river season). An overview of the coding process used in analyzing responses to the open-ended follow-up question (table 4) shows that perceived water-related health risks were organized into water-related and other environmental categories. Because the focus of this project is water-related

Table 3 - Coding for concern for diseases

CODING FOR "ARE YOU WORRIED ABOUT CONTRACTING ANY DISEASES? WHICH ONES? (2016 AUGUST, 2017 APRIL)				
COMPLETE LIST OF RESPONSES	RISK OF EXPOSURE CATEGORY			
	MOSQUITO -BORNE	RAT/ RODENT	OTHER INFECTIOUS	NON-INFECTIOUS
Malaria	x			
Dengue	x			
Zika	x			
Tos (cough)			x	
Fiebre (fever)			x	
Diabetes				x
Bronquios (bronchitis)			x	
Leptospirosis		x		
Infecciones intestinales (intestinal infections)			x	
Enfermedad que trae el Zancudo (mosquito-borne disease)	x			
Tuberculosis			x	
Cancer				x
Por las ratas (rat-transmitted disease)		x		
Gripe (flu)			x	
Chikungunya	x			
Fiebre amarilla (yellow fever)	x			

health, water-related categories are relatively specific, while responses with indirect to no relation to water were coded as **other**.

Because discussions of regional climate and climate change are within the scope of this project, **climate** emerged as a broad but important category on the spectrum between water-related environmental health risks and "other." Weather and climate are certainly not the same thing, but because this project is in-part grounded in a discussion of climate change effects on weather, and because these responses do not specify whether they are referring to isolated atmospheric conditions or larger climate

trends, all mentions of weather and/or climate are coded as climate.

Some responses listed were quite descriptive and complex, potentially falling into multiple categories. For example, a case could be made for *água retenida* (standing water) and *água de charco* (puddles) scoring as wastewater, other waste, vectors, and climate. Because the climate connection is not explicit in the response' wording, these items did not score in the climate category. But because standing water poses a health risk by exposing people to **wastewater**, because it often gathers in **solid waste**, and because it offers breeding ground

Table 4 - Coding for environmental health risk perception

CODING FOR "ARE YOU AWARE OF ANYTHING IN YOUR COMMUNITY THAT COULD HURT YOU OR MAKE YOU SICK? IF YES, WHAT?" (2016 AUGUST, 2017 APRIL, 2017 OCTOBER)						
COMPLETE LIST OF RESPONSES	ENVIRONMENTAL HEALTH RISK CATEGORY					
	SANI-TATION	SOLID WASTE	OTHER POLLUTION	VECTOR DISEASES	CLIMATE	OTHER
Zancudo (mosquito)				x		
Basura (trash)		x				
Olores (smells)			x			
Creciente del agua (rising water)					x	
Gripe (flu)						x
Mosquito diseases (malaria, dengue, zika, chikungunya, yellow fever)				x		
Rata (rat)				x		
Desague (sewage)	x					
Hepatitis	x					
Agua retenida/agua de charco (standing water/puddles)	x	x		x		
Deshechos (waste)		x				
Aire (air)			x			
Venta (wind)					x	
drogas (drugs)						x
Humedad (humidity)					x	
Agua contaminada (contaminated water)	x					
Orine (urine)	x			x		
Heces (feces)	x					
Insectos (insects)				x		
Serpientes (snakes)						x
Cucuracha (cockroaches)						x
Contaminacion/suciedad (contamination/dirtiness)	x	x				
La lluvia (rain)					x	
Parasites por animales (parasites from animals)				x		
Moscas (flies)				x		
El monte (the hillside)		x				
Sol (sun)					x	
Escalera (stairs)						x

for mosquito **vectors**, these responses do score in each of those three categories. Allowing items to fall into multiple categories was an important decision that speaks to the layered environmental aspects of health risks in the community.

Other responses required more extensive analysis to categorize. One response was hepatitis, which, because hepatitis is transmitted via unsanitary water, scored under **sanitation**. *Gripe*, or general illness like flu or cold, was another response. Because *gripe* usually refers to infectious illness passed from human to human, rather than stemming explicitly from the environment, it scored as **other**.

Question: What do you and your family do with household food waste and non-food waste?

Categories were created based on common open-ended responses to the “other” option: *quema* (we burn it), *no hay* (there isn’t any), and *monte* (we put it on the hillside). For people who answered *bolsa* (bag), their responses were counted with “trash can.” The response, *fuera de la casa* (outside the house) counted under “river.” Responses *dar para vecinos* (we give it to the neighbors) and *hay suficiente* (there is enough) counted as *no hay* (there isn’t any).

Indicator: stool consistency

The Bristol Stool Form Scale (BSFS) has been a widely used validated tool since its development








BRISTOL STOOL FORM SCALE		
TYPE 1		Separate hard lumps (very constipated)
TYPE 2		Lumpy _ sausage like (slightly constipated)
TYPE 3		A sausage shape with cracks in the surface (healthy)
TYPE 4		Like a smooth, soft sausage or snake (healthy)
TYPE 5		Separate soft blobs with clear-cut edges (lacking fiber)
TYPE 6		Mushy consistency with ragged edges (inflammation)
TYPE 7		Liquid consistency with no solid pieces (inflammation + diarrhea)

Figure - 35 - Bristol Stool Form Scale [Medical News Today]

in 2000. It uses seven illustrated stool consistency types to gain an understanding of stool consistency, which indicates the level to which stools are absorbing water, the amount of time spent in intestinal transit, and inflammation. While detailed stool sample analysis is resource-intensive, requiring a lab, the BSFS is a resource-low alternative that has been shown to indicate accurate results (Blake, Raker, & Whelan, 2016).

METHODS OVERVIEW

The tables on the next three spreads, tables 5, 6, and 7 summarize in detail data analysis methods and limitations. Instruments were designed and carried out by Traction's teams. Methods refer to the secondary analysis in this thesis. Limitations refer both to Traction's instruments and to the methods and analysis in this thesis.

The first methods columns describe a preliminary analysis of each data set. For data sets that warranted further analysis, those methods are detailed in the additional methods columns.

Data sets are highlighted by colors to indicate high river season (blue), low river season (orange), or transition months (pink).

Tables 8, 9, and 10 at the end of this chapter correspond with these tables and present summaries of findings, relevant connections between the health data and the built environment, and potential design opportunities that stem from the data analysis.

Table 5 - Part 1 methods + limitations

PART 1: WHAT ARE THE WATER-RELATED HEALTH PROBLEMS IN CLAVERITO?				
SHORT NAME	INSTRUMENT			METHODS
	SURVEY	QUESTION	RESPONSE TYPE	METHODS/CODING
CONCERN FOR DISEASES	Household surveys: 2016 August 2017 April (see table 2 for n values)	Are you concerned about getting any diseases?	Yes/no	Counted yes and no responses and compared to n values for each survey.
		If yes, which diseases are you concerned about getting?	Open-ended short answer	Listed and counted responses.
FEVER	Household surveys: 2016 August 2017 April 2017 October 2018 February 2018 July 2019 August (see table 2 for n values)	Has anyone in your household had a fever in the last six months?	Yes/no	Counted yes and no responses and compared to n values for each survey.
DIARRHEA	Household surveys: 2016 August 2017 April 2017 October 2018 February 2018 July 2019 August (see table 2 for n values)	Has anyone in your household had diarrhea in the last six months?	Yes/no	Counted yes and no responses and compared to n values for each survey.
STOOL CONSISTENCY	Individual verbal surveys: 2018 February (n=59) 2018 July (n=84) 2019 August (n=173)	Which stool sample image most closely matches your typical stool in the last week?	Bristol stool scale, 1-7	Counted prevalence of each number on the scale for each survey, before adding up rates of 1, 2, and 3, which indicate diarrhea or soft stool.
PARASITES	Individual physical exams: 2017 April (n=87) 2018 February (n=123) 2018 July (n=73)	1 fecal sample per participant was collected and tested for parasites using the Directo, Concentrado, Baerman and Ziehl Nielson methods	Positive/negative for each in a long list of parasites.	Three rounds of fecal tests tested for presence of parasites in fecal samples. Traction analyzed data to calculate percentage of positive parasite presence.
INFECTIOUS DISEASES	Household surveys: 2016 August 2017 April 2017 October (see table 2 for n values)	Has anyone in your household had any of these infectious diseases?	Check if yes: malaria, chikungunya, dengue, zika, rabies, yellow fever, cholera, ringworm, flu, chickenpox, measles, mumps, rubella, leptospirosis, tuberculosis, leishmaniasis	Listed all diseases per household per year to compile cumulative responses. Coded for overall yes/no per household.

PART 1: WHAT ARE THE WATER-RELATED HEALTH PROBLEMS IN CLAVERITO? (CONTINUED)		
METHODS (CONTINUED)		LIMITATIONS
ADDITIONAL ANALYSIS	ADDITIONAL METHOD/CODING	
n/a	n/a	People may not be concerned about getting the diseases that are actually most prevalent. People might also be concerned about getting diseases they think they have had, but that were never diagnosed by a medical professional.
Of the diseases mentioned, what is the proportion of infectious diseases? Of the infectious diseases mentioned, what is their mechanism of infection?	Sorted responses into columns and summed up totals (see <i>table 3</i>): mosquito-borne, rat/rodent, other infectious, non-infectious	
For highest prevalence of fever, 2016 August, what was the age distribution?	Traced participant IDs to pull in age data, and sorted responses into age groups: under 5, 6-10, 11-20, 21 and older, unspecified	Self-reporting and reporting as a household representative may miss some cases of fever. Further, people are typically not using thermometers, and may not perceive a common recurring symptom as abnormal.
For highest prevalence of diarrhea, 2018 July, what was the age distribution?	Traced participant IDs to pull in age data, and sorted responses into age groups: under 5, 6-10, 11-20, 21 and older, unspecified	Because bathroom matters are private, household representative may not know whether each member of the family had had diarrhea or not. Another limitation of self-reported diarrhea is that people may only report abnormal consistency; if normal is diarrhea, it might not seem noteworthy. That rates got higher over time could indicate that people became more aware of soft stool, through exposure to Bristol stool consistency chart imagery that study researchers provided.
n/a	n/a	Participants might be shy or embarrassed by the stool chart; participants might give the answer that they think is best.
n/a	n/a	Typical parasitic analysis includes three days of fecal samples but was unable to be achieved because of cost and logistics. Anticipate results are lower than actual parasitic infection prevalence.
Which infectious diseases have been most common in Claverito? Of reported diseases, what is the proportion of mosquito-borne diseases?	Created columns with most common responses: dengue, zika, yellow fever, chikungunya, malaria, chicken pox, unknown. Added "other" for responses where participant either did not know or did not specify.	Responses were self-reported (Traction did not look at doctor's notes or hospital visits); less than half of people reported that they went to a western medicine doctor; when they did, they were treated for symptoms and may not have been tested. Surveys do not account for mortality of community members from infectious diseases, as household representatives were asked to respond based on current household members; participants may have included infectious diseases that people now living in Claverito acquired while living outside of Claverito; surveys do not account for repeat cases in one person – for example, if someone had malaria or dengue more than once in their lifetime.

Table 6 - Part 2 methods + limitations

PART 2: HOW DO THE HEALTH PROBLEMS CONNECT TO THE BUILT ENVIRONMENT?				
SHORT NAME	INSTRUMENT			METHODS
	SURVEY	QUESTION	RESPONSE TYPE	METHODS/CODING
ENVIRONMENTAL HEALTH RISK PERCEPTION	Household surveys: 2016 August; 2017 April; 2017 February (see table 2 for n values)	Are you aware of anything in your environment that could harm you or make you sick?	Yes/no	Counted yes and no responses and compared to n values for each survey.
		If yes, what?	Open-ended short answer	Listed responses.
E. COLI + COLIFORM COUNTS	Physical environmental measures: water quality tests 2017 at four points in the high river season	What are the E. coli and coliform counts in the river water in Claverito?	Open-ended number value	Samples were taken at four points in the same three locations in open river water at 8 cm and 40 cm depths within Claverito that did not have immediately close proximity to vegetation or bathrooms. E. coli and coliform counts were determined using 3M™ Petrifilm™ Coliform Count Plates.
MOSQUITO PERCEPTIONS + CONTROL	Household surveys: 2016 August 2017 April 2017 October (see table 2 for n values)	Do you have a problem with mosquitoes in your home/community?	Yes/no	Counted yes and no responses and compared to n values for each survey.
		Do you control for mosquitoes in any way?	Yes/no	
		If yes, how?	Open-ended short answer	Listed responses.
MOSQUITO BITES	Household surveys: 2016 August 2017 April 2017 October (see table 2 for n values)	In the past week, how many mosquito bites did you get?	choose: none, a few, many	Counted prevalence of each response and compared to n value.
		If you had to guess, about how many is that?	open-ended number value	Averaged values associated with "a few" and "many" ("none"=0)
RAT SIGHTINGS	Household survey: 2017 October (see table 2 for n values)	Have you seen rats in the community in the last week?	Yes/no	Counted yes and no responses and compared to n value.
		If yes, how many did you see?	Open-ended number value	From list of positive responses (excluding zero), calculated range, average, and median.
		If yes, where did you see them?	Choose: at home, neighbor's home, on the hillside, elsewhere	Counted prevalence of each response and compared to n value.

PART 2: HOW DO THE HEALTH PROBLEMS CONNECT TO THE BUILT ENVIRONMENT? (CONTINUED)

METHODS (CONTINUED)		LIMITATIONS
ADDITIONAL ANALYSIS	ADDITIONAL METHOD/CODING	
n/a	n/a	n/a
Of responses, what broad categories exist?	Created columns based on responses, and sorted responses into them (see <i>table 4</i>): wastewater, other pollution, climate, trash, vector-borne diseases, other	
n/a	Averaged counts for 8 cm and 40 cm depths for each of E. coli and coliform counts at four different points in the high water season.	This thesis was limited to one year of data analysis. Further examination into depth of water, time of day, time of season, and human exposure are needed for better understanding of burden of disease, but overall the presence of any E. coli or coliforms in the water renders it unsafe.
n/a	n/a	People may not be paying attention to or looking for mosquitoes. Further, what is considered a mosquito problem likely varies drastically from one person to the next.
Among methods participants listed for managing mosquitoes, what strategies are most popular?	Created categories based on responses and organized responses: kill with hands, bed nets, incense, insecticide, fan or air, bag of water trap, petroleum, bleach, other	
n/a	n/a	Defining "none," "a few," and "many" was based on participant estimations of how many each of those is. The responses ranged drastically, with one person defining "a few" as 100 bites, while no estimations for "many" were that high. Thus, quantities corresponding with "none," "a few," and "many" are not exact. Further, because they are so prevalent, people may not notice mosquitoes, and are likely not methodically counting them or the bites that they get.
n/a	n/a	People may not be paying attention to or looking for rats. It is also very unlikely that they are methodically counting them.

