Closing the Loop:
Restoring the Hydrologic Cycle Through Architecture

by

David D’Andrea

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CONTENTS

ABSTRACT

As water scarcity has become one of the most important environmental and social issues of the 21st century, the way cities and the built environment interact with water must be reconsidered. A worldwide reliance on groundwater has stressed the fossil resource to its limits of use. As a result, there is an urgent search occurring for a new source of water supply yet there has been little research done exploring the potentials of stormwater reuse. Architecture can play a vital role in creating a more efficient and sustainable urban water system, while increasing the public awareness of issues related to the water cycle. Physical and technical constraints of stormwater infrastructure, such as gravity and topography, limit the siting of a stormwater reuse facility to existing dense urban areas in order to avoid pumping across vast distances. Havana, Cuba provides an excellent test city to explore water related projects due to its isolated closed loop system of supply and use. This thesis will explore the idea of using architectural works as hubs in the hydrological cycle, allowing people to access rain water harvested from traditional stormwater infrastructure, creating a more socially equitable system of water conveyance.

Keywords: water supply, potable reuse, stormwater, architecture, socio-spatial

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My Parents Margaret and Gaetano

CHAPTER 1: INTRODUCTION

Water Supply: The Social and Technical Paradox

The modern method in which water is conveyed to the public, via complex networks of pipes, pumps, reservoirs, and filters can be seen as both a technical achievement and a sociological failure. The convenience and high quality of life provided by modern plumbing has created a paradox. Urban water systems have become technically more efficient with long life spans and relatively low maintenance, able to supply water directly to the homes of a large population. However it is through the urban water systems inconspicuous design and ease of domestic use that society has lost the social and environmental benefits that came from water consumption in the public realm.

Historically, people have consumed water from their environment in ways that are far more sustainable and social than modern water delivery methods. Early methods of water supply in cities were far more visceral, social, and public experiences than the privatized water pumped into the domestic world of today. In much of the western world, if one can not afford access to the municipal water supply, their remaining options are limited. In City of Flows: Modernity, Nature, and the City, Maria Kaika describes how water has become a commodity, and as a result removed from urban life, “Public fountains, for example slowly disappeared from the urban domain in the Western world, corresponding to the reconceptualization of water as a commodity...Indeed, in Western metropolises publicly available, free-of-charge, clean drinking water is a rare species.”[1]

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1. Maria Kaika, *City of Flows: Modernity, Nature, and the City* (New York: Routledge, 2005), 57.

Historic Case Studies

Rome

Water has long been a commodity, although monetary profit has not always been the driving motive. In ancient Rome for example, “Private persons could get licences to draw water from the public supplies for particular premises only after an approach to the emperor, so it must have been very much a privilege.”[2] The distribution of water, controlled and commodified, in ancient Rome sustained the city and its large population by protecting the supply and the source. Private service was rare in ancient Rome, and the masses survived from the numerous public fountains that adorned the urban fabric. In contrast to today, water was a focal point of the public sphere, a daily part of urban life, “The public fountains-salientes-were free, and the majority of the population must have drawn their water from them, or from the basins, for drinking, cooking, washing, and keeping.”[3] This egalitarian method of delivering water ensures that people consume only what they need, constantly aware of the water consumption habits of themselves and their neighbour.

The importance of the fountains is demonstrated through their prominent location in many European cities, “As with Roman fountains, the Venetian wells and campi were social foci, neighbourhood meeting points and centres for network control by leading patricians.”[4] The venetian wells were placed in the center of the campi and piazzas, arguably the most important public space in the city. Clearly, if water is to be consumed as a communal practice, it requires a site of social value. The legacy of Rome’s public water works have remained a delightful and useful

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[2] O. F Robinson, *Ancient Rome City Planning and Administration* (New York: Routledge, 1992), 89.

[3] Ibid., 89.

[4] Christopher Black, *Early Modern Italy a Social History* (New York: Routledge, 2001), 68.

piece of infrastructure as the cities many free fountains still supply tourists and Romans alike with drinking water.

Contemporary society is unable to understand the spatial parameters of modern water supply networks. The infrastructure has no foci similar to the grand and elaborate wells of Rome or other ancient civilizations. Even the service manholes of modern piping, one of the few parts visible on the surface of the city, are made to be inconspicuous. The discreet circular or square covers spotted across the streets of our cities conceal a world of pipes, chambers, vaulting, and valves below, equally as impressive as the Roman aqueducts or qanats of the middle east. Modern infrastructure is not celebrated in the same way however in urban planning or in architecture. For example qanats, the middle eastern equivalent to the aqueduct, typically enters many Iranian towns with a grand public and civic gesture by forming a canal along the main street.[5]

Indian Stepwells

The ancient stepwells of India have created a relationship for their users with water that is highly sustainable, social, and spiritual. The wells are more than a simple piece of infrastructure, they are sacred places laden with spiritual symbology.[6] The spiritual relationship with water found in Hinduism is not the only reason the wells are such elaborate structures. Typically, wells provide water in much the same way as a stepwell, through exposing a below ground aquifer. The stepwell however, fulfills many social needs that a typical well could not. The stepwell supports a diverse user group and a multitude of functions, “Stepwells fill the needs of people, animals, and plants...the rich mix of uses amply validated the building of

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[5] Marq. De Villiers, *Water: The Fate of Our Most Precious Resource* (Toronto: M&S, 2003), 59.

[6] Morna Livingston, *Steps to Water: The Ancient Stepwells of India* (New York: Princeton Architectural Press, 2002), 7.

an estimated three thousand elaborate wells."[7] Stepwells programmatically serve the community with all the necessary social and technical functions of life. The stepwells are thus hubs of community life surrounding a source of water,

> In contrast to the quiet underground stairs and shrines, the small terrace around the stepwell cylinder sees noise, splashing, and action. Here, women beat clothes and scour metal pots, camels and cows drink from troughs, men talk and sharpen knives on the stones, and children run everywhere.[8]

The technical aspects of the stepwell also have a profound social impact on the surrounding communities. The wells are visual indicators of the health and capacity of the groundwater aquifer in the area, "since the stepwells depend on a hidden water table, they mark an underground aquifer."[9] The water level in the well rises and falls with the seasonality of the rains, people and their resource supply are visually connected. Modern piped water is hidden, conveyed vast distances from its source making people unaware of the amount of supply stored in nature. Contemporary privatized domestic water supply, while convenient, fails to offer social interaction in urban space. The process of attaining water is a personal and instantaneous endeavour in most modern cities. It is an act that now lacks ceremony and importance, something that is taken for granted.

Social Issues of the Modern Plumbing Paradigm

Adolf Loos heralds the plumber as a hero of the twentieth century equating plumbing with cultural progress, "the idea that at the end of the nineteenth century there is a country with a population of millions, all of whose inhabitants cannot bathe daily, would be outrageous in America."[10] Access to clean running water is considered a human right in contemporary society, and infrastructure was

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[7] Livingston, *Steps to Water*, 7.

[8] Ibid., 4-5.

[9] Ibid., 10.

[10] Adolf Loos, "Plumbers", in *Plumbing* Ed. by Nadir Lahiji and D. S. Friedman (Princeton Architectural Press, New York, 1997), 17.

previously celebrated and cherished for achieving such a feat. Throughout the 19th century infrastructure was advancing and able to supply larger populations more securely, “urban networks and their connecting iconic landmarks were prominently visual and present in the urban landscape. They were iconic embodiments of, and shrines to, a technologically scripted image and practice of ‘‘progress’’.”[11] In the wake of the great depression and World War II, industrial cities and their outward displays of technological networks were no longer symbols of hope for a better future. Instead, Kaika describes the remaining public works such as dams, water towers, and pumping stations as the technological “dowry”, remnants of urban networks that once promised a better future.[12] During the twentieth century, a new dream of a clean city unobstructed by unsightly infrastructure and services materialized.

According to Kaika,

> with the patina of time added over them, urban technological cathedrals turned from landmarks into scrap heaps, rusting like the modern urban dream of emancipation and equality. Dams ceased being popular destinations for weekend excursions, and the once visually prominent technology networks started gradually disappearing underground or fell into ruin.[13]

The modernist dream of rationalizing public space promised efficiency and cleanliness as exemplified by Le Corbusier’s Ville Radieuse.[14] Hiden urban infrastructure and the concept of the individual house as a “machine for living,” further added to the privatized consumption of water. The modernist architectural ideals of the utopian, fully serviced domicile removed the need to interact with water and infrastructure in the public realm, “With the aid of technology, buildings and people alike would become individualized, sanitized, and disconnected from

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[11] Kaika, *City of Flows*, 28.

[12] Ibid., 29.

[13] Ibid., 43-44.

[14] Ibid., 47.

each other and from social and natural processes."[15] The "doweries" of the urban systems that have remained are currently going through a final transformation which promises to further dilute the memory of their former function from society. Kaika identifies examples of adaptive reuse such as the Tate Modern, a former power plant, converted into a museum as the last step of erasing the palimpsest such monuments of urban systems held.[16]

Modern water delivery systems, although they increase our quality of life, have also created a slew of social and environmental problems. The hidden pipelines and private treatment plants that form the waterworks of modern cities have created a social disconnect with the source and capacity of global water reserves. In Elizabeth Shove's Converging conventions of comfort, cleanliness and convenience, she identifies the dissolution that modern plumbing has created amongst the general populous. Shove argues that the convenience provided by modern infrastructure has created false perceptions of what is normal in terms of practice and consumption,

> domestic consumption and practice are intimately linked in reproducing what people take to be normal and, for them, ordinary ways of life... much environmentally significant consumption - and in particular, consumption of energy and water - is quite simply invisible. It is bound up with routine and habit and with the use as much as the acquisition of tools, appliances, and household infrastructures.[17]

Along with a false sense of security and the excessive consumption that modern plumbing has enabled, society has become disconnected from the natural resources we consume and the processes used to delivery them. In Richard White's The Organic Machine, he identifies the disconnect humans have with nature by contrasting the lives of Aboriginals on the Columbia River to those of

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[15] Kaika, *City of Flows*, 41.

[16] Ibid., 45.

[17] Elizabeth Shove, "Converging Conventions of Comfort, Cleanliness and Convenience," *Journal of Consumer Policy* 26, no. 4 (2003), 395.

later modern settlements, “we forget the awesome power-the energy-of nature. There is little in our day-to-day life to preserve the connection”.[18] White goes on to characterize the mechanized and dammed Columbia as an Organic Machine, “no matter how rationalized the river became, how closely linked with human labor and its products, it remained a natural system with a logic of its own.”[19] To White, the fact that humans exploit the rivers power is not completely negative, but what is adverse is the lack of understanding for the new natural system, “the Columbia has become an organic machine which human beings manage without fully understanding what they have created.”[20] This is not to suggest people need to live closer to springs and artesian wells to better appreciate their water supply, yet the disconnect created by miles of pipe, faucets, or a water truck can be addressed by modern urban systems. Water collection systems close to the homes of people and business using the resource can evoke a better appreciation for its availability. Architecture that makes traditionally complex infrastructure, and its relation to water sources, more transparent and easily understood can change attitudes towards water use. A shift towards water use in the public sphere, in the form of fountains, bathhouses, and public waterworks infrastructure could help to change public ideas of normal consumption. Reducing the importance of water in the home would help forge connections between society and the hydrologic cycle. Architects charged with building future public works projects should attempt to recapture the promise and spirit such buildings held in the 19th century. If successful, at creating a new typology of infrastructure, people could attain an increased awareness of the cities relationship to natural resources and the urban systems that convey them. Increased social interaction in the public realm and more sustainable consumption practices are promising benefits of this new architectural typology.

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18. Richard White, *The Organic Machine* (New York: Hill and Wang, 1995), 4.
19. Ibid., 79.
20. Ibid., 108.

