AquaCalifornia

Water Infrastructure in the Age of Scarcity

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis including any required final revisions, as accepted by my exminers.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

FIG.0.1: San Luis reservoir at only 10% of capacity during drought

Water scarcity has always been a defining issue of the American West; and California is one of the western states that have long struggled with the management of its water resources. Over the past 5 years, California's water system was confronted with one of its biggest challenges, the state's worst drought in 1200 years[1]. A series of natural phenomenon triggered by climate change have caused significant depletion in the regional freshwater supply, leading to the closure of many agribusinesses and a decrease in employment and food supplies. In California, water scarcity is not only an environmental crisis but also affects economic, political and social systems on multiple levels[2].

In addition to climate instability, outdated water infrastructure systems and failure to capture potential water resources are also key contributors to California's water scarcity. Currently, much of the Golden State depends highly on imported water supplies from distant regions. Under the existing drought however, these large-scale water allocation systems are proven to be unreliable as they further unbalance water stress at the source and end-use locations. Locally, a lack of public interest and effective water infrastructures also hindered the capture of stormwater and recycling of wastewater. Many cities in California fail to capitalize these potential water savings and simply direct them into disposal systems; such contamination and waste of runoff represented a valuable but missed opportunity to offset the drought impacts.

The goal of this thesis is to develop a series of decentralized water systems that could focus on capitalizing alternative water resources in

Californian cities, and simultaneously function as public spaces for additional programs in urban areas. This speculative proposal would not only serve as a prototype for future urban developments, but encourage planners and builders to reimagine the urban fabric as part of the larger hydrological system. It also helps reinvent modern water infrastructures to better facilitate urban life and actively engage the public in order to create a paradigm shift in the water consumption culture.

As dry conditions become the "new-normal" of the American West, designers must become more engaged in the sustainability movement and help renegotiate the relationship between the urban fabric and its water infrastructure. Through the assessment and redesign of the current water network, AquaCalifornia proposes a new direction of water infrastructure development to construct a more potent and reliable water future in California.

ACKNOWLEDGEMENTS

The concept of this thesis first formed during a trip to Western United States at the start of the drought years. I was curious to understand the role of architecture in the larger hydrological cycle, but with a limited experience and knowledge in field of waters studies, the development of this thesis is only possible with the support and guidance from the Waterloo Community. Mona El Khafif, thank you for being an important mentor to me throughout the course of this thesis. Your extensive knowledge and constructive criticisms have helped me greatly in clarifying the thesis direction from the start, and your drive and passion in your work has truly inspired me to recognize the potentials of design as an essential force of change. Lola Sheppard, thank you for your consistent mentorship throughout my undergraduate and graduate studies. Your insights and expertise contributed greatly in shaping this thesis, especially the design portion of the project. Your constant support and confidence have continually motivated me to produce the best work I was capable of. Ila Berman, thank you for your time, encouragement and criticisms throughout the process, your comments have been extremely valuable in helping me structure this thesis. John McMinn, thank you for your advices and input throughout TRD2, our discussions have inspired many initial ideas that is crucial to the final design. I would also like to extend my gratitude to my external reader, Fadi Masoud, for his time and insight.

Students and faculty members of the Waterloo Water Institute and the Collaborative Water Program, Simon Courtenay and Mark Servos, thank you all for your guidance and encouragement throughout the collaborative water program. My experience in this program is imperative to the development of this thesis and the conversations with members of the program have greatly enriched my knowledge in the field of water studies, providing me many new perspectives in understanding our environment.

I would also like to thank the many experts and contributors that I encountered and interviewed in California, including Raphael Garcia, Manon Fisher, Marsha Sukardi from SFPUC, Laura Tam from SPUR and Spreck Rosekrans from Restore Hetch Hetchy. Your knowledge and perspectives have helped me tremendously in comprehending the water issues in California and the information you provided is fundamental to the development of this project.

To my friends and colleagues, I am grateful for all your support and your friendships. In the past year, I got many chances to interact and have meaningful conversations with all of you, your talents and perspectives continue to inspired me everyday.