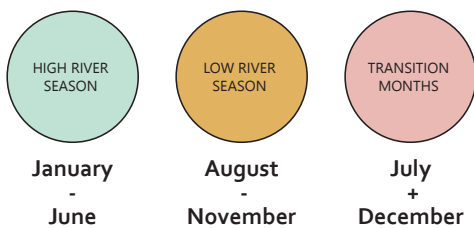
Table 7 - Part 2 methods + limitations, continued

PART 2: HOW DO THE HEALTH PROBLEMS CONNECT TO THE BUILT ENVIRONMENT? (CONTINUED)				
SHORT NAME	INSTRUMENT			METHODS
	SURVEY	QUESTION	RESPONSE TYPE	METHODS/CODING
BATHROOMS	Household survey: 2016 August (see table 2 for n values)	Where do you and your family go to the bathroom?	Choose all that apply: in-home bathroom, outhouse, outdoors, directly in river	Counted prevalence of each response and compared to n value.
WATER QUALITY SATISFACTION	Household surveys: 2016 August 2017 April 2017 October (see table 2 for n values)	How happy are you with the water quality/ water contamination in your community?	Scale, where 1=not happy; 6=very happy	Counted prevalence of each response and compared to n value.
WATER SOURCES	Household survey: 2016 August (see table 2 for n values)	Where do you get water for the following seven uses: drinking during low river season, drinking during high river season, laundry, dishes, bathing, watering plants, handwashing?	Choose all that apply for each: bought outside community, bought inside community, public water/city tap, well/ groundwater, individual bottled water, collected rainwater, river water	Counted prevalence of each response and compared to n value.
SOLID WASTE MGMT: HOUSEHOLD FOOD WASTE	Household surveys: 2016 August 2017 April 2017 October 2018 February 2018 July (see table 2 for n values)	Where do you and your family dispose of household food waste?	Choose all that apply for each: trash can, fed to animals, composted, river, other	Counted prevalence of each response and compared to n value for each survey.
SOLID WASTE MGMT: HOUSEHOLD NON-FOOD WASTE	Household surveys: 2016 August 2017 April 2017 October 2018 February 2018 July (see table 2 for n values)	Where do you and your family dispose of household non-food waste?	Choose all that apply for each: trash can, fed to animals, composted, river, other	Counted prevalence of each response and compared to n value for each survey.
SWIMMING IN THE RIVER	Individual verbal surveys: 2018 February (n=69) 2018 July (n=70)	How often do you swim/bathe in the river?	Choose: always, usually, sometimes, rarely, never	Counted prevalence of each response and compared to n value for each survey.
SHOES	Individual verbal surveys: 2018 February (n=70) 2018 July (n=91)	How often do you wear shoes inside your home?	Choose: always, usually, sometimes, rarely, never	Counted prevalence of each response and compared to n value for each survey.
		How often do you wear shoes outside your home?		
		What type of shoes do you typically wear?	Choose: close toed, sandals/ flip flops, no shoes	

PART 2: HOW DO THE HEALTH PROBLEMS CONNECT TO THE BUILT ENVIRONMENT? (CONTINUED)		
METHODS (CONTINUED)		LIMITATIONS
ADDITIONAL ANALYSIS	ADDITIONAL METHOD/CODING	
n/a	n/a	People may be embarrassed or ashamed of where they go to the bathroom and therefore "outside" and "in the river" may be underreported.
n/a	n/a	Response based on perception, as the community did not have access to water quality tests to understand contamination at the microbial level.
n/a	n/a	Doesn't take into account water storage methods. Options "bought inside community" and "bought outside community" do not get at the root source, which may vary. Further, residents may be embarrassed or ashamed about getting water from the river, well, or rainwater, so these levels are anticipated to be underreported. The results also rely on memory for the high river season, as the question was asked during the low river season.
Among open-ended responses under "other," what are the most common practices?	Based on "other" responses, three additional categories that were mentioned at least twice were created: we burn it, their isn't any, and we put it on the hillside.	This question relies on honesty, and participants may be embarrassed or ashamed about responses other than trash can or bag. It also doesn't capture what happens with bags and whatnot after the fact.
Among open-ended responses under "other," what are the most common practices?	Based on "other" responses, three additional categories that were mentioned at least twice were created: we burn it, their isn't any, and we put it on the hillside.	This question relies on honesty, and participants may be embarrassed or ashamed about responses other than trash can or bag. It also doesn't capture what happens with bags and whatnot after the fact.
n/a	n/a	Participants may be bathing in the river and not consider it to be swimming in the river.
n/a	n/a	Participants may include their porches and the pathways right outside their homes as inside. Because houses are open, inside the house and outside the house are very similar, in terms of exposure.

FINDINGS, PART 1

What are the water-related health problems in Claverito?



This section examines any data that suggests prevalence and perceptions of water-related infectious disease, including concern for diseases, self-reported rates of fever and diarrhea, Bristol stool consistency surveys, rates of parasites from physical examinations of stool samples, and self-reported cases of water-related infectious diseases. Findings are roughly color coded (and always noted otherwise) by high river season (roughly January through June), low river season (August through November) and transition between high and low (roughly the months of July and December).

Indicator: concern for diseases

The best starting point for gauging health risks in Claverito is to ask the residents. Responses to the open-ended question, "are you concerned about getting any diseases?" yielded 68 separate answers in the former and

62 in the latter. An analysis of responses reveals household representatives' perceptions of health risks and suggests possible starting points for design solutions.

Of the 44 responses from 2016 August, 33 people (or 75 percent) responded yes, listing 68 diseases or health risks. Of the 38 responses from 2017 April, 34 people (or 89 percent) responded yes, listing 62 diseases or health risks. Of the diseases that were listed, 96 percent and 100 percent, respectively, were infectious diseases related to water.

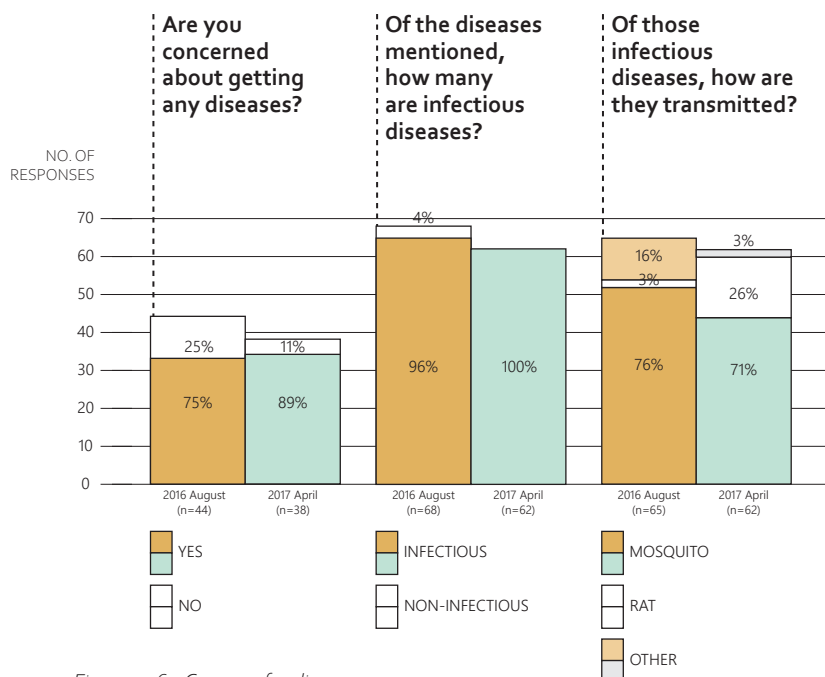


Figure - 36 - Concern for diseases

Participants were most concerned about mosquito-borne diseases including malaria (with 21 and 19 mentions, respectively) and dengue fever (with 23 and 19 mentions, respectively). Other mosquito-borne diseases mentioned were Zika, chikungunya, and yellow fever. Several people listed leptospirosis, an infectious disease contracted by humans when they come into contact with the urine or feces of infected rats or other mammals, while others simply listed "rats" or "illness from rats." Other illnesses listed included cough, flu, respiratory infections, and other infections. Non-infectious disease mentions (of which there were three in the 2016 August survey and zero in the next) included cancer (1) and diabetes (2).

Indicators: fever and diarrhea

Visits to the doctor are rare for people living in Claverito, and those visits will often yield treatment of symptoms without official diagnoses. Thus, use of broad indicators offers insight into overall prevalence of infectious disease. Common causes of both fever and diarrhea are bacterial, viral, and parasitic infections. All six of Traction's community health surveys asked household representatives whether anybody in their household had experienced fever or diarrhea in the last six months, in separate questions.

Instances of fever and diarrhea are frequent and shifting. Across the six point-in-time measurements,

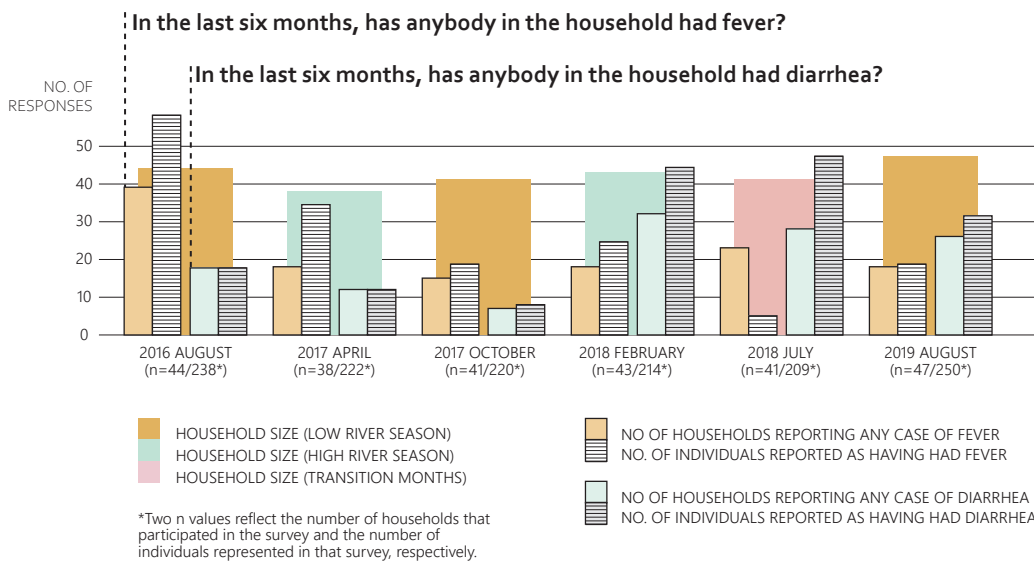


Figure - 38 - Self-reported prevalence of fever and diarrhea

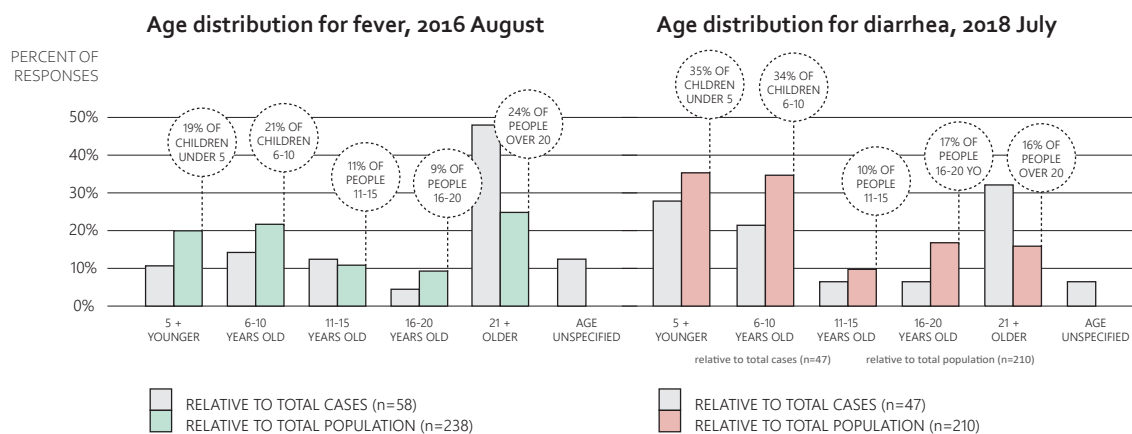


Figure - 37 - Age distribution for fever and diarrhea

households reporting at least one case of fever ranged from 15 out of 41, or 37 percent of households, to 39 out of 44, or 89 percent of households, with individual instances ranging from 19 to 58 people. Households reporting at least one case of diarrhea ranged from seven out of 41, or 17 percent of households to 32 out of 43, or 74 percent of households, with individual instances ranging from eight to 47 people.

Illness affects people at different ages differently. For adults, symptoms like fever and diarrhea prevent people from working or tending to children, putting critical income and families at risk. While acute illness is frequent in young kids, they are kept from school, which can put kids at a disadvantage. Repeated, severe, or chronic illness is also detrimental to physiological development, setting young ones up for increased risk of exposure and stunted growth and brain development throughout their lives.

diarrhea occurred in children aged 10 and younger, affecting one in three children—a disproportionately high rate for Claverito’s youngest ones.

Though rates of these symptoms did not reach these levels in other surveys, recurring high rates are striking, nonetheless. That spikes in both symptoms coincided with early low river and transition to low river season may point to increased exposure to infectious diseases when the community is recently grounded on the floodplain.

Indicator: stool consistency

The Bristol Stool Form Chart was distributed to individuals in three individual physical surveys, 2018 February, 2018 July, and 2019 August. The results showed that up to a third of people had diarrhea for three different points in time, indicating prevalence of infection likely related to water and sanitation in the community.

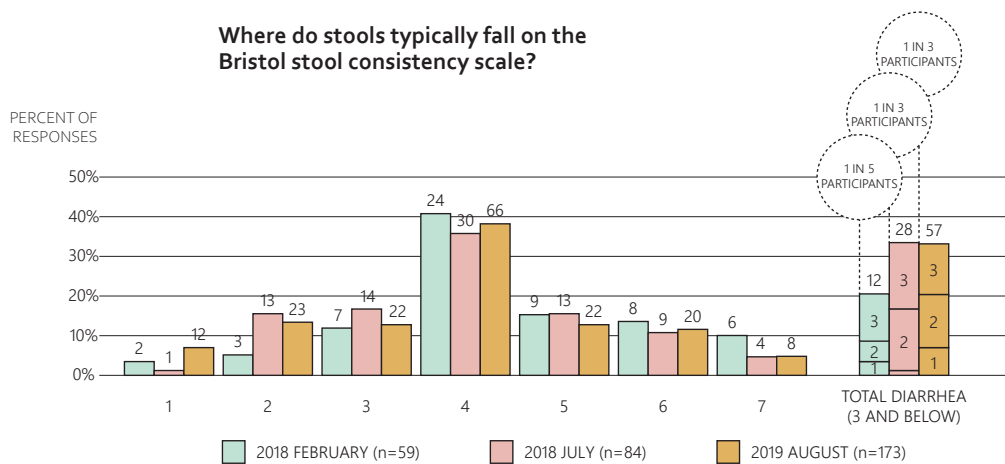


Figure - 39 - Bristol stool consistency

An analysis of age distribution for the surveys showing the highest rates of fever and diarrhea, 2016 August and 2018 July, respectively, shows that rates of fever were common across age ranges, with one in five children aged 10 and younger with fever, while about one in four people over 20 had fever. In July 2018, about 50 percent of reported cases of

Indicator: parasites

Results from stool sample lab tests that tested for parasites showed that over 80 percent of participants consistently had parasites in their stools. Even though people with positive test results were treated with medicine following each test, cases were reoccurring. This is likely due to

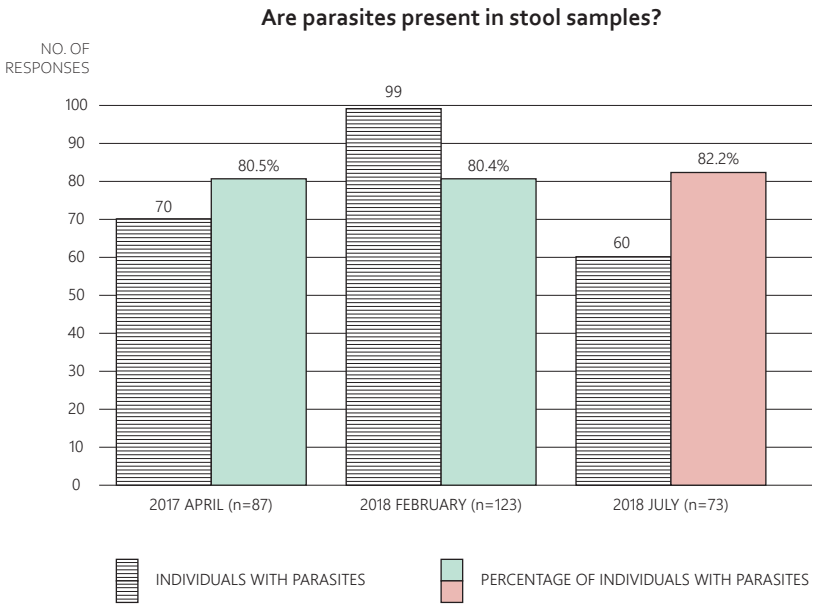


Figure - 41 - Parasites in stool samples

constant re-exposure to untreated wastewater and contaminated drinking water infrastructure, contamination in river water, exposure to non-human animal species carrying parasites, and parasite habitat on Claverito’s walking surfaces.