The Groundwater Problem

“By some estimates, humans already appropriate almost 50% of all renewable and accessible freshwater flows, leading to significant ecological disruptions.”[21] Such estimates have sprung the concept of peak water, the equivalent to peak oil, which identifies a time at which human consumption of the resource has reached a point where it is impossible for the system to recover and future demand cannot be sustained. It is believed by some that the United States has already reached the point of peak water use and an urgent change in water resource management is required for a sustainable future.[22] The finite and diminishing quantity of water available on earth has tremendous economic, social, and environmental implications that have only recently began to manifest. The crux of the problem lies in the conventional source of water that has dominated urban supply worldwide for centuries, groundwater.[23]

Groundwater, like all water in the hydrologic cycle, is essentially a renewable resource used by approximately 50 percent of the worlds nations.[24] This water source can remain in a state of homeostasis naturally, yet anthropologic alterations such as overconsumption and increased surface runoff from our cities have stressed the global supply to its limits. The problem according to Peter Gleick is the immense time required, hundreds or thousands of years, to replenish groundwater supply, “when slowly renewed resources are used by humans at a rapid rate, they

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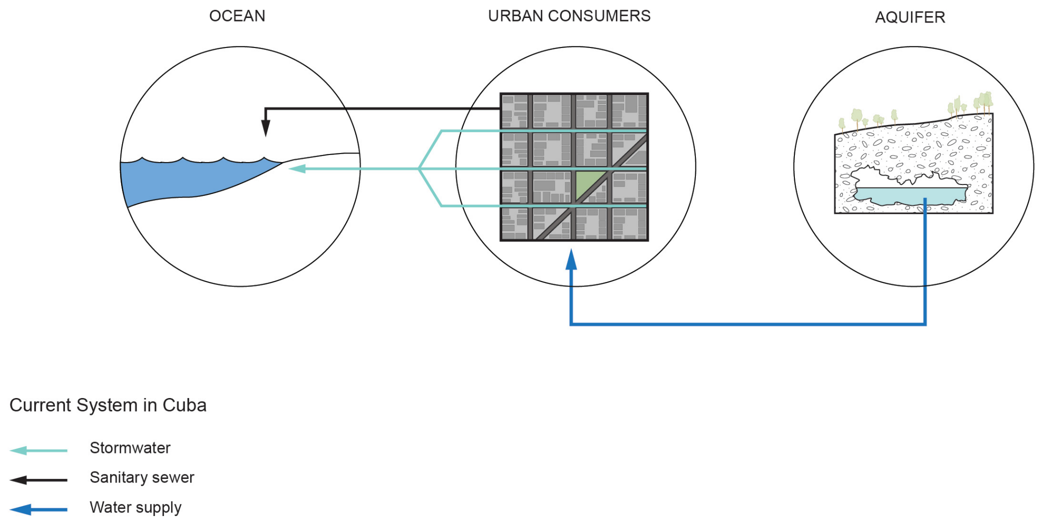
21. Peter H. Gleick and Palaniappan, Meena. “Peak Water Limits to Freshwater Withdrawal and Use,” Proceedings of the National Academy of Sciences of the United States of America 107, no. 25 (2010), 11160.

22. Ibid., 11161.

23. Robert J. Glennon, *Water Follies : Groundwater Pumping and the Fate of America’s Fresh Waters*, (Washington, D.C.: Island Press, 2002), 23.

24. Klaus-Peter Seiler, and Gat, Joel. “Groundwater Recharge from Run-off, Infiltration and Percolation,” *Water Science and Technology Library*; 55. (Dordrecht: Springer, 2007), 1.

effectively become non-renewable resources with subsequent disruptions of the natural cycle.[25] The environmental and social implications of damaging groundwater supplies are revealed on the surface in sinkholes, ground surface subsidence, and varying degrees of damage to surface waters.[26] The realization that groundwater can no longer support the current and growing population indefinitely has generated a search for alternative sources of water supply.



Urban water system with no reuse scheme, storm and waste water is deposited in the ocean

Traditional Urban Water Systems

Water is an essential element for life on earth, and as such, no urban system is of greater importance to the viability of cities as the water system. Unlike other urban systems, such as power or transportation, the water system is one that links cities directly to the environment through the hydrologic cycle. The built environment becomes a critical component in this natural cycle as water is diverted from its natural course. J.B. Rose states that, “Water is now the most important at-risk

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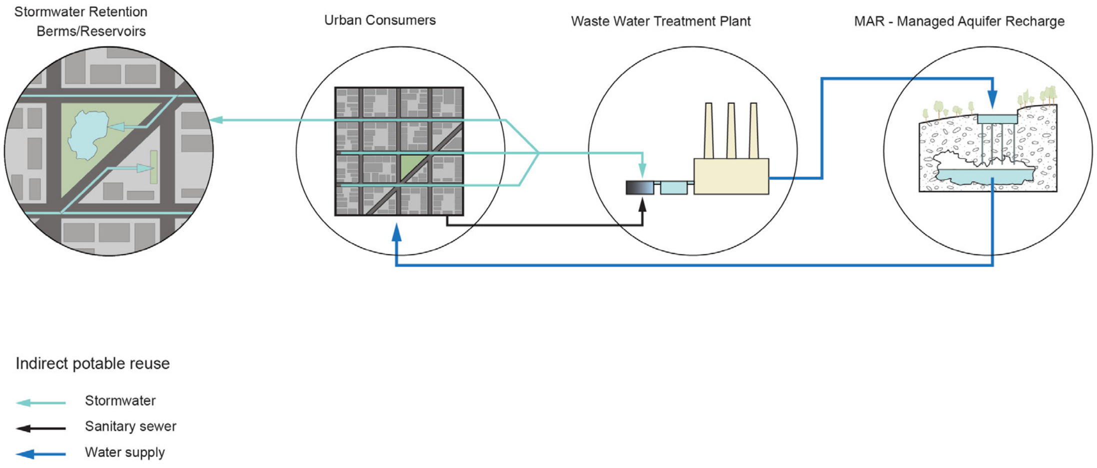
[25] Peter H. Gleick, and Stockholm Environment Institute. *Water in Crisis : A Guide to the World’s Fresh Water Resources* (New York: Oxford University Press, 1993), 15.

[26] Glennon, *Water Follies*, 34.

natural resource worldwide,” and as a result, the manner in which cities relate to the hydrologic cycle needs to be re-evaluated.[27] Currently, it is most common for cities to pump water vast distances from various sources of supply, requiring different levels of treatment, to quench the thirst of its inhabitants and industry. This water is typically consumed by both potable and non-potable uses and discarded as raw sewage, or as an environmentally safe alternative, treated sewage effluent flows to the nearest body of water. In most cities, a separate system known as the storm water system carries rain water along the shortest and most efficient path to the nearest creek, river, or body of water. In some cities a combined sewage system handles both storm water and sewage waste together. These systems are typically being phased out of use as they require treatment plants to process a larger volume of fluid with the addition of rain. Cost efficiency has been the long dominating paradigm for the design and implementation of stormwater systems. Before water scarcity was an issue in the minds of urban planners and engineers, the fastest and cheapest method of shedding rainwater away from our impermeable cities was employed. These archaic systems are found throughout the cities of the world



Urban water system with Indirect Potable reuse, storm and waste water are filtered and returned to the aquifer to be used again

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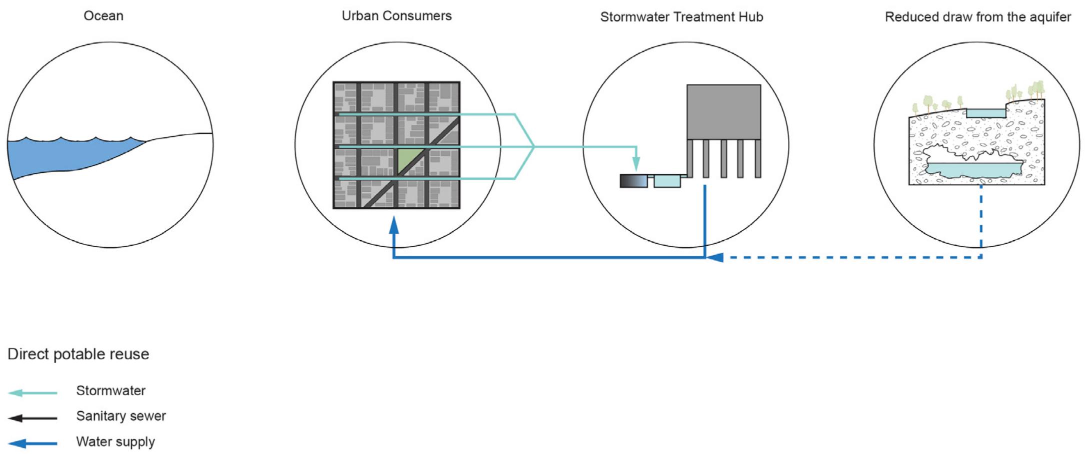
27. J.B Rose, “Water reclamation, reuse and public health”. Water Science and Technology: a Journal of the International Association on Water Pollution Research (2007), 276.

and it is time they were re-evaluated.

Progressive Urban Water Systems

Indirect Potable Reuse

The most progressive and sustainable urban systems take additional steps in the way waste water and stormwater is returned to the environment. Recently, new methods of water management under the umbrella term water reuse have attempted to create a system that is environmentally sustainable and also promises to ensure future water supply is maintained. In 1992, the Environmental Protection Agency published the first document to establish health and safety as well as economic and feasibility guidelines to water reuse.[28] Currently, the most advanced method of water resource management employed is indirect potable reuse. This process involves the treatment of sanitary sewage and industrial waste water to a near potable standard, it is then returned back to the groundwater supply through engineered surface flooding or injection.[29] In this method, the treated effluent is temporarily stored in an environmental buffer then returned to the city as potable



Urban water system with direct potable reuse, stormwater is treated an reused directly reducing the draw on the aquifer

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[28] United States. Manual, Guidelines for Water Reuse. U.S. Environmental Protection Agency :-- U.S. Agency for International Development, 1992, 40.

[29] Ibid., 41.

water. The scientific community is often divided over the efficacy of indirect potable recharge with concerns for both the environment and water quality, “Natural systems lead to dilution which does not remove contaminants but only spreads them wider.”[30]

Direct Potable Reuse

Direct potable reuse is a much less common method of water reclamation where effluent sewage is taken from the city and converted to potable water via advanced filtration techniques.[31] This method of water reclamation effectively forms a closed loop system and is thus extremely sustainable however it is currently only used in one city worldwide, Windhoek, Namibia.[32] Direct and indirect potable reuse primarily deals with waste water that is collected and pumped to a central location and stormwater is not a large contributor to this form of water reclamation. Stormwater is often segregated, due to gravity flow constraints which are governed by topography, and thus it typically ends up in the ocean or other large body of water. As a result rain water is often not a principal contributor to indirect potable recharge despite it being far less polluted than waste water.

Stormwater Management

Stormwater management as a means of water supply has received far less attention and research than wastewater treatment. Stormwater is most commonly directed to the nearest surface body of water and strategies have been employed to reduce this volume by increasing permeability in urban areas. Low

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30. J. Van Leeuwen, “Reclaimed Water - an Untapped Resource,” *Desalination* 106, no. 1 (1996): 239.

31. Ibid., 41.

32. Petrus L. Du Pisani, “Direct Reclamation of Potable Water at Windhoek’s Goreangab Reclamation Plant,” *Desalination* 188, no. 1 (2006): 82.

impact development (LID) seeks to limit the amount of stormwater runoff occurring by designing urban spaces that replicate natural conditions. Techniques such as bioswales, retention ponds, and permeable concrete or asphalt attempt to mimic nature slowing the path of rain water to the sea, “A major emphasis is placed on maintaining and enhancing natural processes. This includes promoting infiltration instead of runoff.”[33] These methods can aid groundwater recharge and improve the quality of stormwater runoff reducing the effects of entrained pollutants on the environment. They do not however, contribute to water supply despite being collected by a massive amount of existing infrastructure and in close proximity to the end users. This is a wasted opportunity, especially when it is considered that 60 percent of potable water consumption is used for non-potable purposes in the United States.[34] This percentage of water could be easily supplemented with greywater captured by the stormwater system in many cities with adequate rainfall. Supplying greywater for non-potable purposes could reduce the consumption of finite sources such as groundwater by greater than 50 percent however supplying people with reclaimed water can be problematic and costly. In order to supply the populous with grey water, a separate supply system is needed to protect the potable supply from contamination, such as the dual system used in St. Petersburg, Florida, the largest in the United States.[35]

The high cost of construction for additional pipe networks in established urban areas often makes them limited by feasibility.[36] The Throsby Creek

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33. Allen P., Davis, and Richard H., McCuen, *Stormwater Management for Smart Growth* (New York: Springer, 2005), 347.

34. United States, Manual, Guidelines for Water Reuse. U.S. Environmental Protection Agency :-- U.S. Agency for International Development, 1992. 84.

35. Daniel A., Okun, “Water Reclamation and Nonpotable Reuse: An Option for Meeting Urban Water Supply Needs,” *Desalination* 106, no. 1 (1996): 206.

36. P., Mcardle, et al., “Centralised Urban Stormwater Harvesting for Potable Reuse.” *Water Science and Technology : A Journal of the International Association on Water Pollution Research* 63, no. 1 (2011): 16.

Catchment project in Newcastle, Australia provides a unique case study exploring the possibility of treated stormwater for potable reuse. McArdle et al identify that, “Treatment of stormwater to a potable standard, however, would allow the use of existing pipe networks for distribution.”[37] Moreover, the Newcastle case study provides proof that converting stormwater to potable water can be done in a cost effective manner with other benefits more difficult to quantify, “it can produce a number of direct and significant social impacts which may transcend cost and yield considerations.”[38] The Newcastle case study presents two significant problems that can perhaps be addressed through architectural design. Firstly, the need to store large volumes of water require appropriation of land, and secondly, public acceptance of drinking treated stormwater.[39] Architecture can protect against water scarcity and environmental damage by creating a new treatment and storage typology throughout the city. These buildings would be self contained storage and treatment hubs, which express their function, educate the public, and provide new ways of consuming both grey and potable water in the public realm.

Thesis Question

> If you’re short of water, especially clean water, the choices are conservation, technological invention, or the politics of violence.[40]

The statement made by De Villiers presents three options to address the current water crisis. Technological invention and conservation also need not be separate solutions. Some technological forms of invention can also create and promote conservation. Stormwater collection is an untapped source of water throughout

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37. Mcardle, et al., Centralised Urban Stormwater, 16.