Indicator: infectious diseases

This question asked whether anyone in the household had ever had any one of a long list of infectious diseases: malaria, chikungunya, dengue, Zika, rabies, yellow fever, cholera, ringworm, flu, chickenpox, measles, mumps, rubella, leptospirosis, tuberculosis, and leishmaniasis.

Cumulative responses from three household surveys showed that 30 out of 45 households (67 percent) responded that someone in their household had had one or more of the infectious diseases in the survey, with 62 individually listed diseases. The most common diseases included those transmitted by mosquitoes: malaria—transmitted by *Anopheles* mosquitoes—and dengue and Zika—transmitted by *Ae. aegypti* and *Ae. albopictus* mosquitoes.

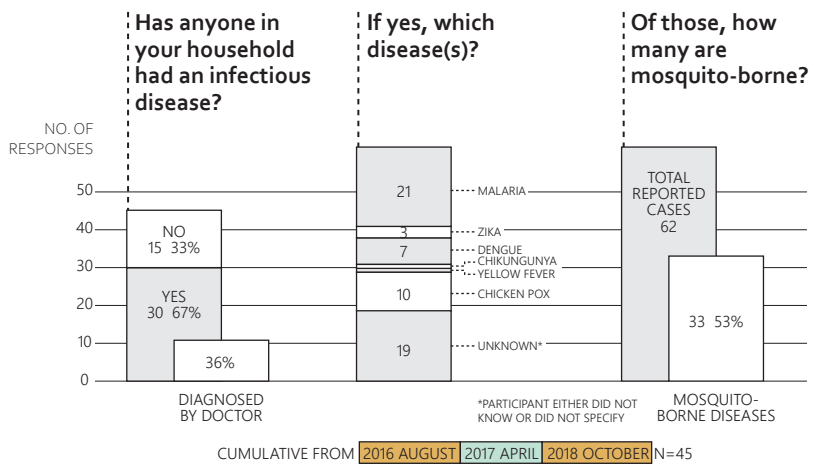
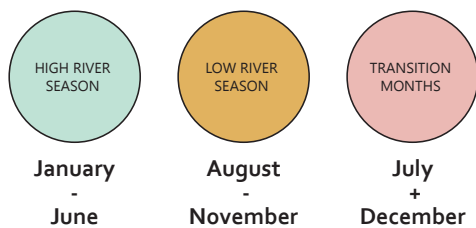


Figure - 40 - Infectious diseases

FINDINGS, PART 2

How do the health problems connect to the built environment?



This section examines the results from analysis of 12 different data sets that capture perceptions of environmental health, perceived and tested water quality, mosquitoes, rats, bathrooms, access to water for drinking and household needs, solid waste management, and behavioral questions about shoes and swimming in the river. The results begin to suggest community design priorities and starting points for mitigating water-related health problems in Claverito.

Indicator: environmental health risk perceptions

In beginning to assess the extent to which established health risks connect to the built environment, it is again important to start by asking community members. Analysis of responses to the question, "Are you aware of anything in your environment that could harm you or make you sick?" paints a picture of community perceptions of the relationship between infectious diseases and the built environment related to water. Nearly 90 percent of participants said that they are aware of things in the environment that could harm them or make them sick. Among most common responses to the open-ended follow-up were wastewater, vector-borne diseases, climate/weather, pollution, and trash. These responses suggest community design priorities.

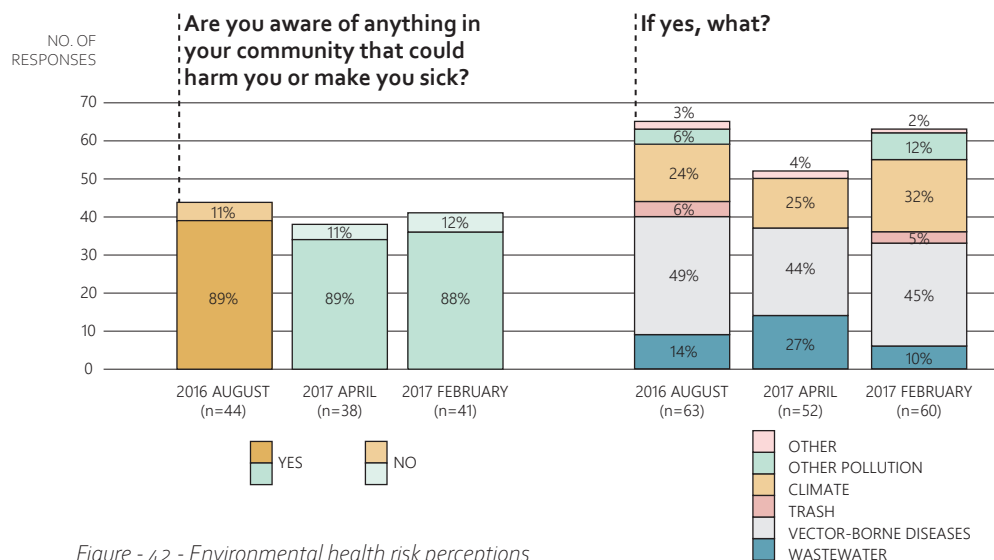


Figure - 42 - Environmental health risk perceptions

Indicator: E. coli + coliform counts

Water quality tests from a 2017 exploration of the effects of aquatic plants on Escherichia coli (E. coli) and coliform counts in Claverito's water offer insight into pathogen prevalence in the water at different points during the high river season. The

E. coli + coliform counts in river water

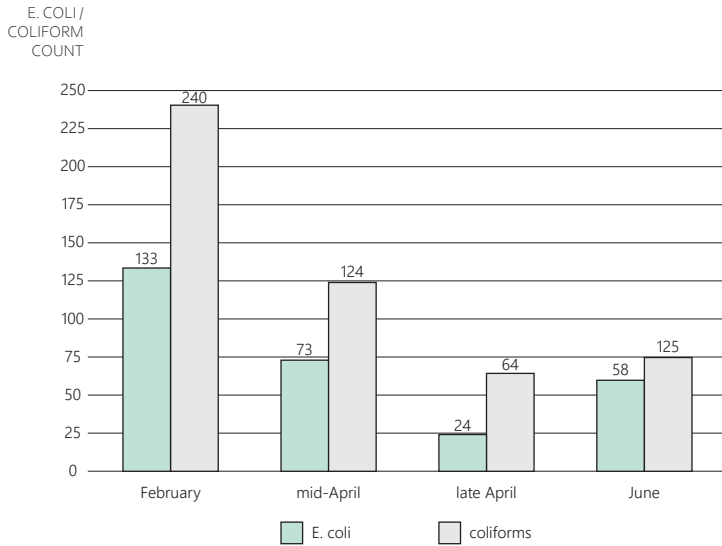


Figure - 43 - E. coli + coliform counts

water quality tests measured E. coli and coliforms during February (early high river season), April (mid-high river season), and June (late high-river season). E. coli and coliform counts in river water were well above zero (the safe level for drinking) in every test, rendering water unsafe for drinking and putting people in close contact with it at high risk of bacterial infection. While not analyzed in this thesis, counts were usually significantly lower in areas with aquatic vegetation (Traction, 2017). These findings indicate lack of wastewater treatment and high risk of exposure to pathogens for the community during

the high river season, while also suggesting that design with aquatic vegetation could significantly reduce that risk.

Indicators: mosquito perceptions, control + bites

When asked whether there is a mosquito problem in Claverito, over half of respondents at three different points in time said that there is, and that they attempt to control for mosquitoes using a variety of methods including use of incense, killing them with their hands, bed nets, insecticide, and other methods. No participant listed reduction of standing water. Contrarily, a few reported using a bag of standing water as a trap, one of whom included a note: "doesn't work." Most participants perceive a mosquito problem in their home or community and attempt to control for exposure to mosquitoes in some way.

When asked to estimate how many times they had been bitten in the past week, over half answered, "a few," which averaged to about eight mosquito bites per week, as defined by participants. This information gives an idea of the risk of exposure to mosquito-borne diseases like dengue fever, yellow

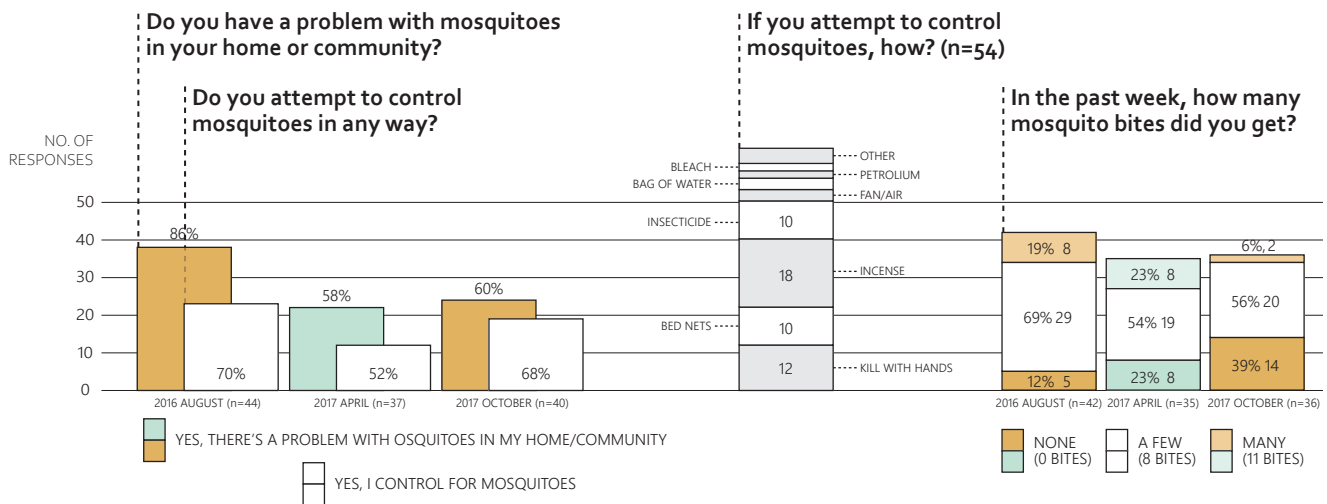


Figure - 44 - Mosquito perceptions, control + bites

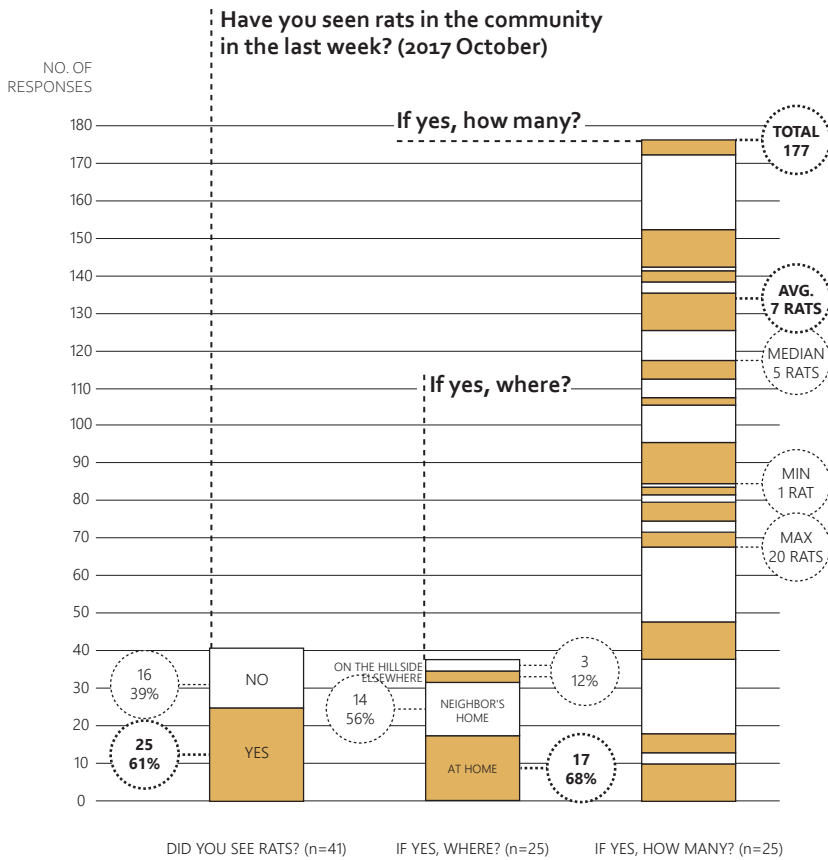


Figure - 45 - Rat sightings

fever, chikungunya, and Zika (transmitted by *Ae. aegypti* and *Ae. albopictus* mosquitoes) and malaria (transmitted by mosquitoes in the *Anopheles* genus).

Indicator: rat sightings

In the 2017 October (low river season) survey, 61 percent of people reported having seen rats around the community in the last week. Of those positive responses, the reported number of rats seen ranged from one to 20, with a total of 177 rats, an average of seven rats, and a median of five rats. Of people

who saw rats, 17 (68 percent) said they saw them in their own homes, 14 (56 percent) said they saw them at their neighbors' homes, three (12 percent) said they saw them on the hillside, and three (12 percent) said the rats they saw where elsewhere. This assessment of rat sightings helps to gauge the risk of exposure to rat-related pathogens like leptospirosis and shows that rats are finding habitat in and around people's homes.

Indicator: bathrooms

From the standpoint of sewage, all places that people are going to the bathroom in Claverito are essentially the same; they send sewage directly onto the floodplain or into the water, depending on the season. An examination of responses to the question, "where do you and your family go to the bathroom?" suggests starting points for wastewater treatment design.

The survey found that 31 out of 44 households (70 percent) were using outhouses, and nine (20 percent) were using in-home bathrooms. Only two participants reported going to the bathroom outdoors, and one reported going to the bathroom directly in the river. This information points to potential for outhouse and in-home restroom redesigns that could mitigate exposure to wastewater in Claverito.

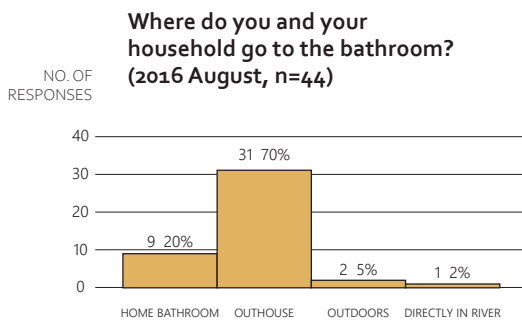


Figure - 46 - Bathrooms

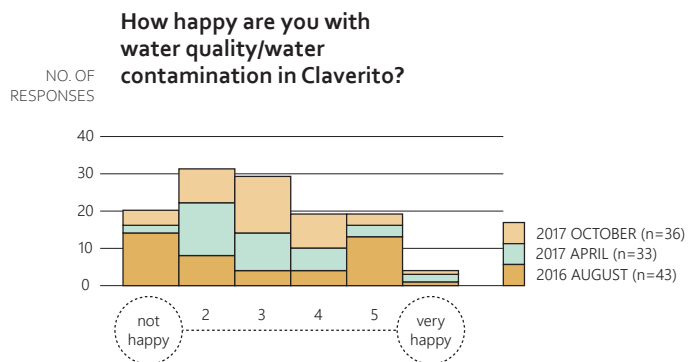


Figure - 47 - Water quality satisfaction

Indicator: water quality satisfaction

In three household surveys, household representatives were asked how happy they were with a variety of different aspects of the community, including water quality or water contamination. On a scale of one to six, where one was not happy and six was very happy, very few participants said that they were very satisfied or happy with the water quality in Claverito, while the most popular

were rainwater, public water, or buying it inside the community. Of particular interest are the prevalence of river water and well/ground water, which are likely to be highly contaminated, and a lack of use of rainwater, which has both relatively low contamination and price.