38. Ibid., 23

39. Ibid., 23.

40. De Villiers, *The Fate of Our Most Precious Resource*, 356.

the world. It has long been something the city only intended to rid itself of. Now however, it must be considered as a viable source of supply. Many cities already have the infrastructure in place to capture this source of water and perhaps the impermeability of our cities can be considered as a positive attribute for the first time. Rather than conceiving of new forms of permeable ground cover and “green” city softscapes, perhaps it is adaptive reuse of a widely used impermeable infrastructure that can be the most sustainable option. Capturing and distributing rain for potable consumption is both conservation, as it reduces the need for other water sources, and technological innovation as it has yet to be used directly for supply.

The distribution end of the urban water system must also be reassessed. Private domestic supply, while a reasonable luxury, has created a culture of overconsumption. The social benefits and public awareness that came from water consumption in the public realm have been lost and with them a sense of conservation. A new typology for filtration and distribution infrastructure, placed in a dense urban area and offering public programming, could help achieve conservation and sustainability

Can architecture be used to help restore the hydrologic cycle and distribute it in a new and public way to increase the communal awareness of the finite resource required for survival?

Study Site: Havana, Cuba

The city of Havana, Cuba provides an interesting case study into the water habits of a dense urban system. The island provides an example of a closed-loop water cycle, isolated from external inputs such as transnational distribution of water. Cuba’s colonial history can be traced from a country, “originally populated by traditional societies that were in equilibrium with their environment” to the expansive Antillean metropolis of today.[41] As the city of Havana grew, so did its need for resources and infrastructure. In, Conquering nature: the environmental legacy of socialism in Cuba, Sergio Diaz-Briquets states, “the satisfaction of humanity’s water needs demand that the natural environment be altered.”[42] Altering the environment and the hydrologic cycle are inevitable consequences of the modern city, yet the degree to which nature is altered must be minimized. The path of water used by the city is of utmost importance to the hydrologic cycle, “How water is used has important consequences; it could contribute to the lasting use of water and other renewable resources or to the degradation of the natural resource base.”[43] The historical paradigm is that water must be attained at almost any cost, both environmental and economic, as its capture supports life. Analyzing the water systems of Havana and the historical decisions that have created its current state of peril, it can be seen that a social and environmental disconnect have produced an unsustainable relationship with the hydrologic cycle. These issues can be addressed by reconsidering the urban relationship with the environment, the function of traditional infrastructure, and the use of storm water capture.

Havana is faced with water scarcity and a range of environmental problems as a result of human interference with the islands delicate water cycle. In Havana: two faces of the Antillean metropolis, the authors claim that half of Cuba’s waters supply may be polluted, and “estimates are that the water table

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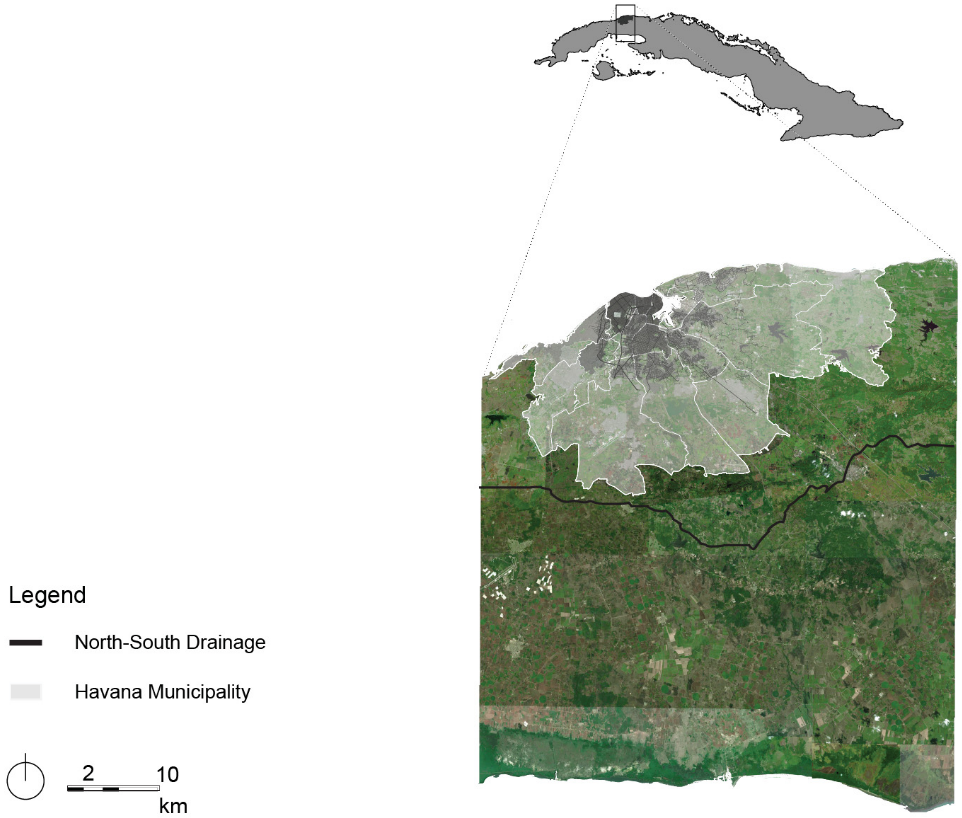
41. J. Anton Danilo, Thirsty Cities Urban Environments and Water Supply in Latin America (Ottawa: International Development Research Centre 1993), 23.

42. Sergio Diaz-Briquets and Jorge Pérez-López, *Conquering Nature: the Environmental Legacy of Socialism in Cuba* (Pittsburgh, Pa: University of Pittsburgh Press, 2000), 112.

43. Diaz-Briquets et al, 112.

has fallen about 30 percent.”[44] Despite the high average rainfall of 1400 mm per year, water has difficulty percolating into karstic aquifers.[45] The physical geography of Cuba, a country with a thin long profile of 100km from coast to coast, means that water runoff is high, a factor increased by deforestation and paved urban areas.[46] The hydrologic cycle of Cuba is thus working against the physical interference of urbanity to replenish the ground water supply.



Havana’s context within Cuba and the north - south drainage ridge. Imagery: Havana, 2016; from Google Earth Pro.

Potable water in Cuba comes almost entirely from these ground water aquifers, “In Havana, almost 100% of the water supply is drawn from

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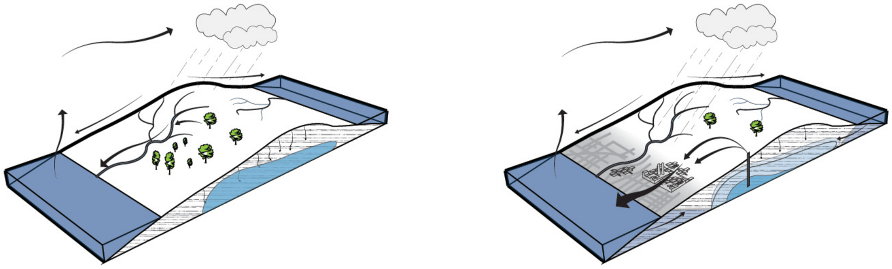
[44] Joseph L. Scarpaci, et al., *Havana: Two Faces of the Antillean Metropolis* (Chapel Hill: University of North Carolina Press, 2002), 6.

[45] Ibid., 4.

[46] Ibid., 6.

groundwater."[47] This presents a major interference in the hydrologic cycle, the fact that Cuba is drawing groundwater from aquifers faster than it can be replenished naturally. In order to increase the amount of water available for the country, the government created successive built works to satisfy the needs of the populous. The city was originally supplied with fresh water via the Almendares River, "this supply was very inadequate. In order to obtain a better and more abundant supply… a large number of springs were found… about 10 miles from Havana." [48] As demand increased, the response was to continue to tap sources of water progressively further from the city, creating the new aqueducts of Aguada del Cura in 1927, Paso Seco in 1950, Coscuelluela in 1954, and Ariguanabo in 1958.[49]



A section through Cuba in homeostasis (left) and the negative affects to the aquifer produced by urbanity (right)

The water intensive irrigation processes used for agricultural production in Cuba also interfered with the hydrologic cycle heavily. Water in the rural areas of the country was captured and stored through the use of reservoirs and damns. In the 1960's and through the special period Fidel Castro pushed this policy, "a network of water storage areas through a major dam reservoir

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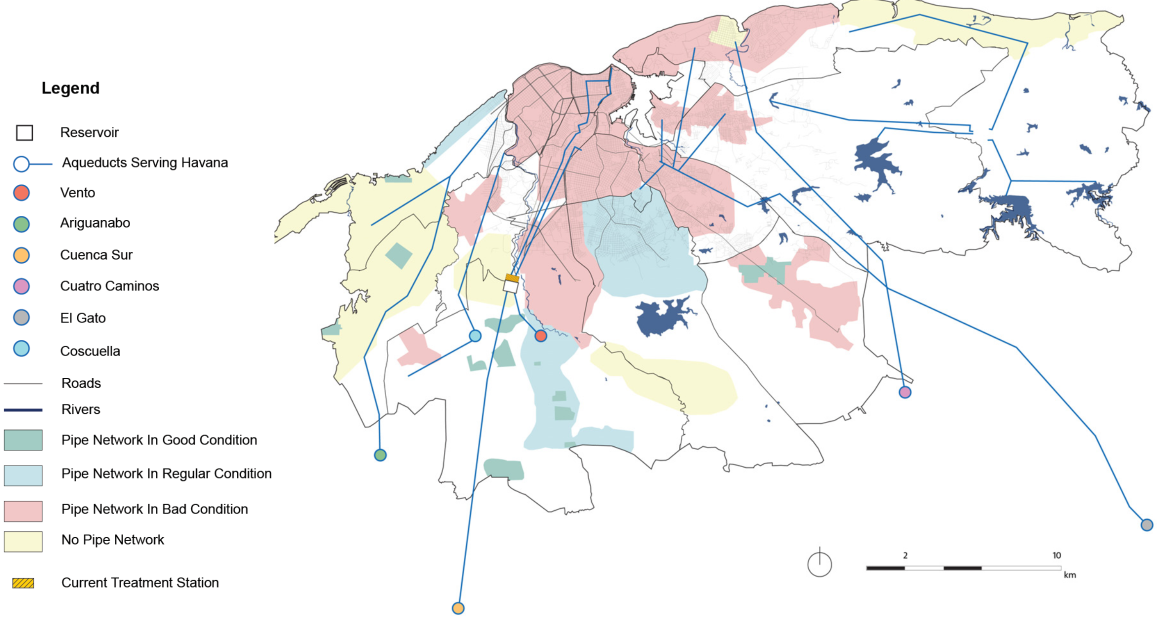
[47] Danilo, *Thirsty cities*, 5.

[48] Sherman E. Gould, " The new Water-Works of Havana, Cuba". Transactions of the America Society of Civil Engineers. (New York, 36,2, 1896), 217.

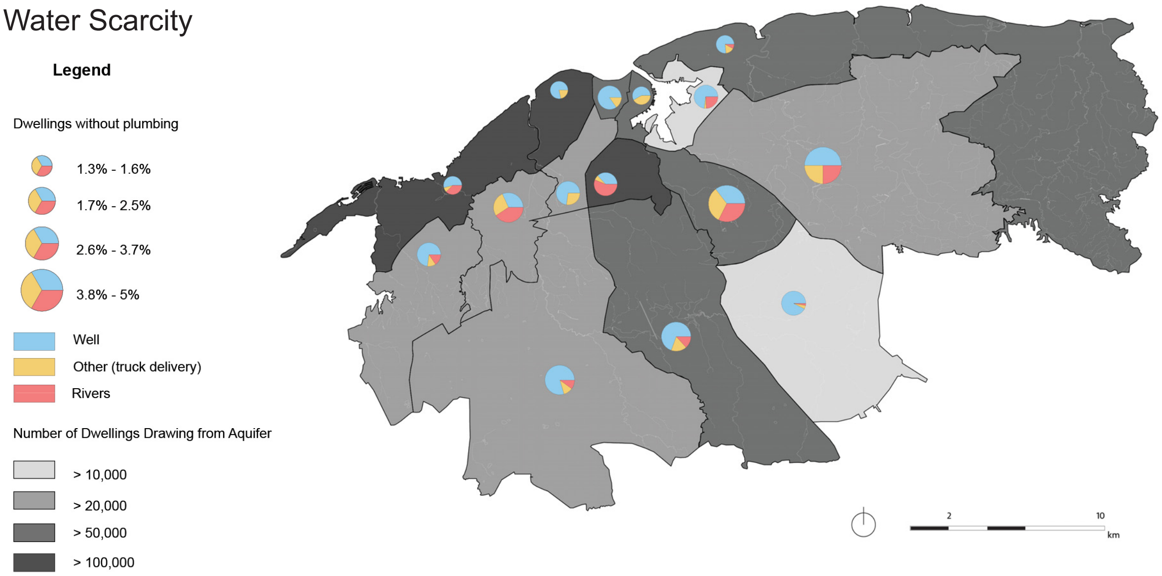
[49] Scarpaci et al., *Havana: two faces,* 104.

Dilapidated Infrastructure



Dilapidated infrastructure and chronological additons of aqueducts 2013, data from Direccion Provincial de Planificacion Fisica La Habana.