Indicator: solid waste management

Several survey participants listed trash as something in the environment that could harm them or make them sick (see Indicator: environmental health risk perceptions). Most participants reported that they are disposing of food waste in either trash bags or cans or feeding it to animals, while non-food waste is typically put in trash bags or cans. Understanding how solid waste is managed

responses were two and three. This indicates an awareness that water quality could be improved and potential desire among community members to implement strategies to improve water quality.

in Claverito can help designers to gauge risk of contamination and exposure to mosquitoes, which breed in standing water occurring in uncovered trash, and rats, whose infected urine and feces

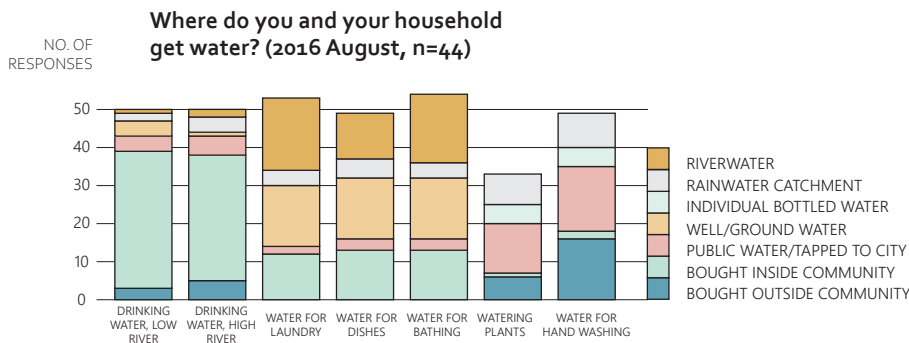


Figure - 48 - Water access

Indicator: water sources

An examination of where people are getting water for drinking and household needs offers windows into exposure to pathogens that live in water, including bacteria, viruses, and parasites. Most participants said that they are buying water for drinking within the community. The most common sources for laundry, dishes, and bathing were the river, wells or groundwater, or buying it inside the community. Common sources of water for plants and handwashing

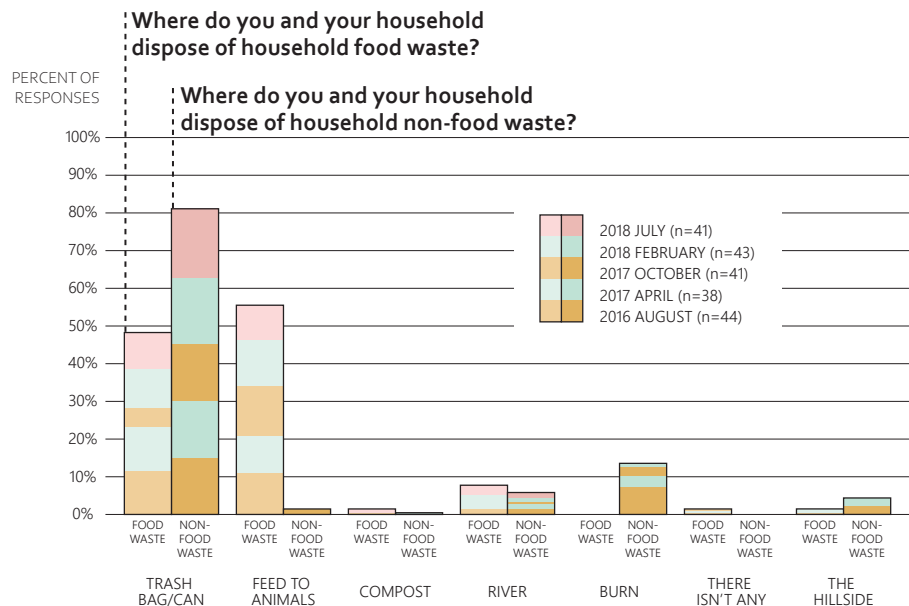


Figure - 49 - Solid waste management

collects exposed trash. That trash bags and cans are the most common destination for solid waste suggests an opportunity for adjusting the design of those to mitigate exposure.

Indicator: swimming in the river

Most participants in two different surveys responded that they either “always” or “usually” swim in the river. This data demonstrates that most participants are exposed to any contamination present in river water, and points to an opportunity to design swimming and bathing areas with improved water quality that support existing behavior and reduce exposure to pathogens in river water.

Indicator: shoes

About half of all respondents said that they always wear shoes, while almost nobody responded that they rarely or never wear shoes outside the home. Inside the home, it is also more common to wear shoes always, usually, or sometimes, than rarely or never, though instances of people rarely or never wearing shoes are significant. Almost all participants reported that their shoes are sandals or flipflops, which are much more likely to expose skin to

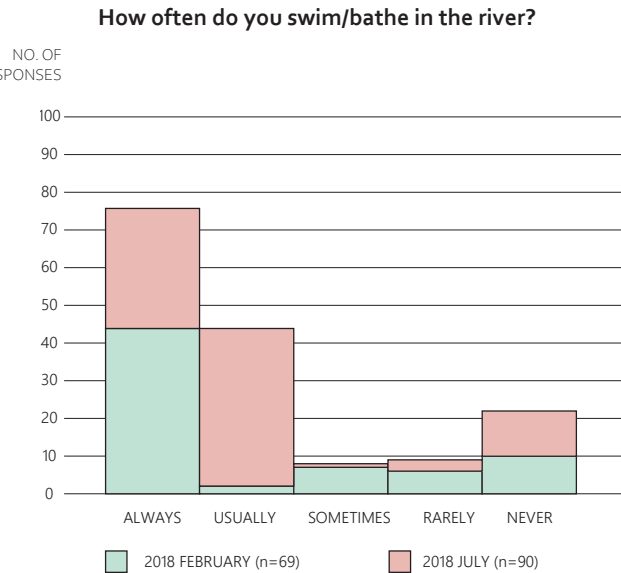


Figure - 51 - Swimming in the river

contaminated earth or water than close toed shoes. This points to an opportunity to design well-drained walking surfaces that support open-toed shoe use and bare feet alike, while reducing risk of exposure to parasitic and bacterial infection through skin contact.

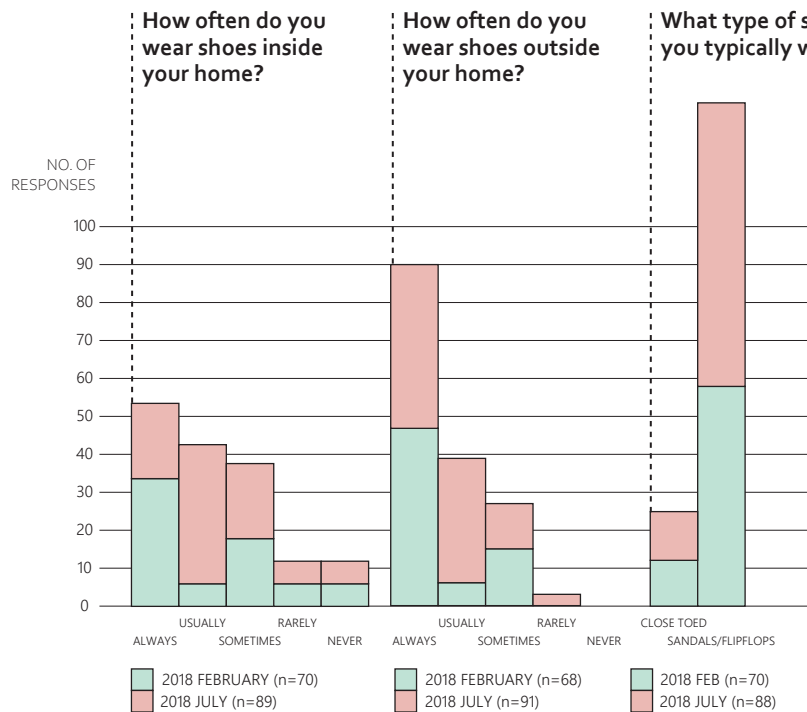


Figure - 50 - Shoe behavior + type

SUMMARY OF FINDINGS

Table 8 - Part 1 findings + design opportunity

PART 1: WHAT ARE THE WATER-RELATED HEALTH PROBLEMS IN CLAVERITO?			
SHORT NAME	FINDINGS	HEALTH + THE BUILT ENVIRONMENT	DESIGN OPPORTUNITY
CONCERN FOR DISEASES	People are most concerned about mosquito-borne diseases.	Mosquito-borne diseases thrive near standing water.	Can design help to mitigate standing water?
FEVER	Rates of fever and diarrhea are significant both during low river and high river seasons and are disproportionately affecting young children.	Indication of overall high rates of infection that are likely linked to sanitation and relationships with water.	Can sanitation infrastructure reduce rates of fever and diarrhea?
DIARRHEA			
STOOL CONSISTENCY	Up to one out of three people had diarrhea for three different points in time, suggesting reoccurring infection.		
PARASITES	Parasites are extremely common and recurring, affecting over 80 percent of participants at three different points in time. Reoccurring infection indicates constant exposure to parasites in the environment.	Parasites live in wastewater, puddles, contaminated drinking water infrastructure, infected rats and other mammals, and on moist surfaces.	Can drinking water, sanitation, well-drained pathways lower reoccurring rates of parasitic infection?
INFECTIOUS DISEASES	67% of households reported that someone in their household had had an infectious disease; most diseases listed were mosquito-borne.	Mosquito-borne diseases thrive near standing water.	Can design help to mitigate standing water?

Table 9 - Part 2 findings + design opportunity

PART 2: HOW DO THE HEALTH PROBLEMS CONNECT TO THE BUILT ENVIRONMENT?			
SHORT NAME	FINDINGS	HEALTH + THE BUILT ENVIRONMENT	DESIGN OPPORTUNITY
ENVIRONMENTAL HEALTH RISK PERCEPTION	Nearly 90% of community members are aware of things in the environment that can make them sick, and among the highest concerns are trash, sanitation, and vectors—all related to water.	Community priorities: trash, sanitation, and vectors are all important social determinants of health that connect to the built environment.	Can design interventions directly address mosquito habitat, rat habitat, climate resilience, wastewater, other pollution, and trash?
E. COLI + COLIFORM COUNTS	Throughout the high river season, E. coli and coliform counts are high in river water, and usually lower near aquatic vegetation.	Any amount of E. coli and coliforms in water puts exposed people at risk of bacterial infection.	How can design be used to improve water quality in Claverito?
MOSQUITO PERCEPTIONS + CONTROL	Over half of participants said that there is a mosquito problem in the community, and that they attempt to control for mosquitoes in some way, either by using incense, by killing them with their hands, or by using other methods.	Killing adult mosquitoes does not adequately address mosquitoes breeding in standing water.	Can design help to mitigate standing water, complementing efforts toward mosquito management and the perceived mosquito problem in Claverito?
MOSQUITO BITES	Most participants responded that they had received “a few,” or about 8 mosquito bites in the last week.	Any mosquito bite puts the entire community at risk of dengue, zika, yellow fever, chikungunya, malaria outbreak.	Can design help to mitigate standing water, thus reducing mosquito bites in Claverito?

Table 10 - Part 2 findings + design opportunity, continued

PART 2: HOW DO THE HEALTH PROBLEMS CONNECT TO THE BUILT ENVIRONMENT? (CONTINUED)			
SHORT NAME	FINDINGS	HEALTH + THE BUILT ENVIRONMENT	DESIGN OPPORTUNITY
RAT SIGHTINGS	61% of people reported having seen rats in the last week; the total estimated count was 177 rats. 68 percent of rats were seen in people's homes, and 12 percent were seen at neighbor's homes.	Rats are common vectors of leptospirosis. Exposed solid waste is part of their urban habitat.	Can designed reduction of rat habitat such as sealed solid waste sorting reduce the number of rats in Claverito, thus mitigating exposure of people to diseases carried by rats?
BATHROOMS	Most community members go to the bathroom in outhouses and in-home restrooms, but all of the sewage goes directly into the river.	Untreated sewage exposes people to pathogens including bacteria, parasites, and viruses.	Can outhouses and in-home bathrooms be redesigned to treat sewage at the source, thus reducing exposure to pathogens?
WATER QUALITY SATISFACTION	Community members reported that they were overall not very happy with the quality of water in Claverito.	Most community members are aware of a problem with water, and might be motivated to change water quality.	Can design process harness community knowledge to include education and participation in interventions that improve community members' satisfaction with water quality and water contamination in Claverito?
WATER SOURCES	Water for different household needs is procured in different ways; very little household water needs are currently met with rainwater. Common use of likely unsanitary river water and well/ground water are of particular concern.	Unsanitary water sources expose people to pathogens including bacteria, parasites, and viruses.	Can mosquito-proof rainwater catchment provide community members with sanitary water for household needs? Can design make rainwater harvesting a more attractive option? Can design interventions improve water quality to support use of river water in household needs?
SOLID WASTE MGMT	Over 80% of participants reported disposing of household non-food waste in trash bags or trash cans, while food waste was divided nearly equally between trash bags or cans and animals. Mosquito and rat prevalence could be related to exposed solid waste.	Exposed trash invites rats whose infected feces and urine expose people to pathogens. Exposed trash also collects water, where mosquitoes breed.	Can the trash cans/bags be redesigned to avoid supporting habitat for mosquitoes and rats?
SWIMMING IN THE RIVER	Most community members responded that they always or usually swim in the river.	If water is contaminated, swimming and bathing in it exposes people to pathogens.	Can implementation of floating wetlands and planting design that promotes phytoremediation be leveraged to improve quality to support safe swimming/bathing in the river?
SHOES	Most community members reported wearing shoes outside of their homes, though the vast majority of shoes that people are wearing are sandals or flip flops, increasing skin and broken skin exposure to parasites and other pathogens living on moist ground and surfaces and in standing water.	Pathogens including parasites and bacteria live on poorly drained moist surfaces. Parasites often infect through exposed skin.	Can Claverito's paths and other surfaces be redesigned to mitigate prevalence of pathogens to which feet are exposed?

FINDINGS DISCUSSION

The secondary data analysis engaged in this chapter offers answers to the question, What are the water-related health problems in Claverito and how do they connect to the built environment? This analysis alludes directly to UN SDG number 3) good health and well-being, with its focus on water-related human health and health perceptions, as well as goal 6) clean water and sanitation, which are central to water-related health problems' connections with the built environment.

In part one, data shows that water-related diseases, especially those transmitted by mosquitoes, are among diseases for which community members have the most concern. Nearly all participants repeatedly tested positive for parasitic infection, and rates of diarrhea and fever—common symptoms of water-borne bacterial, viral, and parasitic infections—are prevalent.

In examining relationships between water-related health and the built environment in part two, the data shows that water quality, solid waste, and vectors are among common environmental health

concerns. Data also shows that most people swim in the river, and that levels of *E. coli* and fecal coliforms in river water render it unsafe for consumption.

Participants are generally aware of mosquito and rat prevalence, with most responding that there is a mosquito problem in the community, that they attempt to control for mosquitoes, and that they get a few bites a week. Most households use outhouses or in-home restrooms. Sources of water for drinking and household needs vary, and rainwater is an underutilized resource.

In tables 8, 9, and 10, each of the findings from the data analysis is accompanied by a larger contextual note connecting it to associated design opportunities. Among design opportunities are improved pathways, solid waste management systems, wastewater treatment for outhouses, rainwater catchment, enhanced ecological buffers, and ecological swimming “pools.” Chapter 6 is an exploration of these design intervention opportunities.

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Design intervention explorations

OPPORTUNITIES FOR HEALTH DATA-DRIVEN IN-SITU ECOLOGICAL UPGRADES



Opportunities for health data-driven in-situ ecological upgrades

DESIGN QUESTION

How can ecological design be a tool for mitigating risk of exposure to water-related infectious diseases in Claverito?

Since informal community redevelopment became an international concern in the 60s, countless approaches have been attempted (Davis, 2006). A wide spectrum of different approaches to redevelopment exists, and at each extreme are relocation and upgrading in place, respectively. No one-size fits all approach will ever exist for informal community redevelopment. The regional government of Loreto, the region where Iquitos is located, has been working toward relocation of informal amphibious communities. Recent efforts to relocate parts of Belén, a district with large informal amphibious communities about ten blocks south/upstream from Claverito, have been largely unsuccessful.