Water Scarcity



Water issues of the Havana municipalities, 2012; data from Nacional De Estadistica E informacion. *Censo de Población y Viviendas*.

construction program, and increasing extraction of underground water."[50] The capture of rainwater throughout the countryside prevents the percolation of this water into aquifers, causing them to further degrade. Briquets et al. have quoted Castro saying, "The sea will not be able to claim a single drop of rainwater falling on the land of our country."[51] This mentality of collecting rainwater and superficial waters in areas that would otherwise absorb and interact with water is a destructive approach to urban supply. In combination with over pumping of aquifer water, the program designed to capture superficial water has led to the salinization of many Cuban aquifers, "by not allowing rainwaters to flow freely... there was a considerable likelihood that coastal aquifers would be infiltrated by seawater."[52] Intrusion of seawater into ground water supply is a major threat to the environment and the availability of water in Cuba, "the gravest environmental threat to the drinking water in Havana come from the saltwater intrusion in the South Havana Aquifer."[53]

Even with the intensive collection of water, and many parts of the environment sacrificed, water availability in Cuba is still not of an acceptable standard. Up to 5% of the population in some of the municipalities in Havana are still without indoor plumbing.[54] According to Scarpaci et al., "an estimated 55 % of the water pumped to Havana is lost through leakage."[55] Although aging infrastructure is certainly to blame for the inconsistent and low quality supply of water Habaneros have come to expect, the larger issue looming over the country is the sustenance of the ground

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50. Diaz-Briquets et al., *Conquering Nature*, 122.
51. Ibid., 118.
52. Ibid., 125.
53. Scarpaci et al., *Havana: Two Faces,* 6.
54. Cuba. Oficina Nacional De Estadistica E informacion. Censo de Población y Viviendas. República de Cuba. Havana: GPO, 2012. Digital.
55. Scarpaci et al., *Havana: Two Faces,* 6.

water supply. Citizens expect that water supply issues are solely a result of their dilapidated infrastructure, Habanero Yaritsa Oliveros states, “In my neighbourhood the lack of water has been aggravated by the reparations taking place, but at least it gives us some hope that things will get better one day.”[56] In 2015 however Havana has experienced the worst drought in the last 50 years and water supply has become even more scarce.[57] This increased level of scarcity due to drought is an indicator that problems are present with the source of water and not solely the condition of the infrastructure.

Water and Society in Havana

Currently, neighbourhoods throughout Havana experience water shutoffs periodically, “We go several days without water and suddenly it starts to flow in our building in the early hours of the morning...We collect all we can in different containers, because we don’t know when the taps will run again.”[58] The social implications of the lack of water are profound. Many people in Havana are still regularly forced to carry water from outside of the home on a daily basis.[59] The government supplies water by truck to augment the lack of available piped water, a distribution method that perhaps disconnects people from the water source even more so than traditional piping. This method of supply has become a part of life, not simply a temporary solution, “more than 100,000 people dependent on tanker trucks for water.”[60] The existing infrastructure of Cuba should be repaired and made to work more efficiently, as is recommended by Danilo Anton, yet doing so does

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[56] Patricia Grogg, Water Shortages Have a Heavy Impact on Women in Cuba, last modified December 2, 2015, http://www.ipsnews.net/.

[57] Ibid..

[58] Ibid..

[59] Rocio Valderrama Hernández and Dolores Domínguez, “Think of Water from a Social Perspective. A research project in Havana”. (Procedia- Social and Behavioral Sciences,132, 2014), 475.

[60] EFE, Cuban Capital Facing “Critical” Water Shortage, last modified January 21, 2011, http://www.laht.com/.

Habaneros fill water into containers from delivery trucks; photograph by Juan Suarez (middle) and Jorge Luis Baños (right), from Havana Times, *Inefficiency, Not Drought.*

not solve the imbalance in the water cycle or alter the publics water consumption habits.[61]

The social problems already described surrounding modern water infrastructure are present in Cuban society. Compounding the lack of supply domestically to Habaneros is the absence of water infrastructure in the public realm. Historically, water supply in Havana was provided through public fountains,

> The public fountains in the 1773 plan served multiple social ranks, including slaves, on a daily basis providing water for drinking, washing, and food preparation. The public utility of fountains and their everyday use made them ideal vehicles for political propaganda.[62]

Today however, many fountains throughout the city are not functioning and fences and signs are used to prohibit people from using water from these public sources.

Habaneros are relegated to using water in only the domestic sphere and despite the problems with the service, there appears to be a lack of conservation culture. The government is forced to warn its citizens to conserve the water they receive from the inconsistent municipal supply, “Another negative factor is “the lack of a culture of water saving” and the fact that “the attitude of waste

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[61] Danilo, *Thirsty Cities*, 139.

[62] Niell Paul B. “Rhetorics of Place and Empire in the Fountain Sculpture of 1830s Havana.” *The Art Bulletin* 95, no. 3 (2013): 443.

continues" despite the dire situation and the fines imposed on all wasteful public entities."[63] The counter intuitive relationship between water scarcity and a lack of conservation is perhaps a result of a society relying heavily on domestic water supply. Improving the existing infrastructure does not solve many of the social or environmental problems associated with water. Cuba's water supply is a finite source that requires protection and conservation for its future security. There must be alternative solutions than simply updating the existing infrastructure to withdraw aquifer water at a higher rate.

The fenced off fountain in Plaza Vieja, signs warning that bathing is prohibited in public fountains Havana, 2015.

Stormwater and Havana

As Briquets et al importantly identify, " how water is returned to the environment has important consequences; it could contribute to the lasting use of water…or to the degradation of the natural resource base."[64] It is this point that is of great interest for the efficient and sustainable urban water system. As described, human intervention has unnaturally intercepted storm water across the country in order to sustain the urban metropolis. The impermeability of the city, and the construction of dams and dikes under Castro, has caused

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[63] EFE, Cuban Capital Facing "Critical" Water Shortage, last modified January 21, 2011, http://www.laht.com/.

[64] Diaz-Briquets et al., *Conquering Nature*, 122.

water to flow through the storm water system to the ocean at an unnatural rate. Soviet and Cuban engineers speculated that 2% of the countries land area is required for surface water capture in order to support irrigation.[65] Dedicating natural expanses of land to water capture impedes the water cycle and consumes otherwise usable agricultural lands. The metropolitan area of Havana accounts for .6 % of the countries total area, most of which is impermeable, built environment.[66] Thus, over a quarter of the area needed to capture the necessary water already exists in only one of Cuba's cities. Examining the ocean during a rain shower along the Malecón, Havana's water front street, brackish water can be seen forming as the sweet runoff mixes with the saltwater. The desperately needed sweet water is wasted, gone from the city for the span of its "residence time," approximately thirty-seven thousand years.[67] Meanwhile, Havana is drawing water from the aquifer, a delicate source that takes thousands of years to renew, the atmosphere however, renews its water content

Stormwater empties into the ocean after a storm along Havanas Malecon creating a strong line of brackis water, Havana, 2015.

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[65] Diaz-Briquets et al., *Conquering Nature*, 125.

[66] Calculation is made by the area of Havana proper divided by the area of Cuba.

[67] De Villiers, *The Fate of Our Most Precious Resource*, 29.

in approximately ten days.[68] The atmospheres renewal and residence time culminates in rain showers, an egalitarian and sustainable water supply across the landscape. Clearly, if architecture and the urban environment can make better use of rainwater and overland flow, stresses on the water supply can be greatly reduced.

Havana's Urban Fabric

In order to make urban systems more integrated with their natural counterparts, they must begin to preform multiple roles and function in harmony together. By reconsidering the existing role of the built environment and the urban fabric, cities can strive to become a more cohesive part of natural cycles. James Corner's Terra Fluxus, provides a theoretical basis for such an argument. Corner analyzes the term landscape, and dismisses the 19th century idea of 'green space', gardens, and esplanades simply as necessary entities because they provide contrast to the, "deleterious effects of urbanization."[69]

Some landscapes however, are built as important systems within the city, acting as infrastructure rather than mere projections of nature. Corner describes these types of landscape spaces as, "important ecological vessels and pathways."[70] Such urban entities need not appear, or be composed of natural elements at all. Recalling The Organic Machine, White argued that nature and inanimate human additions must not be seen as separate entities. White states, "There is no clear line between us and nature. The Columbia, an organic machine, a virtual river, is at once our creation and retains a life of its own beyond our control."[71] The city of Havana has been planned with many of

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[68] Ibid., 29.

[69] James Corner, "Terra Fluxus," (Lotus International, 150, 2012), 24.

[70] Ibid., 24.

[71] White, *The Organic Machine* (New York: Hill and Wang, 1995), 109.

the negative points identified by both Corner and White. The planned greenbelt that surrounds the dense urban area to the south of the city forms a distinct line between nature and the inanimate city described by White. The false images of nature critiqued by Corner can be seen in the neighbourhood of Vedado with its french garden style urban planning, and topiary gardens that line the long paseos.[72] Terra Fluxus, identifies that the ground plane, and the surfaces that compose the city are critical elements to achieving a more integrated urbanity.[73] Corner defines the potential of such surfaces, “unlike architecture, which consumes the potential of a site in order to project, urban infrastructure

Density and the greenbelt

The planned greenbelt surrounding the dense city 2012, data from Nacional De Estadistica E informacion. *Censo de Población y Viviendas*. Imagery: Havana, 2016; from Google Earth Pro.

sows the seeds of future possibility, staging the ground for both uncertainty and promise.”[74] The already dense and impermeable city core serves as the focus

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[72] Scarpaci et al., *Havana: Two Faces,* 69.

[73] Corner, “Terra Fluxus,” 31.

[74] Ibid., 31.

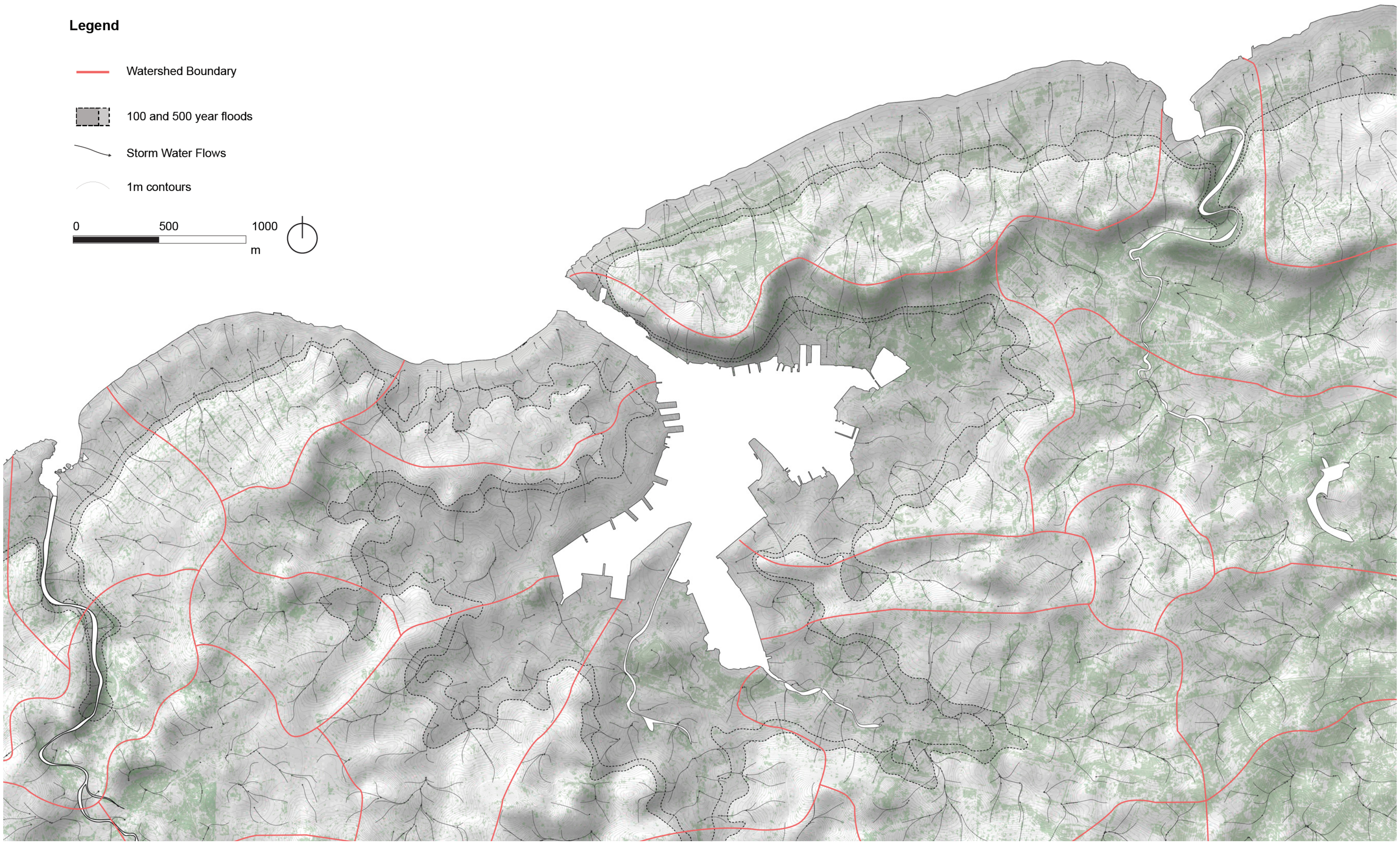
of this investigation. An adaptive reuse of the stormwater infrastructure here and reconsidering the ground surface as a collection area, presents the possibility of a new infrastructure typology. Sited amongst the dense populous and close to the end user it is required to be free public space.