In cases where relocation has been unsuccessful, a variety of reasons are suspected. One common reason is that relocation often cuts people off from income. People build informal communities where there is opportunity for livelihood through access to income and other resources. Relocation projects that have cut access to income have repeatedly failed (Brooks, 2016). In redevelopment cases where relocation is truly the only option, serious effort must be placed on securing the livelihoods of community members to make the projects sustainable. Iquitos has a massive informal economy, through which most produce and many

other products move. Informal communities in Iquitos are close to those markets, and sometimes even house them, as in the case of Belén, just upriver from Iquitos, and they provide numerous jobs.

Then there is the question of social cohesion. Informal communities do not happen randomly. Recent migrants to the city go where they have connections; many people settle where they have a family member or another contact. The close social relationships between people are a support network that must not be underestimated. Too many relocation discussions do not consider the extended social networks that make life in informal communities possible; their very structure thwarts social cohesion therefore undermining even short-term sustainability of such efforts.

The relocation efforts that have been carried out and that are in the works in Iquitos plan to relocate communities to remote outskirts of the city, into homes that they had no part in designing or constructing, where they are estranged from cultural, economic, and aesthetic benefits of the river, and where they will almost certainly lack the access to income that living near the city center provided. These efforts will in all likelihood continue to fail. It is expected that community members will reject the settlements and move back to the informal amphibious communities, as they have in the past.

In considering in-situ upgrades, upstream determinants of health and upgrades that aim to

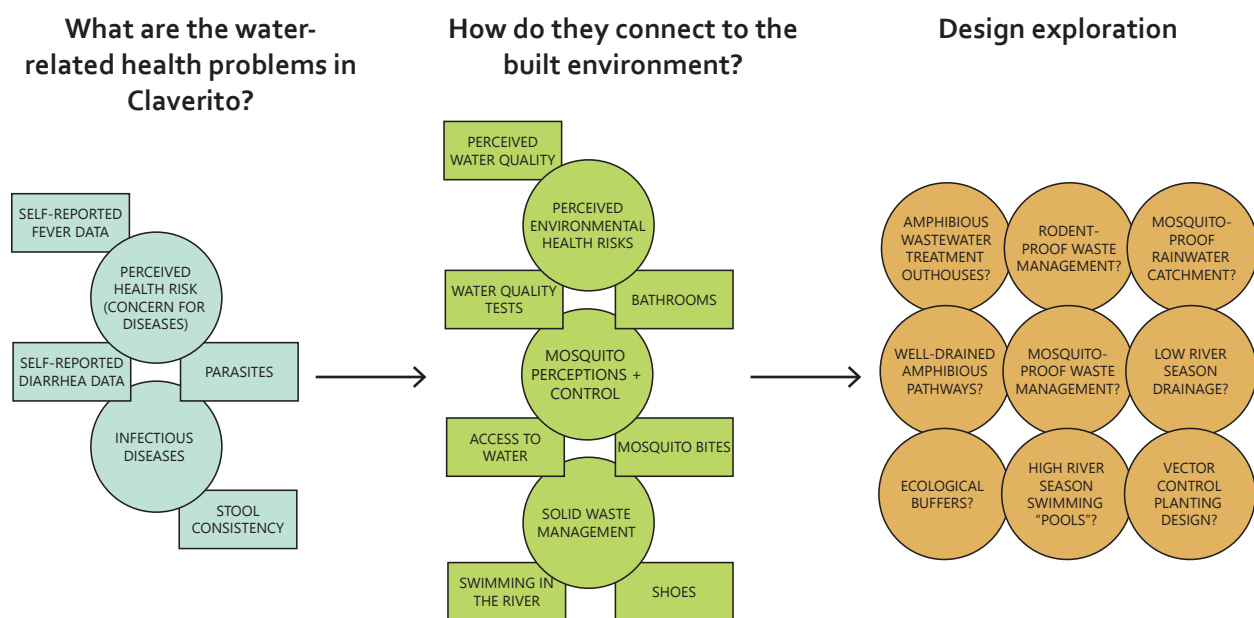


Figure - 52 - From data analysis to design

improve those can be highly effective in driving positive change, augmented by concurrent improvements in health equity (Marmot, 2007). Upgrading in place is considered by experts to be a surer route to health equity and sustainability than relocation (Corburn & Sverdlik, 2017). In most cases, it better aligns with several of the UN SDGs, as presented in chapter 1—including goal 1) no poverty; 2) good health and well-being; 6) clean water and sanitation; 9) industry, innovation, and infrastructure; 10) reduced inequalities; 11) sustainable cities and communities; 13) climate action; 14) life below water; and 15) life on land (United Nations, 2020).

Upgrading in place is possible and can be successful when governments and other organizations center community members in the process. Other factors that must be taken into account are hydrology, continued urbanization and climate change, ecology, and, most importantly, the health and well-being of the people whose housing the processes are concerned with.

This design exploration examines design ideas for upgrading in place that respond to community needs and priorities regarding water-related health, and aims to take an ecological design thinking approach to expanding methods that might be effective in upgrading in an amphibious context.

PRECEDENT STUDIES

This collection of strategies for sanitation, water quality, solid waste management, and vector control for humans living intimately with water suggests potential for ecological systems approaches to water-related health risks in Claverito. Items are organized in the same order as the design intervention explorations that follow and fall under subheadings as such.

SOLID WASTE MANAGEMENT

Container-based solutions (CBS) in Shada, Haiti

This precedent study examines alternative models for sewage management for the informal community Shada, Cap Haitien, Haiti. The NGO Sustainable Organic Integrated Livelihoods (SOIL) implemented a pilot to measure mitigation of exposure to sewage in the environment through use of private containers. The pilot used community-driven design to create CBS at a household scale: each household had one container for use in

the toilet and one containing fresh dry material; SOIL operators collected waste containers from households twice-weekly for transport to a composting facility. Through improved access and design, the household CBS captured significantly more sewage (Tilmans et al., 2015). Limitations are resource- and labor-intensiveness.

Educación Ambiental para el manejo de residuos sólidos en la Amazonía del Perú

This study framed solid waste as a public health risk and analyzed waste management challenges in a city in the Peruvian Amazon, concluding that education and close community participation are vital to improving efficacy of solid waste management systems (Alvites, 2015). This study does not explore design solutions for waste management systems but is included to show that urban Amazonian communities are already framing solid waste as a public health concern.

WASTEWATER TREATMENT

The HandyPod, Tonlé Sap lake, Cambodia

Like the urban Amazon, large populations live in informal amphibious or full-time floating communities in Cambodia. Tonlé Sap lake is home to over 100,000 people who lack access to wastewater infrastructure and thus face high risk of exposure to wastewater. The HandyPod was developed by WaterAid partnered with Wetlands Work! (WW!) as a potential answer to a lack of improved sanitation for these communities. The system connects the household's squat toilet to a drum where anaerobic decomposition first takes place before wastewater moves on to a floating constructed water hyacinth garden that further metabolizes the wastewater before it flows to the lake (Wicken, 2015).



Figure - 53 - SOIL program for sanitation during flood



Figure - 55 - WWI's HandyPod

Limitations derived from the HandyPod's lack of implementation include cost and cultural resistance.

Poop and Paddle, Queens Harbor, New York

This floating closed-loop poop digester collects rainwater for flushing; when the toilet is flushed, it moves the wastewater to another reservoir, where the solids settle and break down through anaerobic digestion. As solids break down, they drain into a constructed wetland "bog garden." Sewage then drains to another container with floating plants. At a marina in Queens, NY, metabolism takes roughly 30 days (Bonner, 2019). In the Amazon, this process would be sped up by the climate.



Figure - 54 - Poop and Paddle Eco-Friendly Floating Outhouse

Composting toilets on houseboats, London

Some 3,500 people living on houseboats in London's central canal lack access to piped water, sewerage, and electricity. With strict regulations for wastewater disposal but no formal system that supports waste management, people living in these floating communities are responsible for managing their own sewage. A growing number of people are transitioning from labor-intensive cassette toilets and pump-out systems to in-situ composting toilets. People remove the organic "resources" periodically which they drop off at decentralized treatment units along the canal to be processed into urban fertilizer (Mackinnon, 2018).

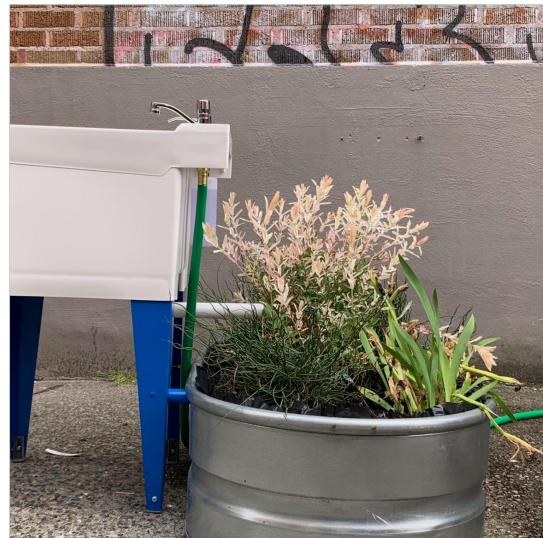


Figure - 56 - Seattle Street Sink for COVID-19 hand-washing

Seattle Street Sink, Seattle, Washington

The Seattle Street Sink prototype no. 1 aims to improve access—including for people experiencing homelessness—to the tools required for maintaining personal hygiene during the COVID-19 pandemic (Hou, 2020). The sink is designed to send grey water into a planter that cleans water and provides green space. This precedent is relevant because it is designed outside of the urban wastewater system and demonstrates opportunities for vegetation to treat wastewater at the source.

RAINWATER CATCHMENT

Sealed gravity-fed systems

Countless examples of well-designed rainwater catchment systems exist world-wide. Key to supporting water-related health are systems that are unattractive environments for pathogens—the input mechanisms and lid must seal. For Claverito, it is essential that mosquitoes can not enter the barrels to breed; furthermore, the top must be rounded to avoid standing water where mosquitoes could proliferate. The included precedent demonstrates how a reservoir can be raised to facilitate gravity-fed water access.



Figure - 59 - Sealed, raised rainwater harvesting [Snohomish Conservation District]



Greywater disposal points

Tree microcatchment and biofiltration

Figure - 58 - Sustainable Drainage for improved health

Sengkang Floating Wetland, Singapore

The Sengkang Floating Wetland is a public space designed to emulate and publicly display Singapore's native mangrove and wetland ecosystems. Constructed wetlands "improve the landscape" while providing habitat for fish and birds and are accessed, in part, by a floating boardwalk that hosts environmental education programming (CPG Consultants, 2020). Image by (IceCool77, 2013). The floating boardwalk is of particular interest for this thesis, as it is an integrated part of the wetland system that provides human access and augments ecology.



Figure - 57 - Sengkang Floating Wetland boardwalk

WELL-DRAINED PATHWAYS

Sustainable drainage, Franchhoek, South Africa

This precedent highlights landscape systems approaches to mitigating health problems in an informal community where standing water was exposing community members to pathogens. Puddling was avoided through implementation of greywater disposal points built from perforated pipes that encourage water to drain into swales filled with stone to avoid puddles, and container plants were implemented for bioretention (Charlesworth, 2017). Though design interventions employed in Franchhoek may not directly translate to an amphibious setting, they demonstrate a landscape-based public health approach to mitigating standing water in community pathways.

ECOLOGICAL BUFFERS

Water Quality + Plants Pilot, Traction, Iquitos, Peru

As briefly touched on in chapter 4, this 2017-2018 study evaluating the efficacy of floating plants in treating pathogens in the river water is directly relevant as it took place in Claverito. The study measured levels of *E. coli* and fecal coliforms in river water directly under and around several aquatic plant species and compared to levels in open river water and found promising links to a reduction of pathogens with the presence of aquatic vegetation (Traction, 2017).



Figure - 62 - Traction's Water Quality + Plants pilot

Floating Wetlands, Green Futures Lab, Seattle, Washington

A series of prototypes from 2013 to 2020 explored design opportunities for floating wetlands as part of a bigger picture demand for innovative ecological design strategies of improving water quality in an urban environment. Prototypes have been deployed and are being monitored for improved water quality and fish and insect habitat (Green Futures Lab, 2020). This precedent demonstrates a design-research approach focused on the layered benefits of water quality and habitat production.



Figure - 61 - GFL Floating Wetland, early iteration

Water-sensitive innovations, Wellcome Trust, informal settlements in Fiji and Indonesia

This massive series of water-focused interventions in 24 informal community revitalization projects in Fiji and Indonesia is taking an ecological design approach to each place with goals of mitigating exposure to wastewater and solid waste in independent ways. Goals include recycling of wastewater, harvesting rainwater, creation of green space to clean water and cultivate food, and waterway restoration for flood control (Brown, Leder, & Wong, 2017). Several aspects of this project are relevant as precedents; this thesis draws on the layered landscape-based water-related infrastructure programming.

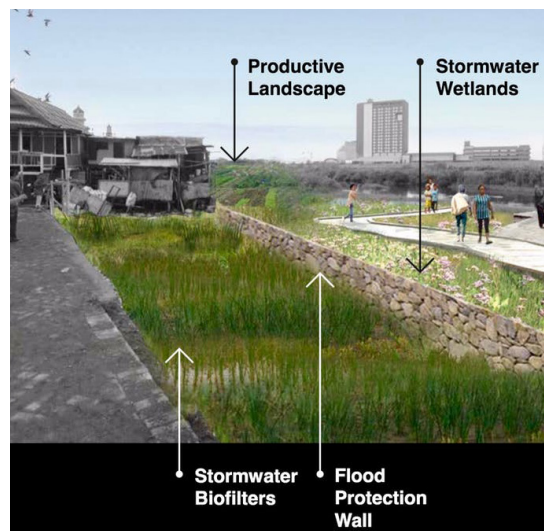


Figure - 60 - Wellcome Trust's Water-Sensitive Innovations

DESIGN INTERVENTION EXPLORATION

Improving aspects of the built environment as an interface between people and water-related health problems can reduce burdens of disease and improve overall health and well-being for people living in Claverito.

Asking community members what their experiences have been with water-related health and how they interact with their built environment can help to identify priorities of the community that are not only starting points but that are also more likely to be embraced as long-term solutions.

The built environment is more than a mere interface between humans and water-related health problems. It is a web of determinants that shapes interactions with water, affects water quality, and shapes risk of exposure to water-related pathogens. Built environment design can be a tool for mitigating risk of exposure, ultimately reducing burdens of disease and improving health and well-being for people in Claverito.

But what could it look like? How could it work? The following sketches illustrate conceptual built environment interventions with potential for layered human and ecological health improvements in Claverito. Ideally, they can be used to communicate to community members possibilities to drive community visioning and continual in-situ upgrading.