The surfaces of the city can be assets to creating a more ecologically sustainable city. Instead of these impermeable surfaces increasing storm water runoff rates, they can be utilized as dual-purpose infrastructure, used to capture rainwater for the purposes of restoring hydrologic homeostasis that urban consumption has disrupted. Stormwater is a new source of water supply that has yet to be implemented as a significant contribution anywhere in the world. The capture of this water and its use for irrigation or human consumption is a logical method for reducing stresses on ground water supply.

Watersheds and Outfalls

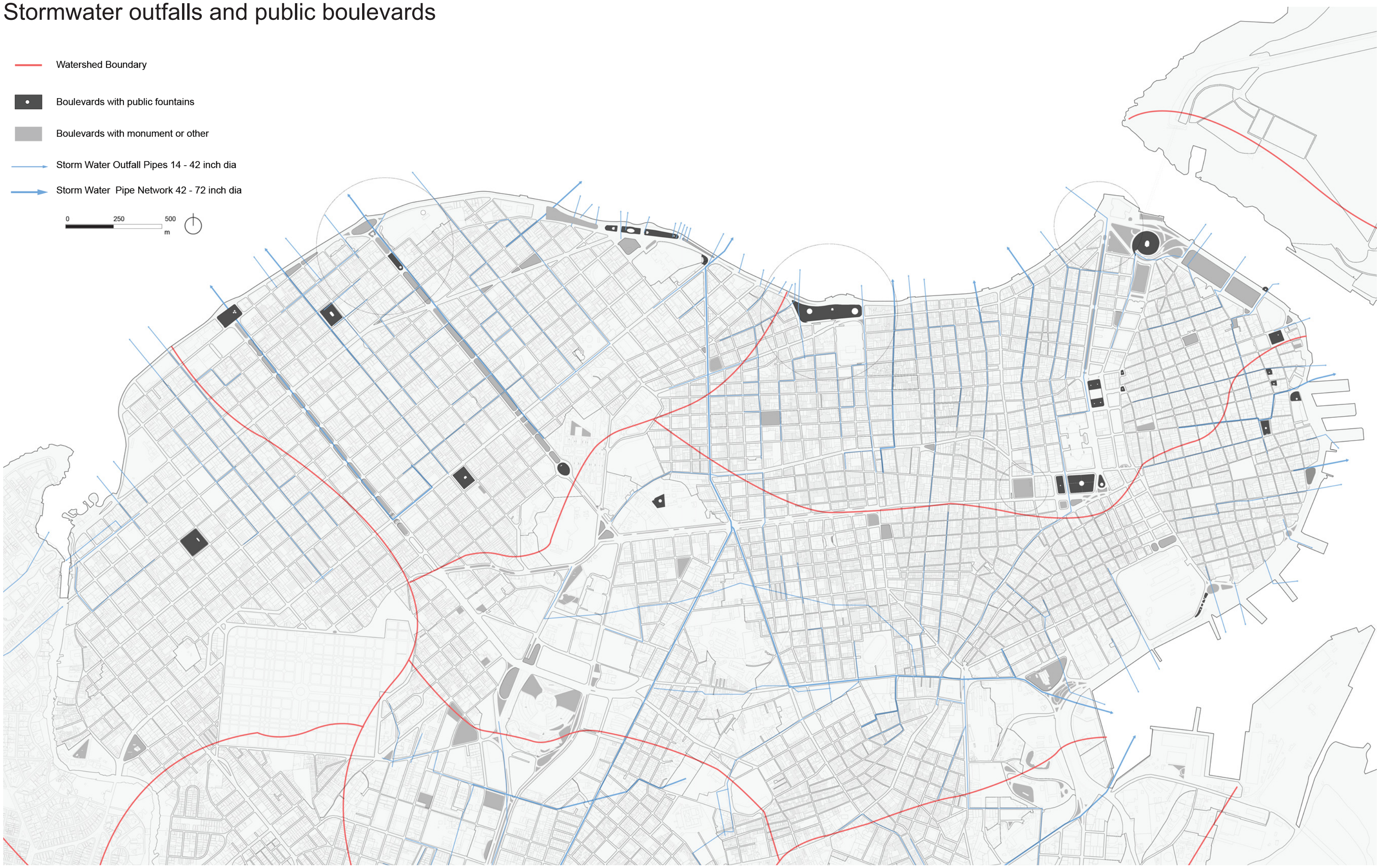
In order to determine the hydraulic potential of the stormwater system, it is necessary to establish the topographical watersheds throughout the city. These watersheds, defined by high points along the terrain, control the path of overland flow. Within these sheds, a stormwater pipe network and their associate outfalls can be mapped. The intervention will be sited and scaled to serve each of these sheds as a system of collection hubs and distribution nodes.

Watersheds and topography



Map indicating topography and the associated water sheds, floodzones, and surface runoff flows.

Stormwater outfalls and public boulevards



Map indicating the water sheds and their discrete stormwater networks within.

CHAPTER 2: DESIGN

Site Selection

Mapping the watersheds of Havana reveals that a multinodal, community scale response is required if it is desired to process stormwater within the cities public realm. This is because at no one point does all the stormwater accumulate for a large central processing operation. The stormwater system is fragmented, serving each of the watersheds discretely. When boundaries are crossed by the stormwater system, the inland sections of pipeline must be laid at great depth to achieve the necessary outfall elevation and corresponding grade slope. The sanitary sewage system, which also functions via gravity, follows a similar layout. Sewage treatment plants are required to process all of a city's piped waste as opposed to the multiple outfalls available along the coast for the stormwater system to discharge. As a result, sewage treatment plants are constrained to specific locations as seen in the map images provided for Detroit and Chicago. Most typically, sewage treatment occurs in the urban fringes, where

Map showing the Chicago waste water treatment plant and its distance from the city core, Chicago, 2015; from Google Earth Pro.

Map showing the Detroit waste water treatment plant and its distance from the city core, Detroit, 2015; from Google Earth Pro.

large expanses of low cost land are available for the large footprint required by these facilities. The location is often optimized to be close to areas of low elevation where the sewage can naturally gather via gravity but this is often not possible. Thus sewage treatment plants typically receive their liquid sewage under pressure, rather than strictly via gravity flow, in order to gather the sewage in a centralized location for treatment. This is the opposite strategy this thesis wishes to explore in order to treat and distribute stormwater as an architectural response. Rather than a single large facility processing all of the stormwater in a central location, multiple smaller facilities, strategically placed in each of the identified watersheds can process a portion of the rain that flows through the city. These multiple hubs can be used to serve their local and surrounding community with filtered potable water and stormwater storage.

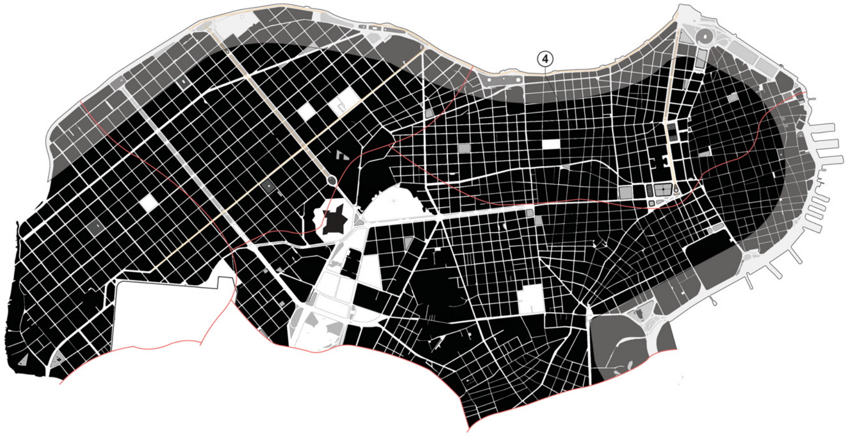
Mapping the site selection criteria reveals that the ideal location for the main hub is at a point of low elevation, close to the waterfront. This is because the lower the collection elevation is, the more stormwater can be captured from the uphill shed. The mapping has also highlighted areas where public water fountains and monuments already exist. These are the boulevards with ornamental topiary gardens criticized by corner for their lack of shade and false representation of nature.

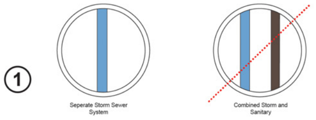
Photos of typical boulevard conditions and lack of public use along Calle G, Vedado, Havana, 2016.

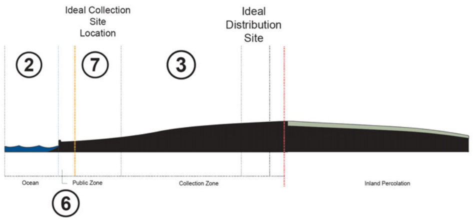
They have little shade during the day and are poorly used public spaces that could be activated by public programing. They are excellent locations for public monuments as the boulevards are separated from the typical city grid, with a strong axiality and vistas to convey their grandeur. The boulevards are also located along major circulation routes with heavy traffic both pedestrian and vehicular such as the Paseos and the Malecón. This would allow access and integration of the proposal into the daily life of Habaneros. The paseo selected, Calle G, runs north-south and contains approximately 30 meters of elevation change from the high point to the end terminating at the waterfront street, The Malecon. The end of boulevard thus becomes the logical site location as the water flows downhill gathering in the proposed building. Finally, the boulevards are part of the road infrastructure and as such, they have close proximity and ease of access to the stormwater network.

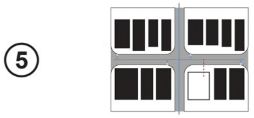
Site selection criteria

1. Must be a Seperate Storm Water System
2. Ocean Front City (Runoff must be headed towards salt water or adjacent rivers).
3. Low Ground Co-efficient (Impermeable City)
4. Located in density close to the end users
5. Site must be in close proximity to stormwater pipeline
6. In a public zone of high pedestrian traffic
7. Proximity to the waters edge and elevation (sea level) to make use of gravity fed storm systems





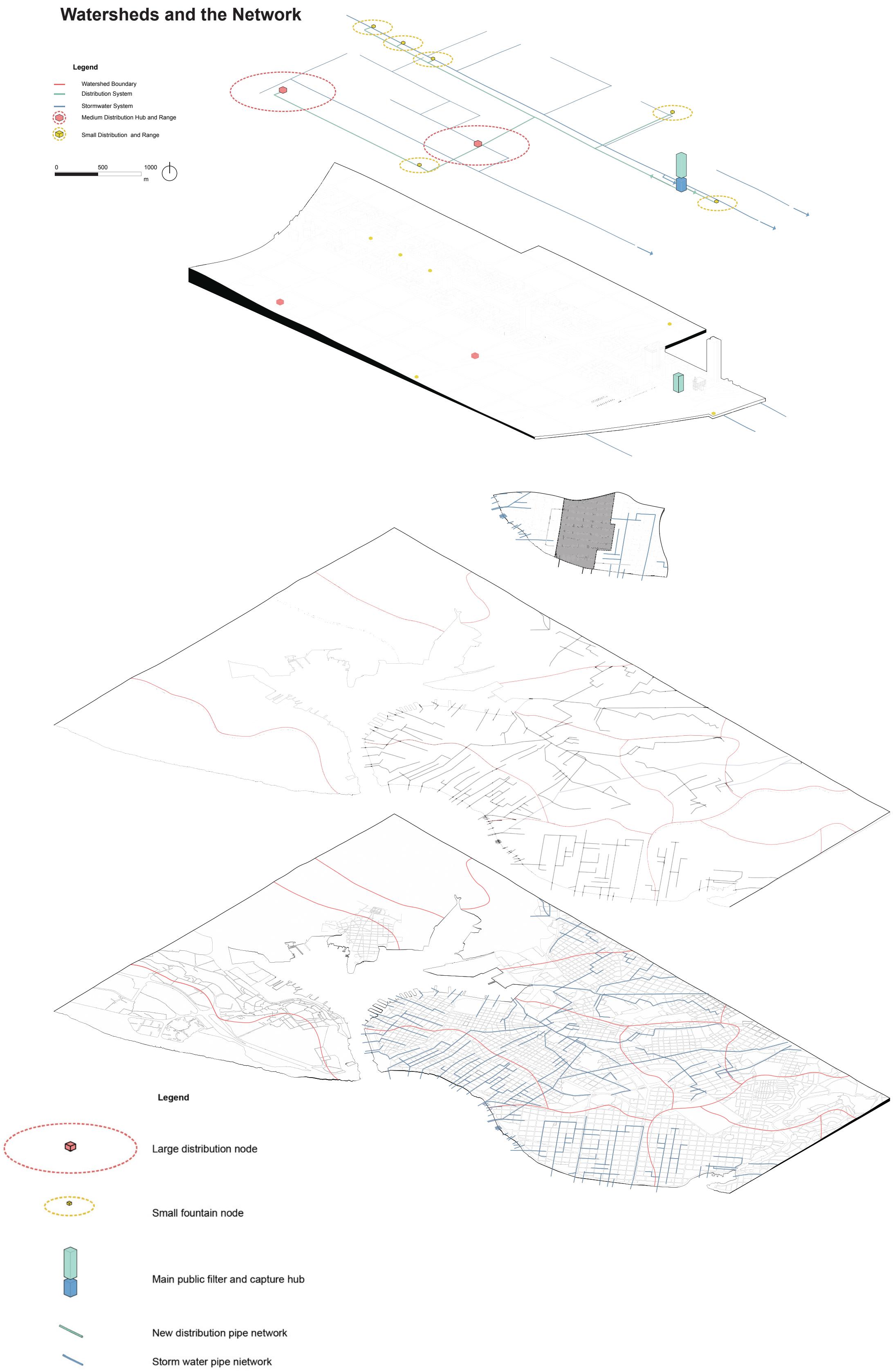




Legend

☐	Low elevation Zone
—	Water Shed Boundary
┈	Pedestrian Traffic Zone
■	Boulevard Condition
●	Existing Public Fountains

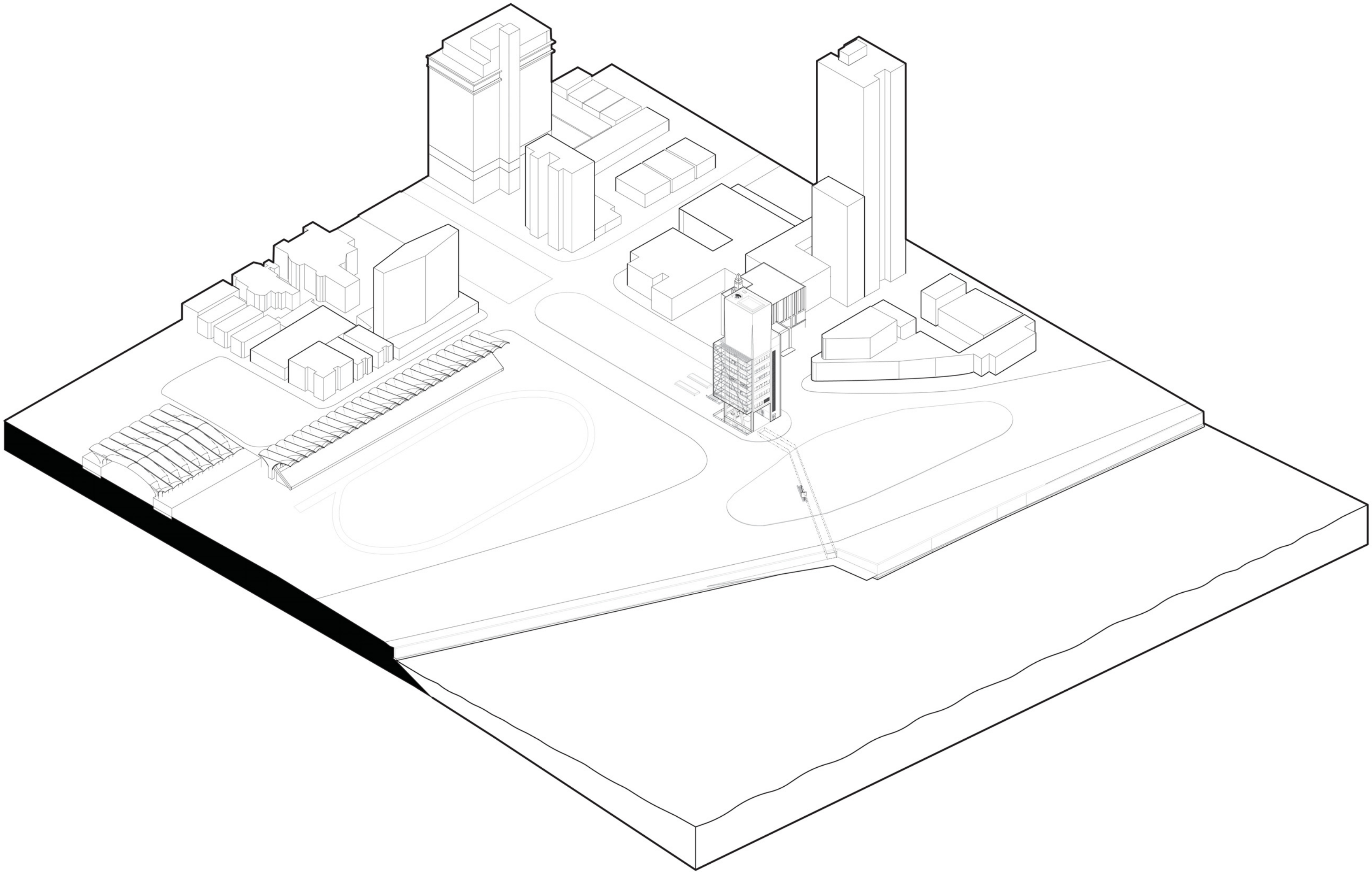
Criteria and principles required for selecting a site within a city, in this case Havana, Cuba.



Exploded Axo of Watersheds, Stormwater infrastructure, and new proposed system.

Site location within its watershed, Imagery: Havana, 2016; from Google Earth Pro.

Site location within its watershed, Imagery: Havana, 2016; from Google Earth Pro.



Axonometric drawing of design proposal and underground tunnel to the Malecon within its site.

Preliminary Design Principles

The chosen location of the thesis project has some inherent difficulties that can be addressed through the structures design. These difficulties control the main framework and generate the designs parti. As Mcardle et al identify, " The intermittent nature of runoff requires considerable storage in a stormwater reuse scheme to ensure an adequate yield from the treatment plant."[75] In order to accommodate the necessary storage a deep, concrete reservoir functions as both foundation and programmable space. This reservoir is placed below grade and is filled with stormwater as it intermittently arrives with the rain. This stored water is visible to the public acting in a similar fashion to the Indian stepwell by providing a visual indicator of the water available as it rises and falls dependent on the weather. The second major barrier is redistributing the processed water. As described, collection must occur at a low elevation and as a result pumping may be required to redistribute water back up hill. Van Leeuwen describes this universal problem,

> Most cities have developed, being supplied in one direction and drained in the other, to maximize use of the topography for gravitation. In coastal settings,there is often no possibility of using reclaimed water downstream, as the sewage treatment plants are already virtually on the coast. Additional expenditure is required to return the water against gravity to prospective consumers.[76]

In order to respond to the redistribution problem the building has been designed similarly to a water tower. The Potable water is pumped to a high elevation where it gains potential energy to flow via gravity to the rest of the city. Placing filtration equipment between the storage reservoir below and the potable tank above integrates the technology making the building more sustainable and its processes more efficient. Pumping energy is thus minimized as the filtration floors require pressurized water and so does the elevated holding tank. In a vertical tower scheme storage, filtration, and redistribution optimize the energy required to process the raw

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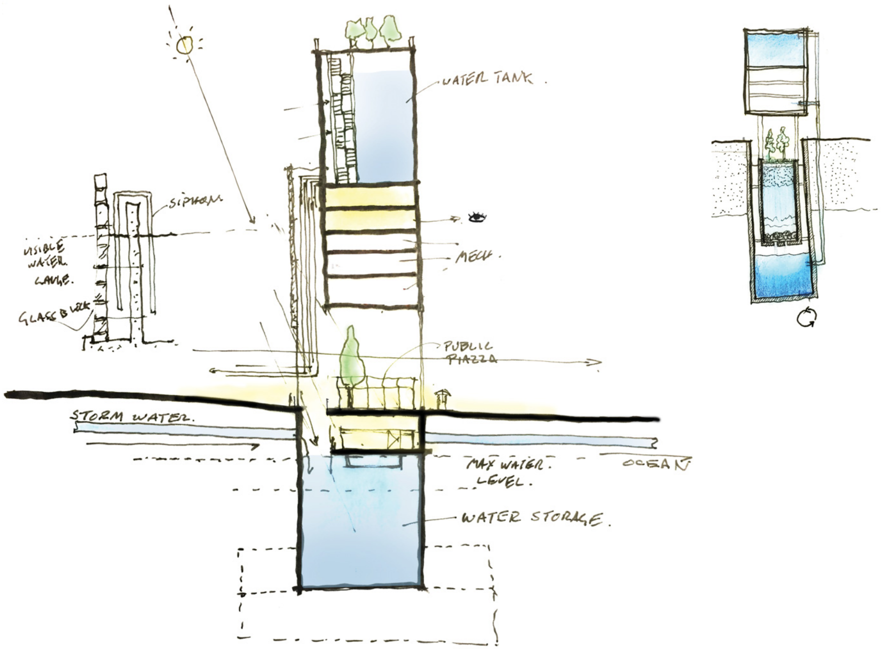
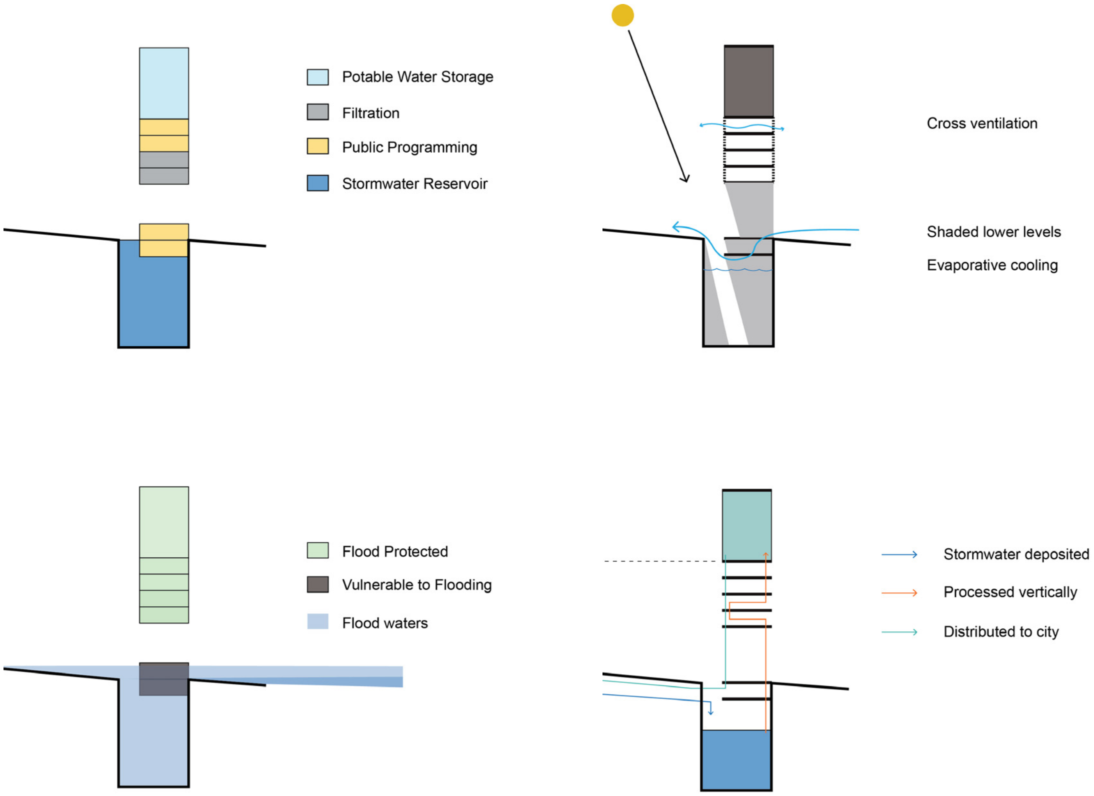
75. Mcardle, et al., Centralised Urban Stormwater, 16.

76. Leeuwen, Reclaimed Water, 234.



Parti section drawings of design scheme and earlier iterations.



Diagrams indicating the driving design principles and basic scheme.

storm water. The modified water tower typology also elevates floors with sensitive equipment, and the potable water itself, away from damage that could incur from flooding ocean water. Floods are likely to occur in most instances where this thesis may be employed, due to the low sea level elevation required for the building site as already described.