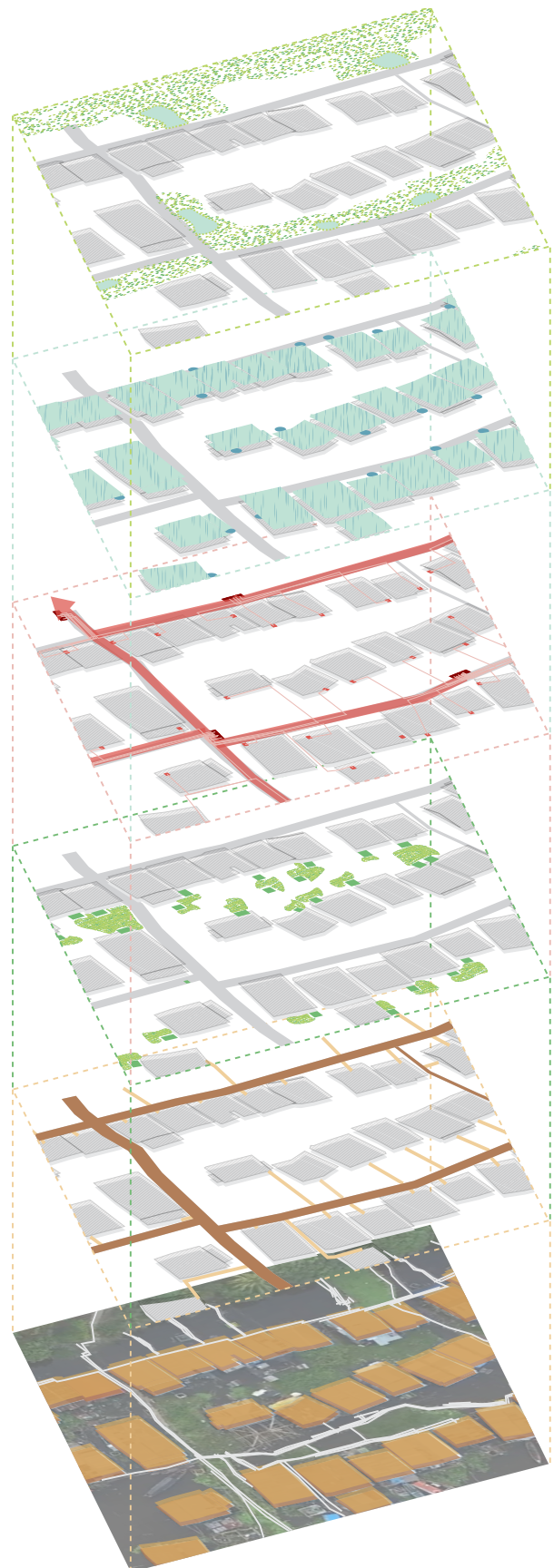


Figure - 63 - Design intervention exploration, axon, zoomed in

DESIGN OPPORTUNITIES TO ADDRESS WATER-RELATED HUMAN + ECOLOGICAL HEALTH IN CLAVERITO

-  SOLID WASTE MANAGEMENT
-  WASTEWATER TREATMENT
-  RAINWATER CATCHMENT
-  IMPROVED PATHWAYS
-  ECOLOGICAL BUFFERS
-  ECOLOGICAL SWIMMING "POOLS"

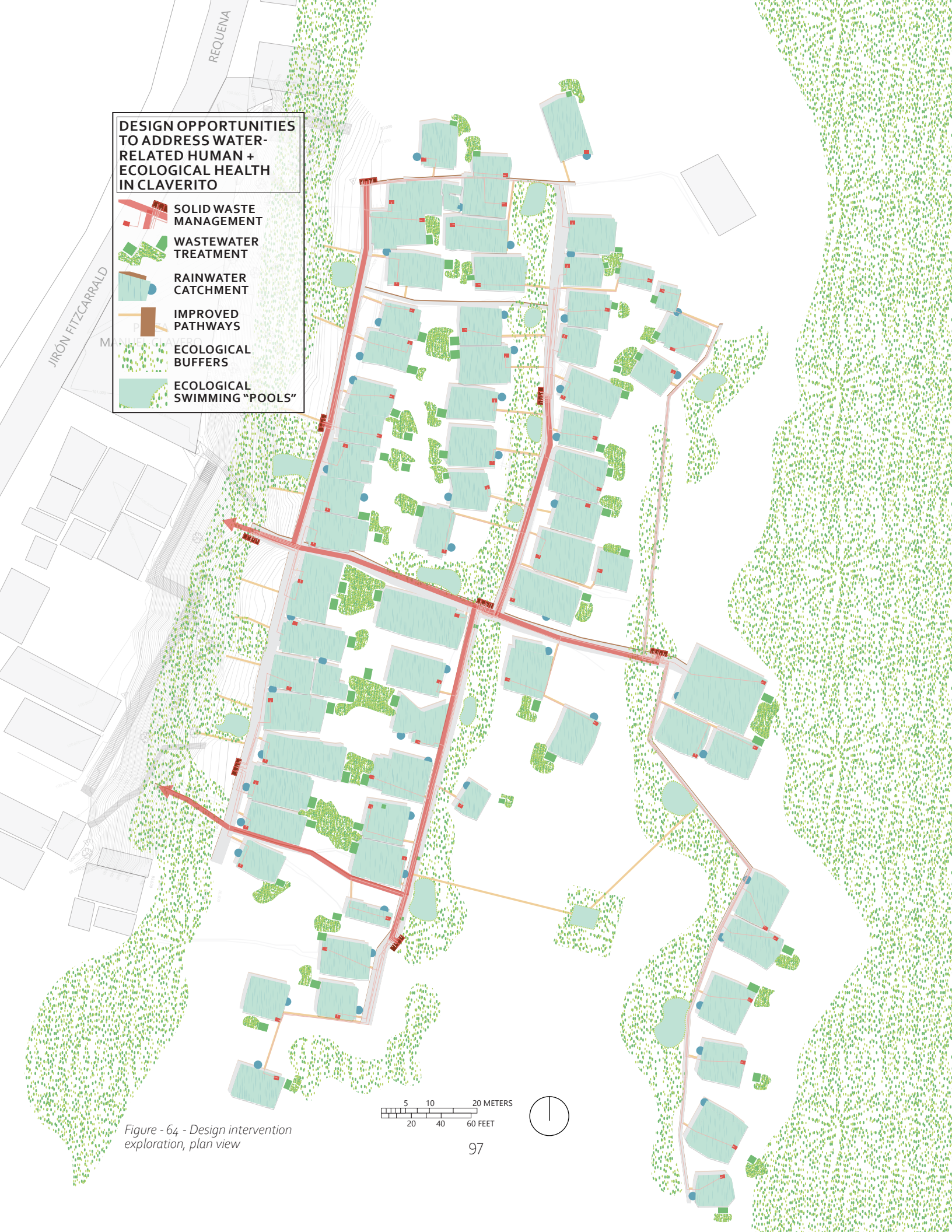
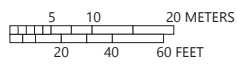


Figure - 64 - Design intervention exploration, plan view



SOLID WASTE MANAGEMENT

Can enclosed solid waste collection thwart mosquitoes and rats?

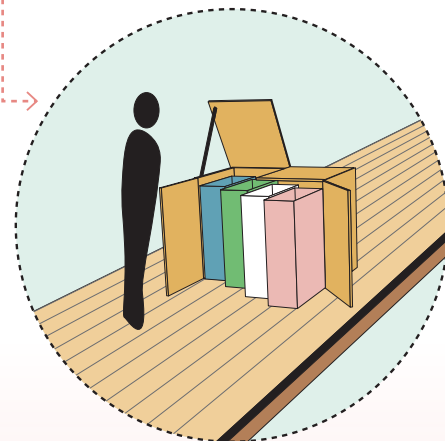
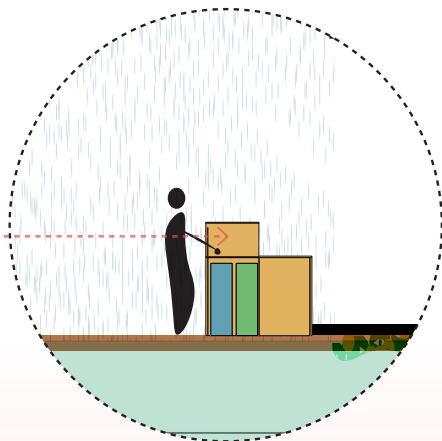
Waste sorting that is sealed and covered is simple to design and can help to control mosquito and rat populations. In Claverito, sorting can start in the home, with larger sorting stations on every street, serving clusters of households. Design priorities include rain-proofing, ease of use, and

light weight for part-time flotation. Through sorting, solid waste can be framed as a resource, setting up the circumstances for reuse. Sorting systems can support recycling and create opportunities for income.

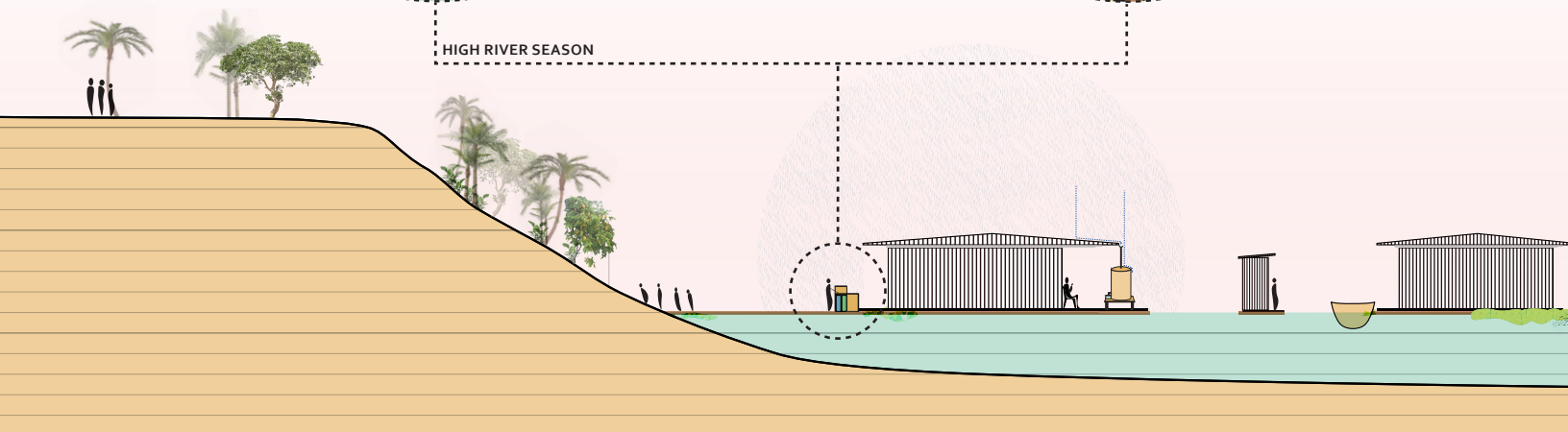
Doors and hatches seal receptacles off from rain, preventing standing water and mosquitoes.

Solid waste systems can be designed with lightweight materials for amphibious context.

Several protected bins for sorting reduces the prevalence of rats while facilitating recycling.



HIGH RIVER SEASON



WASTEWATER TREATMENT

Can an integrated system of rainwater, gravity, anaerobic digestion, and aquatic vegetation reduce water-borne disease exposure?

Floating mini-treatment plants use gravity-fed rainwater to flush. Liquids overflow into constructed wetlands, while solids flow into anaerobic digestion chambers that float during the high river season and rest on the floodplain during the low river season. Solids eventually flow into a constructed wetland where aquatic plant species thrive on the fertilizer,

cycling nutrients from the water before it flows into looser floating wetlands that further clean the water, keeping pathogens away from people. Conversion of all outhouses in Claverito to this system would reduce exposure to pathogens from at least 25,000 liters (6,600 gallons) of sewage each year.

Sealed rainwater catchment facilitates gravity-fed flushing and solid/liquid overflow system.

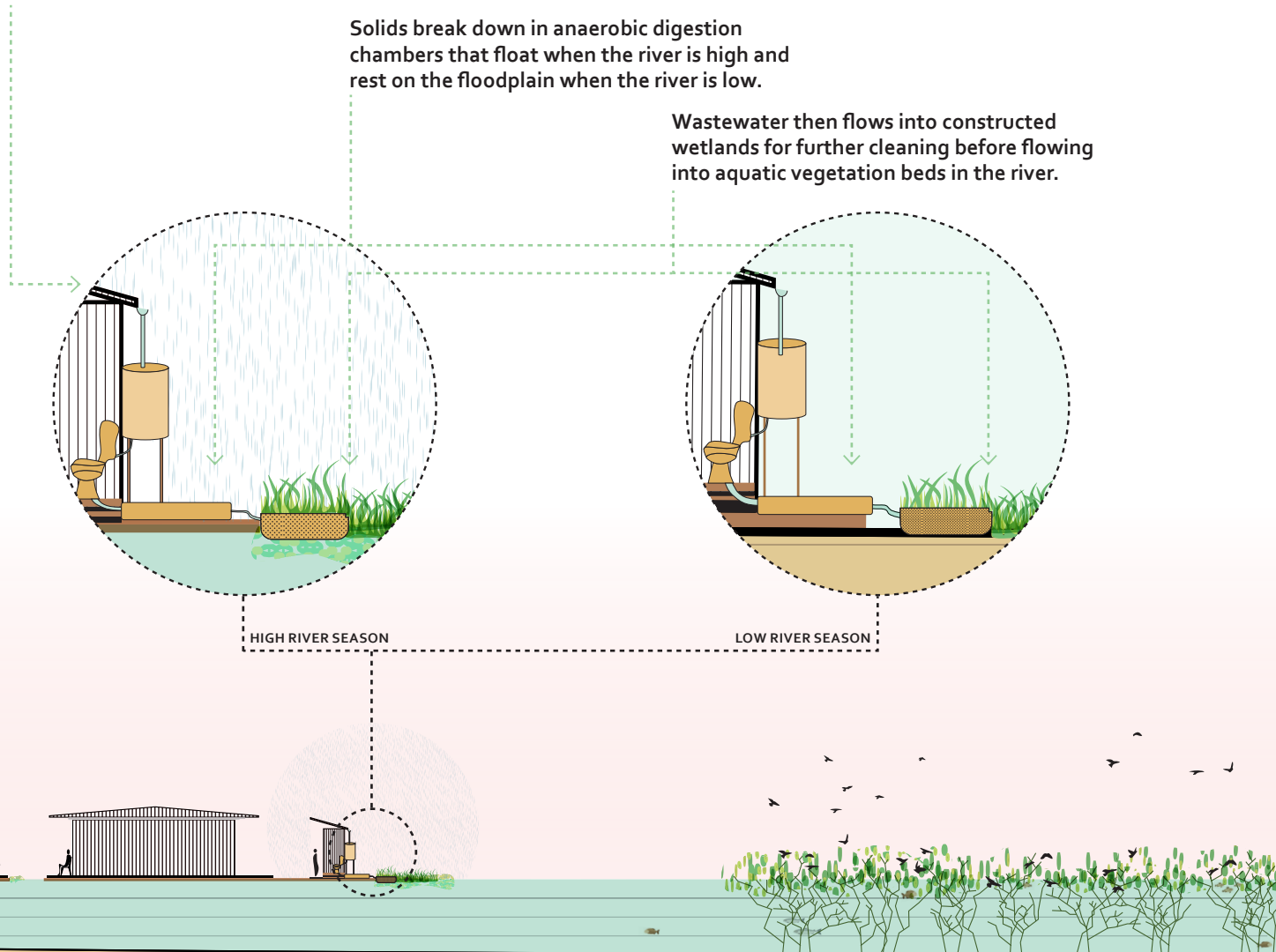


Figure - 65 - Design intervention exploration: solid waste mgmt + wastewater treatment

RAINWATER CATCHMENT

Can sealed rainwater catchment improve access to clean water for household needs + hand washing while reducing risk of exposure to vector- and water-borne diseases?

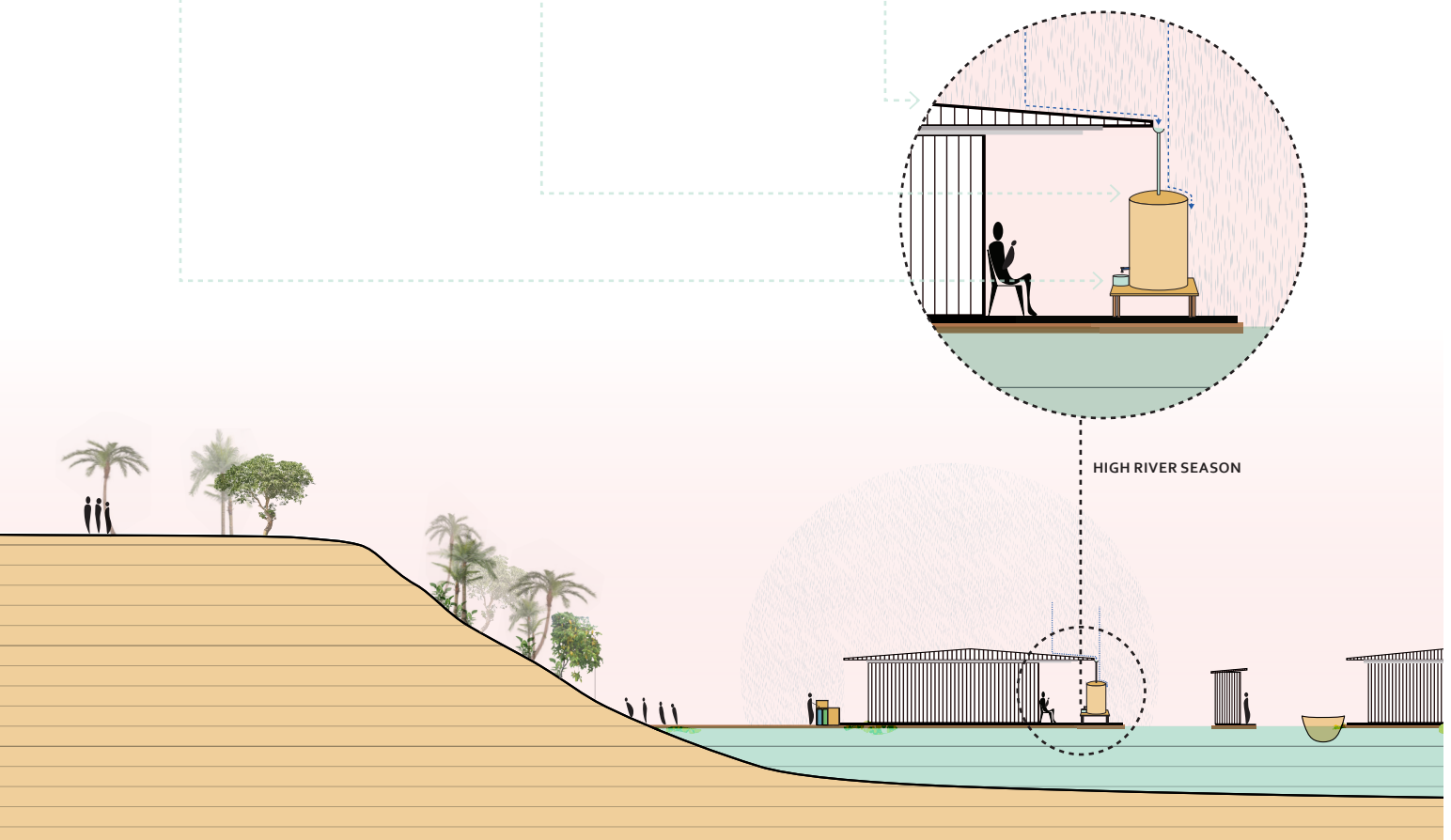
Rainwater is both the cleanest and cheapest water source around. Simple rainwater catchment systems rely entirely on gravity for catchment and use; by raising the system up onto a platform, spigots simply need be opened to release water into containers below. It is essential to seal the

system and prevent pooling on top to prevent mosquitoes and other pathogens from proliferating in the standing water. While not recommended for drinking untreated, raw rainwater has the potential to meet nearly all household water needs in Claverito.

Raised reservoir facilitates gravity-fed access

Reservoir is sealed and top is rounded to prevent mosquitoes from proliferating.

Rainwater is directed from roof to reservoir.



WELL-DRAINED PATHWAYS

Can safe, stable pathways drain water away from people, reducing mosquito habitat and mitigating exposure to parasites and other pathogens that live in standing water?

Employing simple grading can ensure drainage on pathways, reducing habitat for pathogens. Further attention to materiality can also thwart moisture that supports pathogens and improve accessibility through even, stable surfaces and handrails. Other

benefits to pathway redesign include support of solid waste management systems and potential reduction of cuts, scrapes, trips, and falls that provide open wounds and opportunities for parasitic and bacterial infection.

Even surfaces support human movement as well as solid waste management systems.

Handrails can contribute to reductions in cuts and falls that expose people to pathogens.

Attention to grading and materiality can reduce instances of standing water where pathogens thrive.

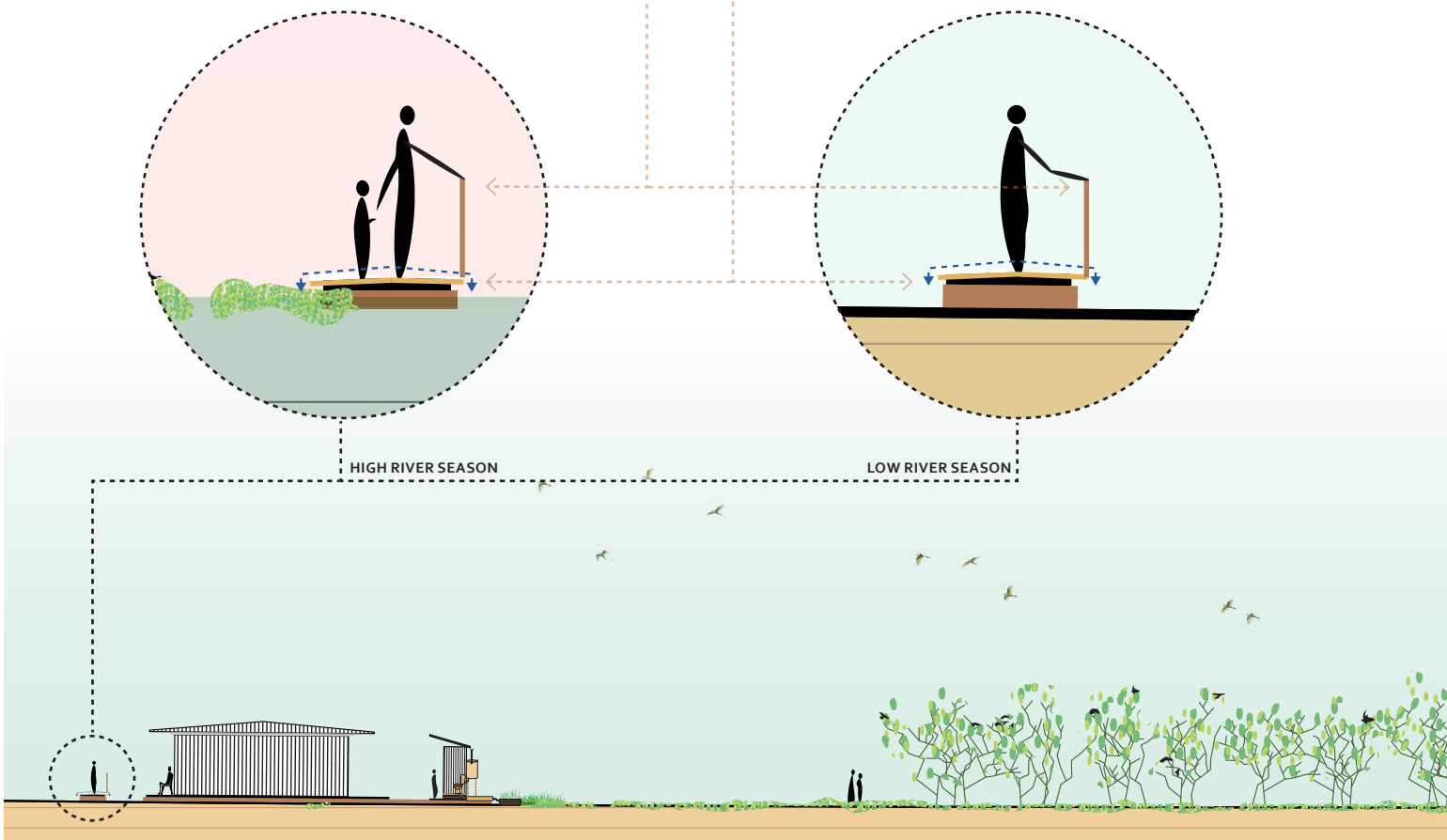


Figure - 66 - Design intervention exploration: rainwater catchment + well-drained pathways

ECOLOGICAL SWIMMING “POOLS”

Can augmented aquatic vegetation form oases of pathogen-free water for swimming and bathing?

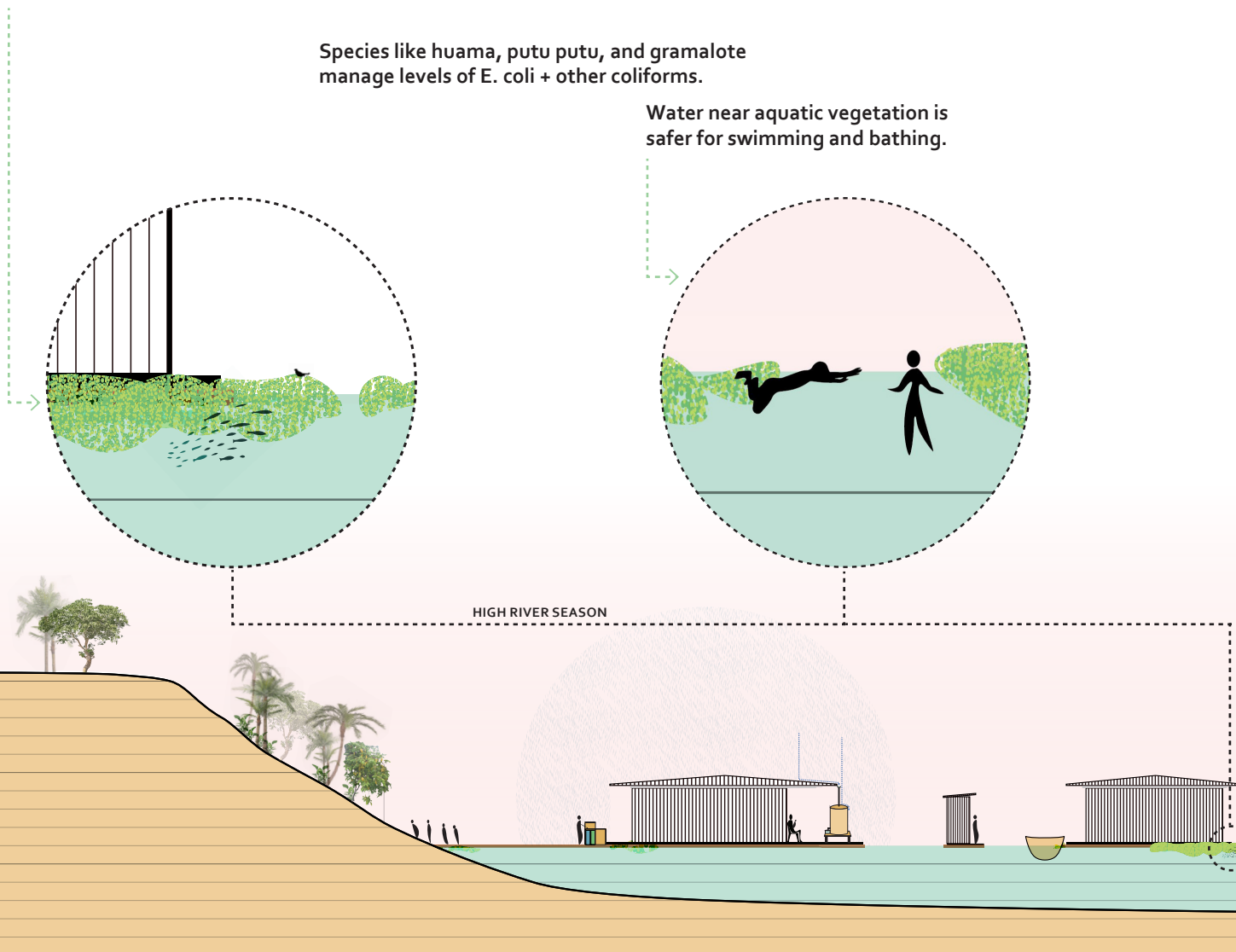
People in Claverito are already swimming and bathing in the river when the water is high. Considering that the water around aquatic vegetation has been shown to have lower *E. coli* and fecal coliform counts, an opportunity exists for setting up safe swimming and bathing areas—

or swimming “pools” surrounded by the aquatic vegetation already growing throughout Claverito. Combined with localized wastewater treatment, planning swimming “pools” away from outhouses can drastically reduce community members’ exposure to pathogens in river water.

Avian, insect, fish, and amphibians are among species that call plant-rich floodplains home.

Species like huama, putu putu, and gramalote manage levels of *E. coli* + other coliforms.

Water near aquatic vegetation is safer for swimming and bathing.



ECOLOGICAL BUFFERS

Can increased floating wetlands and floodplain planting improve water quality while providing habitat for mosquito predators?

Claverito already acts as an ecological buffer in multiple ways. The adjacent camu camu grove maintained by community members performs several ecosystem services like water absorption, water cleaning, carbon sequestration, and support of biodiversity. The community hosts extensive amphibious plant life that is habitat for a diverse array of avian, insect, fish, amphibian, and other

beneficial species, many of whom are known to prey on mosquitoes. Augmenting these buffer habitats through constructed wetlands and increased trapping of aquatic species during the high river season can protect Claverito from Iquitos' wastewater and increase overall ecosystem services of the floodplain landscape, supporting human and ecological health in Claverito and the greater municipality.

The camu camu grove maintained by Claverito residents is a preexisting resource that performs ecosystem services.