Programming

The reservoir space is primarily designed as a place to retreat from the sun and benefit from the evaporative cooling produced by the water below. The reservoir is thus programmed with a bathing pavilion to further increase the cooling effect of the building and also to increase water use in the public realm. A below grade tunnel connects the building to the Malecón and the ocean. This allows people to bathe in both the natural salt-water, and also fresh water processed within the building. The underground tunnel also allows access to the ocean without having to cross the busy street. Water stored in the reservoir is then pumped through three floors of filtration equipment. The Newcastle case study identifies four required types of filtration for stormwater treatment, microfiltration/ultrafiltration, reverse osmosis, and advanced oxidation.[77] These filtration stages occur sequentially as one moves upwards in the building. Site specific public programming is placed in the uppermost floors of the building. In this particular case, the building is situated next to an athletics facility. Thus, additional physical activity programing in the form of a gymnasium has been provided. The community specific programming should be carefully selected to provide public space that is needed based on the site location. This allows the public floors to take advantage of the vistas provided by the height and also forces users to pass the filtration processes as they circulate through the building. The buildings users are thus able to see and understand what

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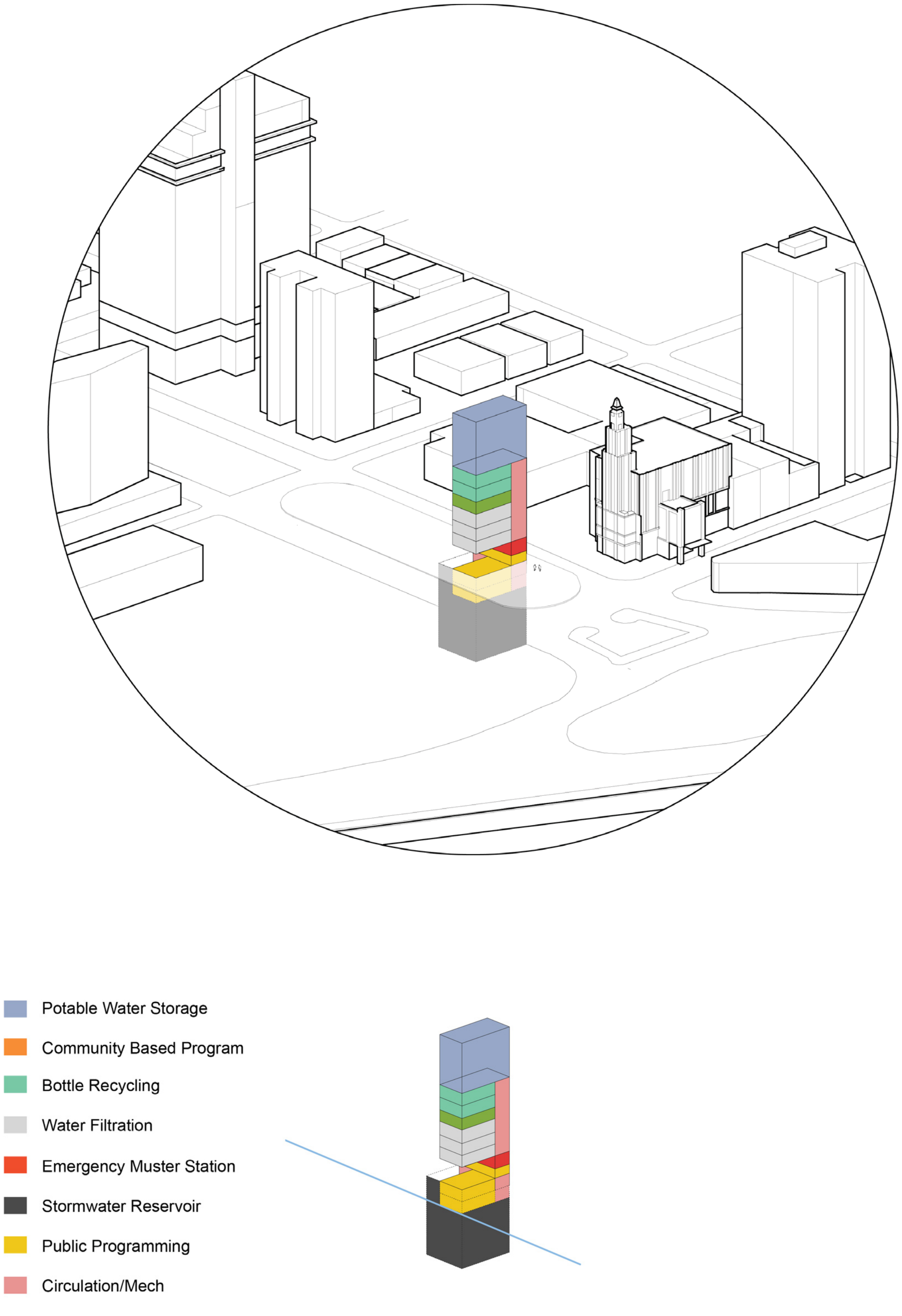
[77] Leeuwen, Reclaimed Water, 19.



Axonometric program diagram shown in its site context in a public boulevard.

processes are occurring to treat their potable water supply. This should increase public awareness of the water infrastructure and help promote conservation. Visible interaction with the stored and processed water should also help people overcome some negative public perceptions towards reclaimed water sources.[78]

Materials and Design Features

This project is envisioned as a monument to water infrastructure. As such, the materiality has been drawn from other monuments that line the boulevards and paseos throughout Havana. Local Cuban limestone and copper typically used in many of the sculptures throughout the city form elements of the buildings facade. Concrete, a widely used material in Havana, makes up the core and structural members. It is finished

From the exterior, a vertical line of glass block rises up the facade of the water tank. Water enters a chamber between the main tank and the glass block wall to produce a meter gauge, indicating to the city the amount of water the building has stored. Copper pipes are integrated into the north and west facades giving users an indication of how the water travels through the building and back out to the city. A copper and steel wrapper covers the glazing on the south and east facades to protect the interior from direct sun exposure. The copper wrapper is imagined as a grate, typical to water and underground infrastructure. The grate appears again on the main piazza allowing filtered water to pass from above to the pool below. The water drops from a sculptural arrangement of copper pipes placed in the center of the ceiling above the piazza.

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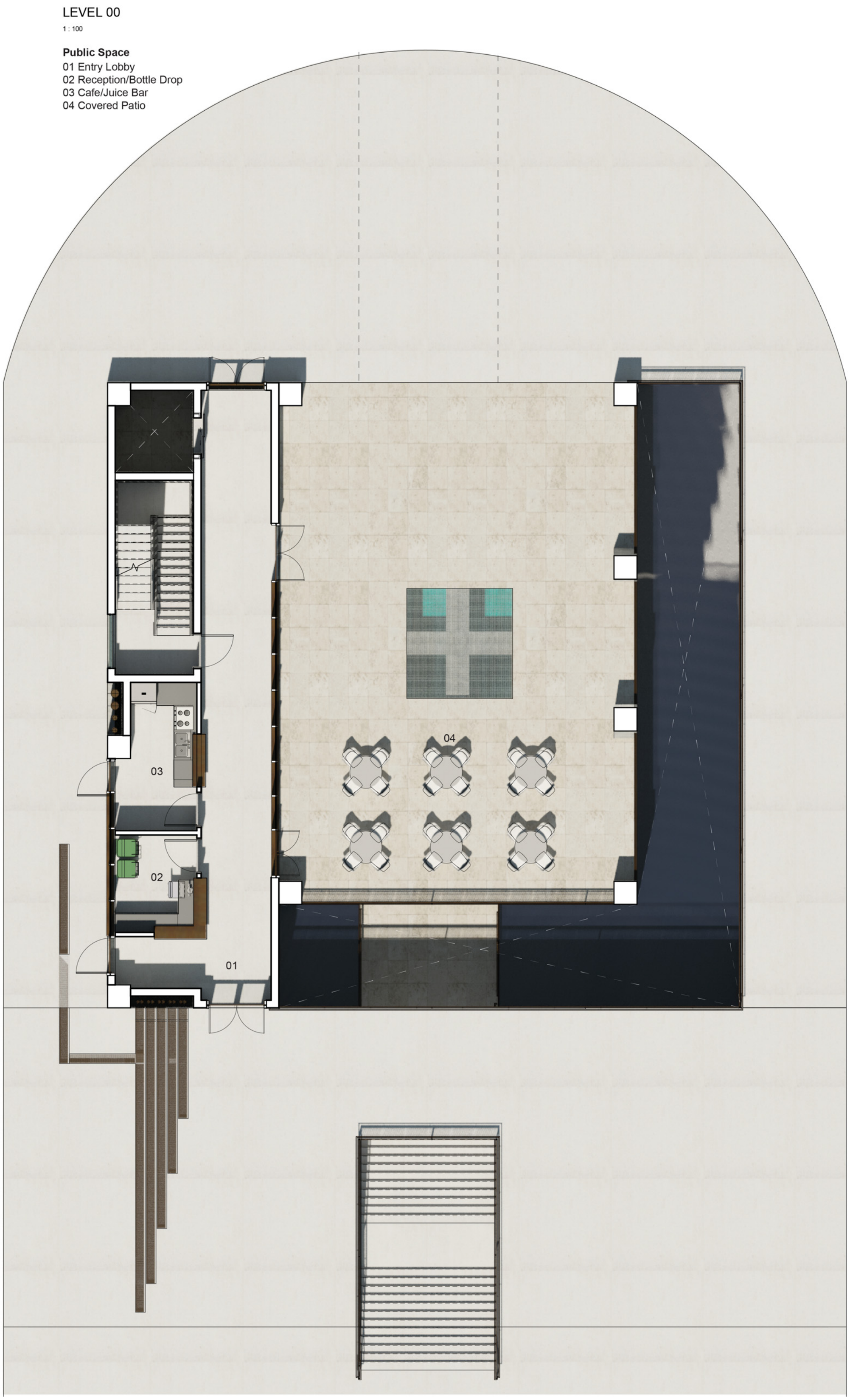
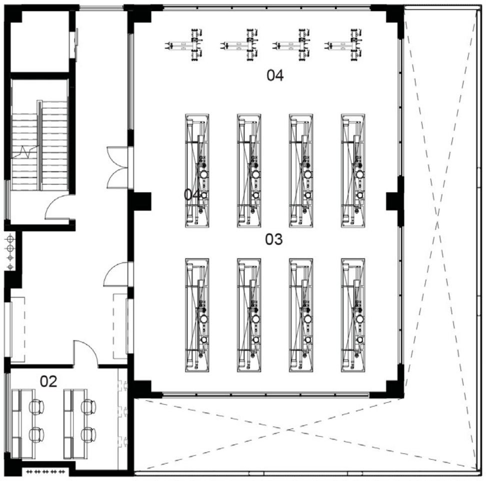
78. Mcardle, et al., Centralised Urban Stormwater, 23.



Main ground floor plan and its position within the boulevard island.

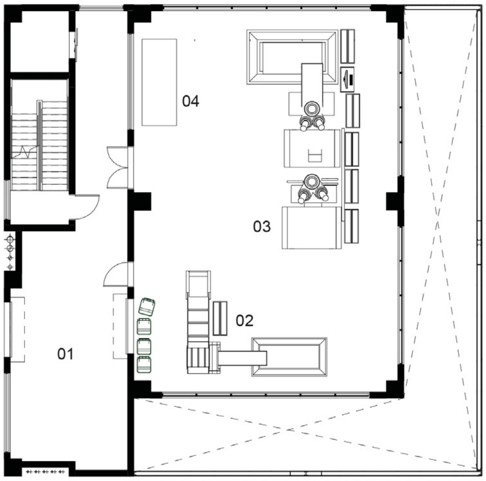


LEVEL 03

1 : 200

Microfiltration

01 Loading Dock/Observation
02 Control Room
03 Reverse Osmosis
04 Ultraviolet

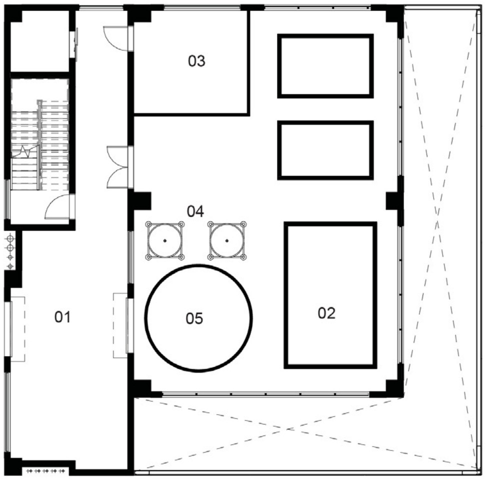


LEVEL 04

1 : 200

Recycling Center

01 Loading Dock/Observation
02 Washing
03 Shredder
04 Extrusion Mold

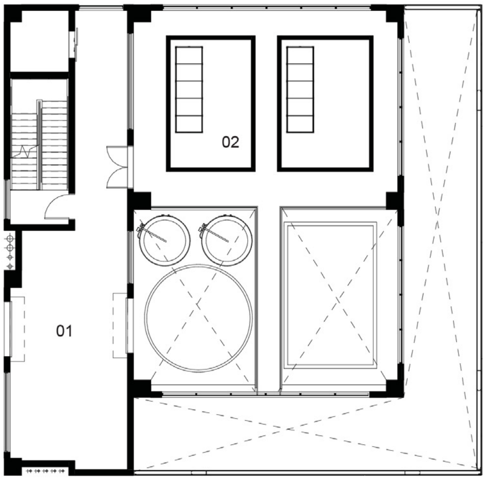


LEVEL 01

1 : 200

Pretreatment

01 Loading Dock/Observation
02 Flocculation
03 Pump Room
04 Chemical Storage
05 Clarification



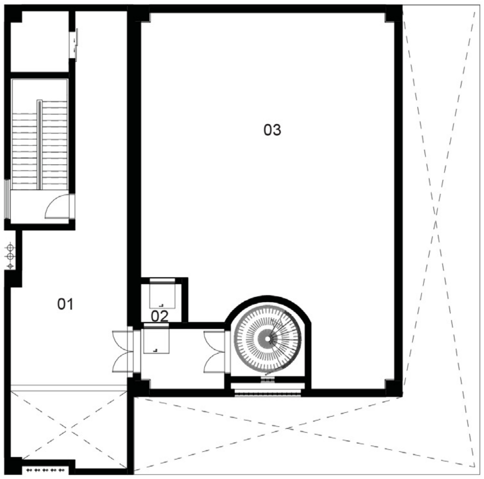
LEVEL 02

1 : 200

Ultrafiltration

01 Loading Dock/Observation
01 Loading Dock/Observation
02 Membrane Bioreactors

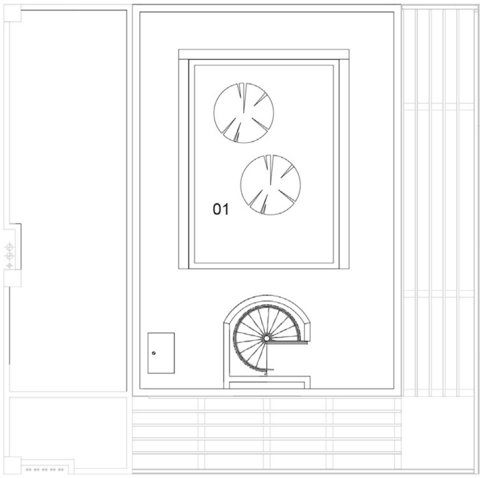
Floor plans and program labels for Levels 1-4.