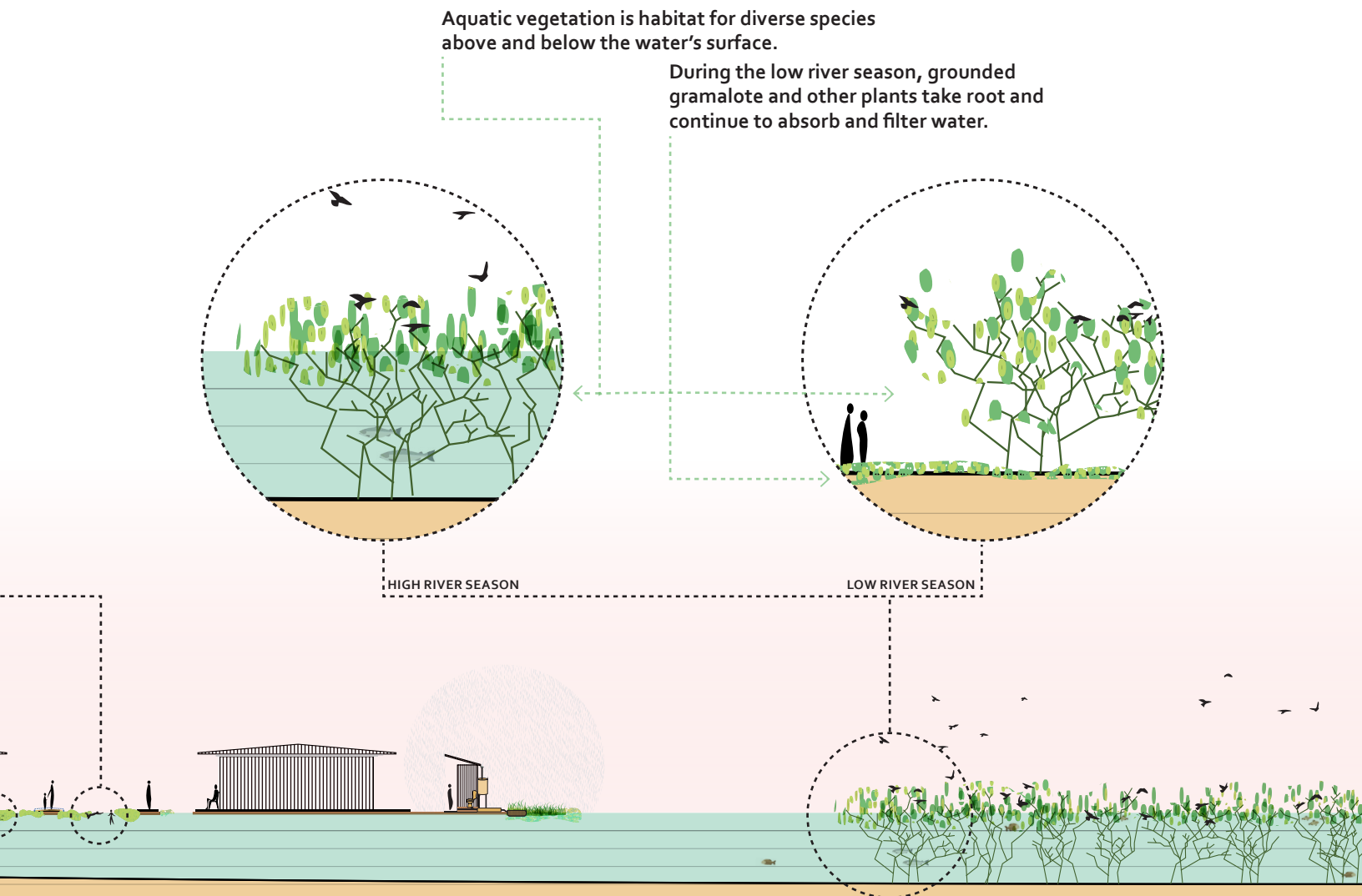
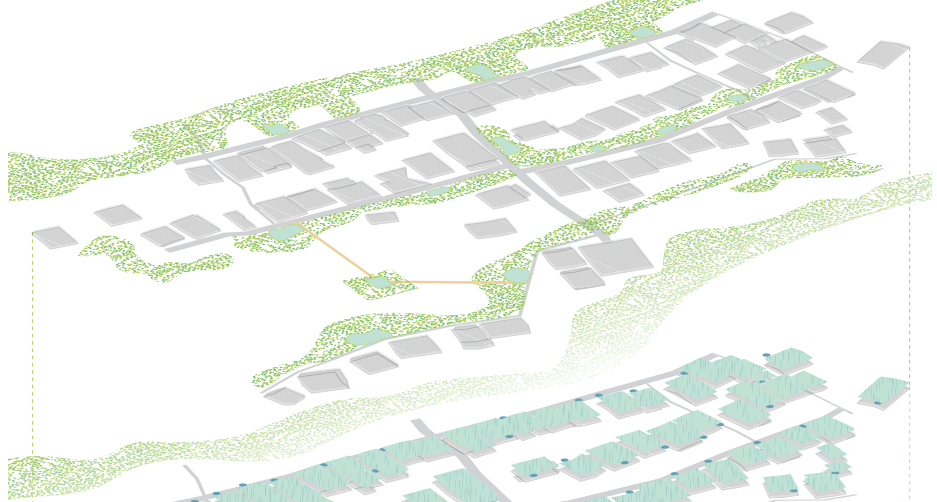
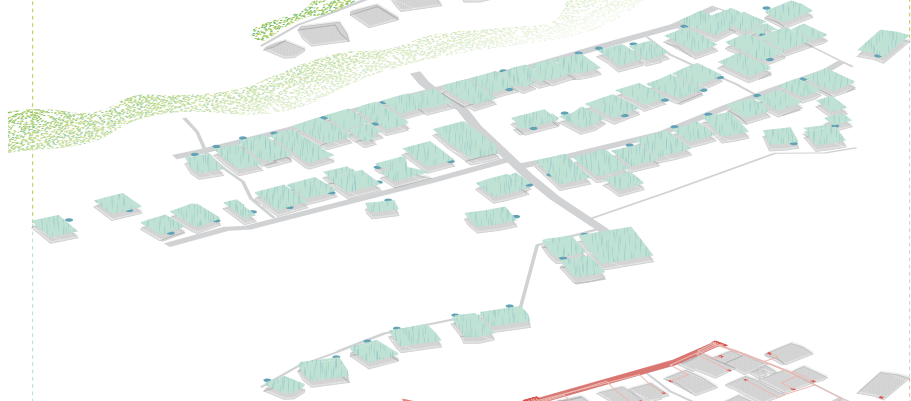


Figure - 67 - Design intervention exploration: ecological buffers + swimming pools

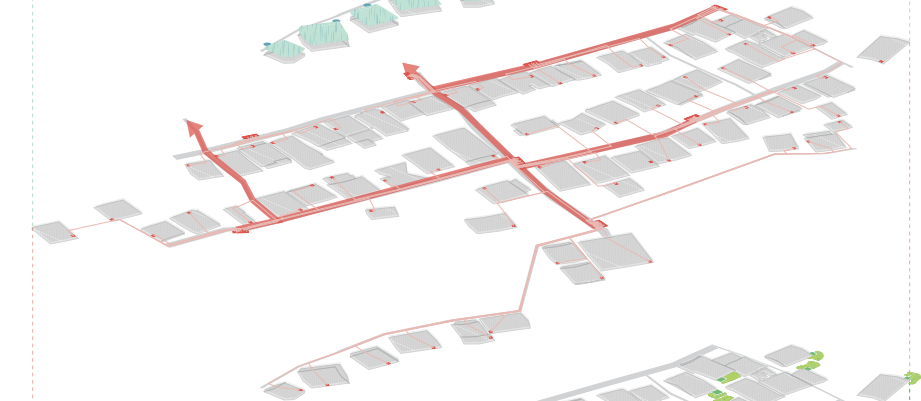
**Ecological buffers +
swimming pools, mosquito
control planting design**



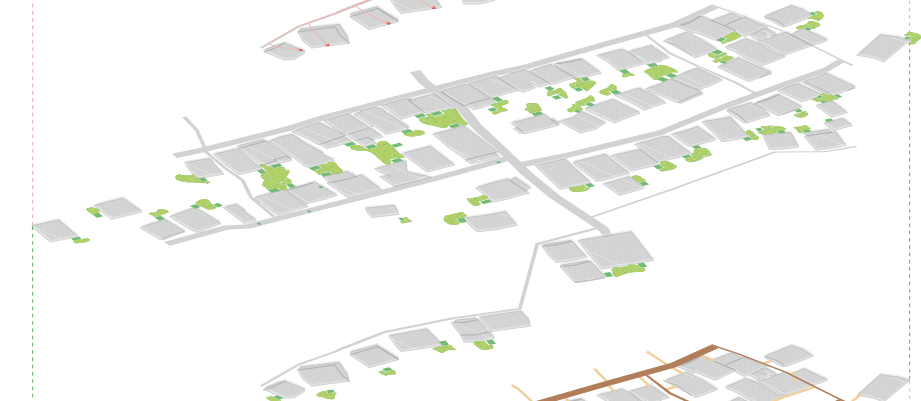
**Mosquito-proof
rainwater catchment**



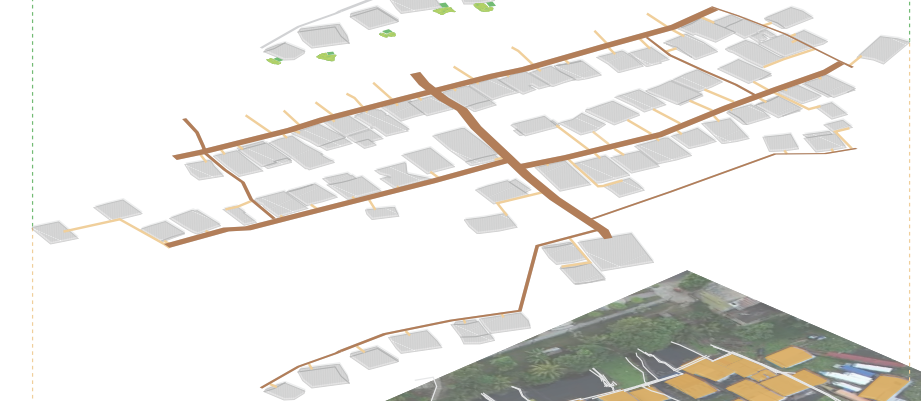
**Mosquito- + rat-proof
solid waste management**



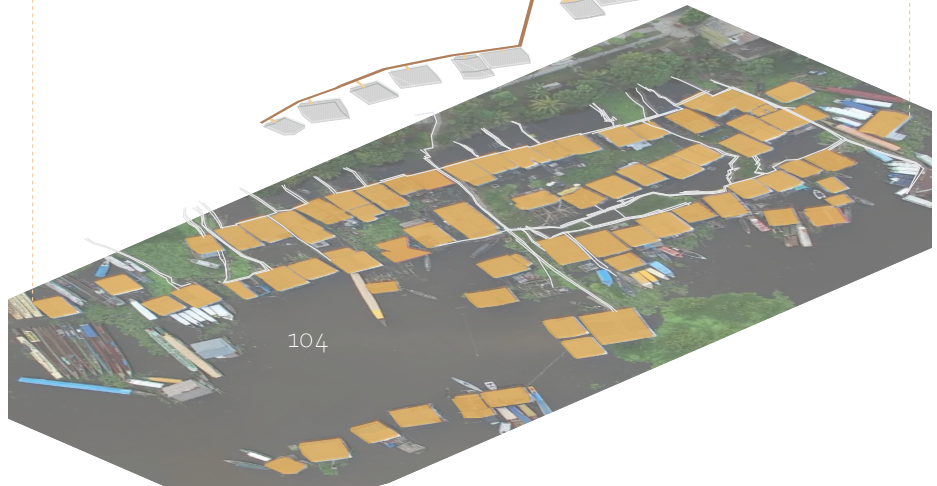
**Amphibious wastewater
treatment outhouses**



**Well-drained
amphibious pathways**



*Figure - 68 - Design intervention
exploration, axon, zoomed out*



DESIGN DISCUSSION

This exploration of design proposals does not aim to prescribe solutions for Claverito, nor does it argue that the design ideas explored here are the best or only approaches to mitigating health problems. Rather, it comes from a place of understanding that Claverito and other amphibious informal communities face unjust risks—threats of eradication and relocation, and health risks stemming from poverty, informal status, and climate change. An analysis of these risks and the complex webs that shape them highlights a disconnect between lived realities and design possibilities.

This exploration pushes design thinking outside the box of conventional urban design prescribed to Iquitos using a colonization lens and advocates for legitimizing, upgrading, and formalizing existing amphibious architecture that stems from Indigenous design, backed by evidence.

A layered landscape systems approach to design sees each intervention supporting the next through layered benefits:

Improved pathways do not only mitigate risk of exposure to water-related disease through drainage and injury reduction, but also by facilitating solid waste management, where ease of transport of

sorted waste bins helps to manage rat and mosquito populations in households.

Use of rainwater for household needs not only protects people from contaminated water, but also saves people money from having to buy safe water and spend time unable to work due to water-borne infection.

Use of aquatic plants in treating wastewater does not only reduce exposure of humans to pathogens, but also provides habitat for mosquito-predators.

The ecological health benefits of these interventions go hand-in-hand with human health at both local and global scales. Increased plant life contributes to biodiversity; solid waste management reduces contamination on the Río Amazonas downstream, ultimately mitigating plastics in our oceans. Wastewater treatment at the source keeps nutrients balanced in peripheral environments, better supporting Amazonian ecosystems.

This exploration aims to demonstrate how sometimes small, simple interventions can set up the circumstances for self-perpetuating improvements to human and ecological health, and to encourage design *with* floodplains.

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Reflections + discussion



CONCLUSIONS + NEXT STEPS

One of the goals of this thesis was to weave a narrative of informal communities that highlights the determinants that have shaped and continue to shape them and that advocates for the people who call them home.

We have seen, in chapter 2, how colonization and resource extraction in the Amazon rainforest catalyzed urbanization through disruption of Indigenous ways of life, and enslavement and genocide of Indigenous people. We've seen how structural adjustment and neoliberal policy have perpetuated disinvestment and socioeconomic inequality. And we've seen how post-colonial, conventional urban design has failed to support human health in the amphibious informal community of Claverito.

The review of water-related health literature in chapter 3 showed how water-related health and the built environment connect: Mosquito-borne diseases like dengue and malaria thrive near standing water where mosquitoes proliferate. Diseases like leptospirosis, for which rats are a reservoir, thrive where rats find habitat and where their infected urine and feces collect. Poor drainage and uncovered solid waste where water collects are culprits of risk of exposure to both mosquito-borne and rat-related diseases. Countless water-borne parasitic, bacterial, and viral infections also connect to the built environment, and thrive in watery places lacking wastewater treatment, effective drainage, and reliable potable water sources.

Chapter 4 examined Claverito through a landscape site analysis, before chapter 5 analyzed data relating to water-related health. This secondary data analysis revealed that water-related diseases, especially those transmitted by mosquitoes, are among diseases for which community members have the most concern.

We learned that nearly everybody has tested positive for parasitic infection, and that rates of diarrhea and fever—common symptoms of infections likely connected to water—are high.

In examining relationships between water-related health and the built environment, the data showed that water quality, solid waste, and vectors are among environmental health concerns for community members. Data showed that most people swim in the river, and that levels of *E. coli* and fecal coliforms in river water make it unsafe for consumption. Data showed that community members are aware of mosquito and rat prevalence, that most people use outhouses, and that rainwater is an underutilized resource.

Chapter 6 explored simple ideas for design interventions to address the water-related health findings in Claverito. Ideas include improved pathways, solid waste management systems, wastewater treatment for outhouses, rainwater catchment, enhanced ecological buffers, and ecological swimming “pools.” The exploration suggests that layering interventions can lead to self-perpetuating human and ecological health benefits.

In transferring these findings from academic to practical, a next step stemming from the design interventions exploration in chapter 6 would be to circle back to Claverito and the participatory processes that led to these water-related health findings. If, in a community meeting, the design ideas were to pique interest, interventions could take form through participatory design iterations and form the basis for measurement of the efficacy of an intervention in achieving established human and ecological health outcomes.

REFLECTIONS + DISCUSSION

The analysis of data collected by Traction over the course of four years provided a basis for digging into the details of human health and its connections to the built environment. In this thesis, it provides windows into lived experiences and suggests possibilities for evidence-based design. Most importantly, surveys give informal community members a voice where they too often are excluded from conversations about their own built environments.

This exploration of methods from data to design aligned with several of the UN Sustainable Development Goals. Goals 1) no poverty and 10) reduced inequalities are broadly addressed through discussions of informal community upgrading. Goals 9) industry, innovation, and infrastructure 11) sustainable cities and communities and 13) climate action are addressed through explorations of non-conventional urban infrastructure design and the role of floodplain ecosystem resilience in the resilience of Iquitos as a whole. Goals 3) good health and well-being and 6) clean water and sanitation are central to this thesis' focus on water-related human health. An examination of the full list of SDGs reveals that each applies to informal community redevelopment in various ways.

This thesis explored intersections between landscape architecture and global health by applying health data to a layered landscape systems analysis and design exploration. A limitation stemming from this intersection is the resource-intensiveness of health evidence-based design. It is extremely rare for built environment designers to have the kind of access to health data that was available for this thesis.

A reason for this, and another limitation, is that built environment professions are client-serving in a capitalist system, and the resource-low communities

that need built environment change most are often eschewed by these professions. Systemic flaws exist from long histories that have shaped these socioeconomic inequalities and continue to shift access away from those who need it most.

This is not to say that access to built environment designers is a human rights issue—quite the contrary. Humans have always designed, built, and maintained their own environments. But in this world where so many of our cities are ravished by inequality, access to built environments that foster human health and well-being is absolutely a human rights issue. Inequity is not abstract; it is spatial, it is layered, and it is grounded in landscapes, across scales of time and space.

A role of landscape architects, who are trained to read the layers of a landscape and understand their implications on human and ecological health, can be to give voice to these issues of inequity in the built environment, and to explore and advocate for systems that empower people to overcome inequality and shape their environments in ways that work for them: to bring the landscapes of informal communities outside of the realm of municipal afterthought and into the realm of legitimacy; to center humans in informal community redevelopment processes, and remind those in power that yes, wrapped up in built environments are human rights issues.

In the post-colonial cities where informal communities inhabit complex landscapes, embracing landscape systems invites reunions with Indigenous architecture that can expand urban resilience. It is my hope that this thesis is part of a much needed movement toward centering humans and employing evidence-based layered landscape systems approaches to informal community redevelopment over time.