LEVEL 07

1 : 200

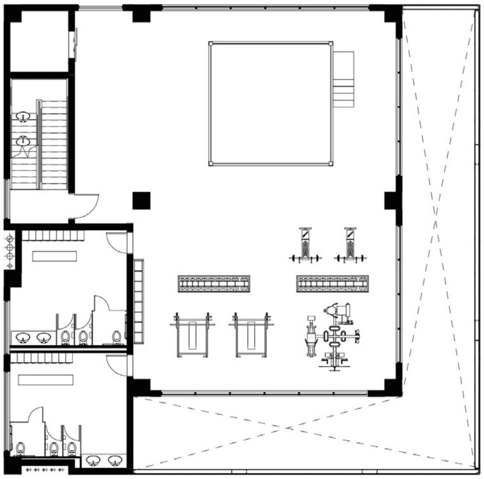
01 Loading Dock/Observation
02 Maintenance/Water Lock
03 Water Tank



ROOF LEVEL

1 : 200

01 Garden/Filter Bed

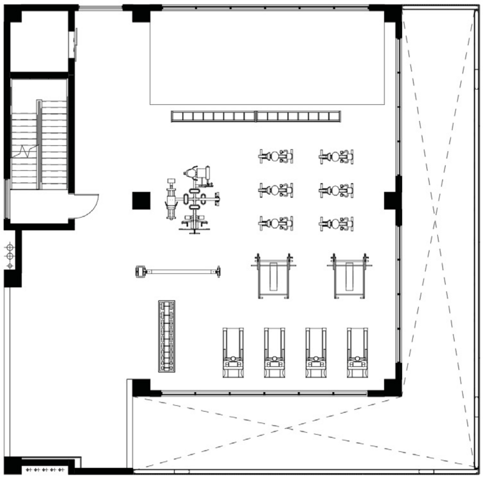


LEVEL 05

1 : 200

Gymnasium

Public Gym/Boxing



LEVEL 06

1 : 200

Gymnasium

Public Gym/Yoga

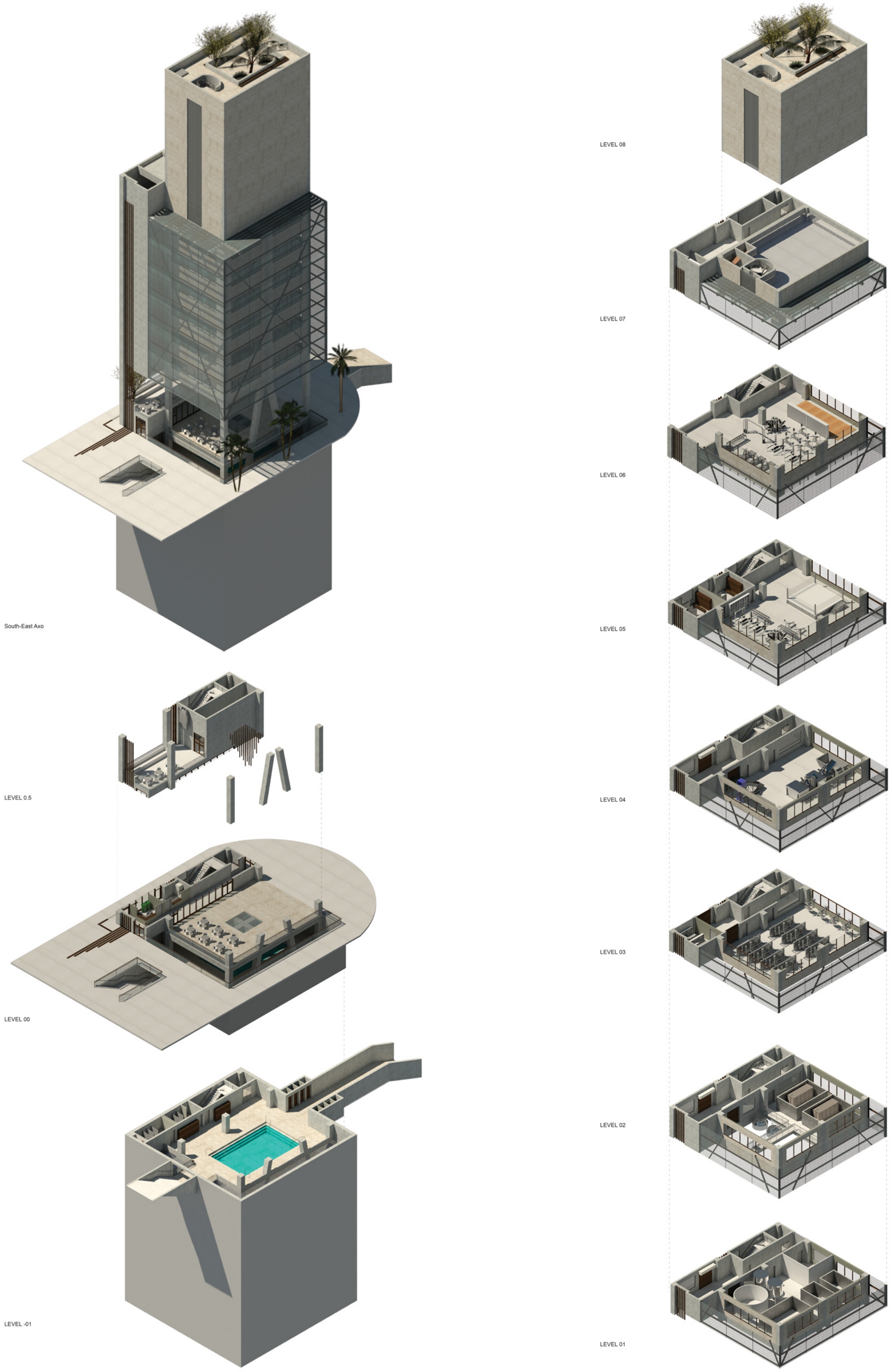
Floor plans and program labels for Levels 5-8.

Main North-South section through building showing raw storage and filtered storage above.

Digital rendering of the the entrance and groundfloor piazza, water is visible trickling through the piazza.

Digital rendering of the lower level bathing area. Water enters the reservoir from stormwater system through a slit in the concrete.

Digital rendering of the the building in its site within a photo of the city.



Exploded axonometric digital renderings.

Sectional model photo. Material Basswood, model Scale 1:200. Photo not to scale.

Axonometric model photo. Material Basswood, Model Scale 1:200. Photo not to scale.

Model photos. Material basswood and mylar, Model Scale 1:200. Photo not to scale.

Model Axonometric and plan photos. Material basswood and acrylic, Model Scale 1:1000. Photo not to scale.

Model plan photo. Material basswood and acrylic, Model Scale 1:1000. Photo not to scale.

CHAPTER 3: CONCLUSION

Stormwater treatment as direct potable reuse has not been tried as a significant source of water. It is clear through the countless water scarcity issues around the world that new sources of water and increased conservation are needed for a sustainable future. This thesis hopes to provide an example of a new source of water by using the already existing infrastructure typical to most large cities. The project attempts to place water into the daily lives of users by highlighting the benefits of water consumption in the puiblic realm. Vast amounts of effort have been dedicated to finding new sources of water, most specifically in desalination. While research into improving desalination has validity it still remains the most costly and energy intesive source of water including treatment of raw sewage.[79] Furthermore, desalination and the like remain alien sources of water to society. Rainwater is a universal part of peoples lives and is a process intrinsically related to survival on earth. Perhaps it is time that contemporary society pays homage to the rain rather than shedding as quickly as possible from our cities.

The solution offered in this thesis is drawn from research in Havana and it has been tailored for this site in many ways. It is conceived however, as a universal solution, capable of being placed in any city that meets the criteria provided in the previous chapter. One can imagine several of these structures along the Los Angeles River for example, awaiting the rain water that will inevitably end up in the ocean while California remains affected by drought. It should be said however, that some difficulties may arise in extremely cold cities where this intervention would have to contend with freezing water. New cities and developments have incredible opportunity to be completely sustainable entities with modern technology. Windhoek in Namibia is an excellent example of a the first city to utilize technology to provide

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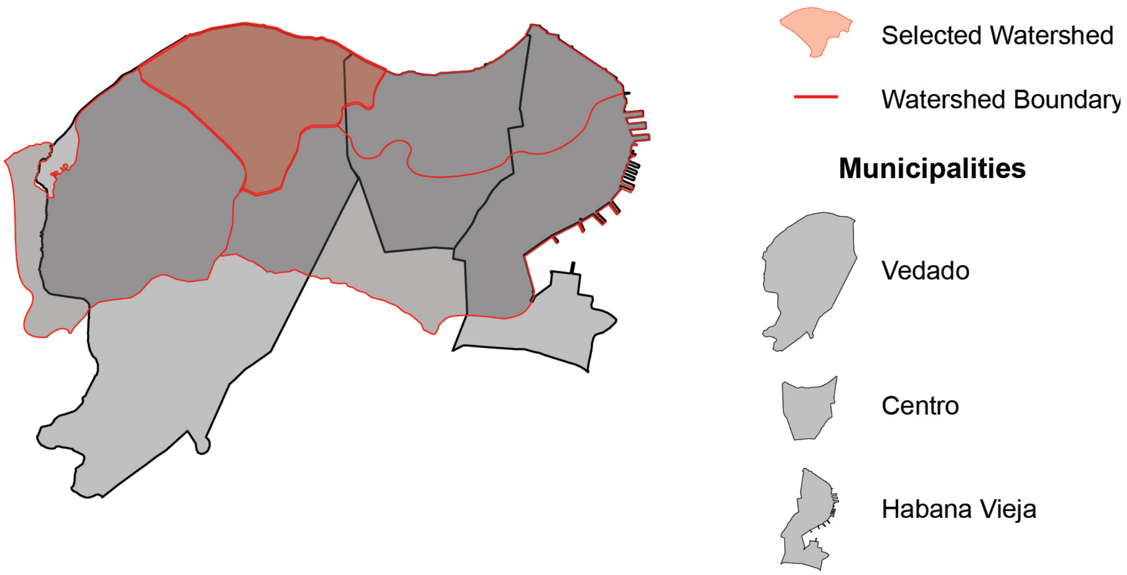
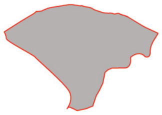
79. Van Leeuwen, Reclaimed Water, 234.

a completely direct potable reuse scheme for all of the cities sewage and water supply. In the future, cities should also reconsider how stormwater is returned to the environment and do so in a way that is public, visible, and beautiful.

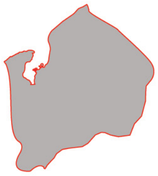
In calculating the average annual rainfall over surface area, it can be seen that the selected site has the potential to produce 5,034,071 m^3/yr. The total potential yield of the four watersheds identified is 23,207,078 m^3/yr. When divided by the average consumption per Habanero of 678.2 m^3/year, a potential 34,218.63 people can be served their yearly water needs. This may seem like a small percentage of Havana’s approximately 2 million people yet this represents collection in a fraction of the area of one city in the country. If the area increases, and more cities adopt such a system, the impact could be tremendous.

Highlighted Watershed Capacities





(3,595,765 m^2) x (1400 mm/yr) = 5 034 071 m^3/yr



(3,795,765 m^2) x (1400 mm/yr) = 5,314,071 m^3/yr

(2,965,278 m^2) x (1400 mm/yr) = 4,151,389 m^3/yr

(6,219,677 m^2) x (1400 mm/yr) = 8,707,547 m^3/yr

Average Rainfall Per Year = 1400 mm

Average Water Consumption 678.2 m^3/yr/per Habanero

Total = 23,207,078 m^3/yr

(23,207,078 m^3/yr) / 678.2 m^3/yr/per Habanero = 34,218.63 people

Water yield calculations based off of annual rainfall and surface area. Data provided by Oficina Nacional De Estadistica E Informacion

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