Finally, I would like to thank my family for their unwavering support. Mom and Dad, thank you for taking the many trips with me across California for thesis research, including that very first trip that inspired me to pursue this thesis. I would not have been able to accomplish this without your encouragement and patience.

DEDICATION

For my father, Felix Fung

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FIG.1.1: Folsom Lake during the drought

INTRODUCTION: SCARCITY AS THE "NEW NORMAL"

INTRODUCTION

FIG. 1.2: Scenes of drought in South Africa

Water was once considered as one of the Earth's most abundant natural resources and the most vital element to life. For million of years, the same bodies of water have been sustaining habitats and supporting human civilization. This vital resource is only available for our constant consumption and enjoyment because of the unique ability of the natural hydrological cycle to filter and replenish freshwater through multiple physical processes.[1] In the past century however, human beings began to actively dictate and alter the natural environment in an unprecedented scale. Rapid population growth and urban development initiated some of the most ambitious infrastructural projects to transform the harshest environments into habitable landscapes, adding enormous pressure to natural climatic systems. The resulting climatic shift has severely interrupted essential hydrological processes and led to the destruction of many regional watersheds. While some parts of the world are threatened by excess water, many parts are now struggling with water scarcity, more specifically freshwater shortage. To put this in context, more than 70% of the Earth's surface is covered in water, 3% of it is freshwater and suitable for human uses.[2] In addition to the limited natural supply, water stress is further intensified as human water demand outstrips natural supplies.

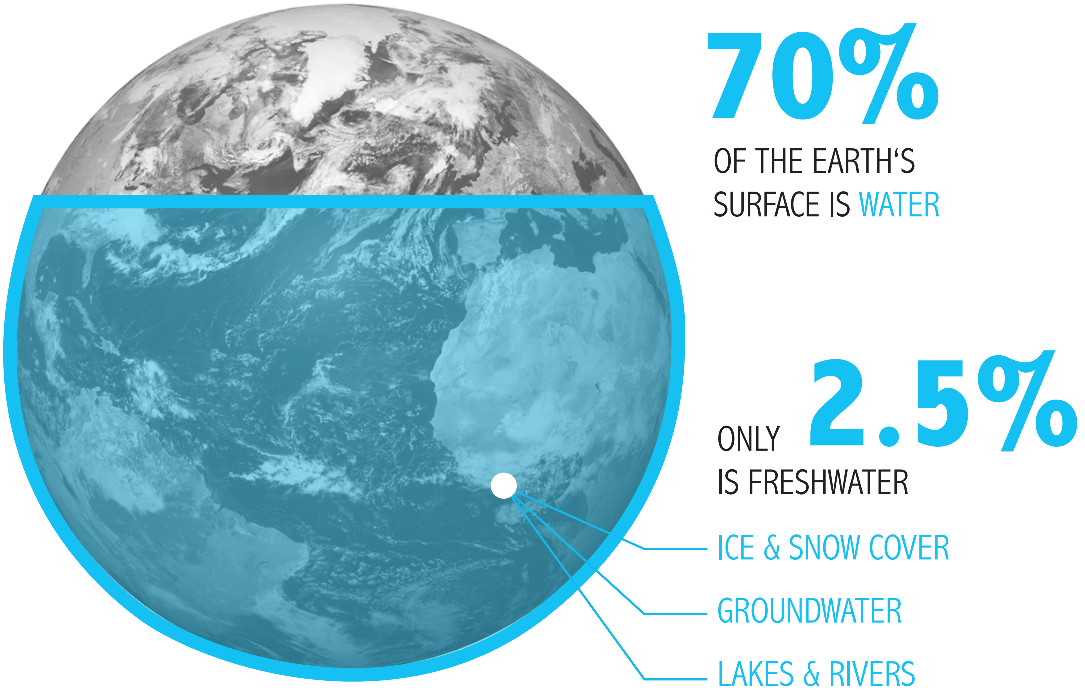
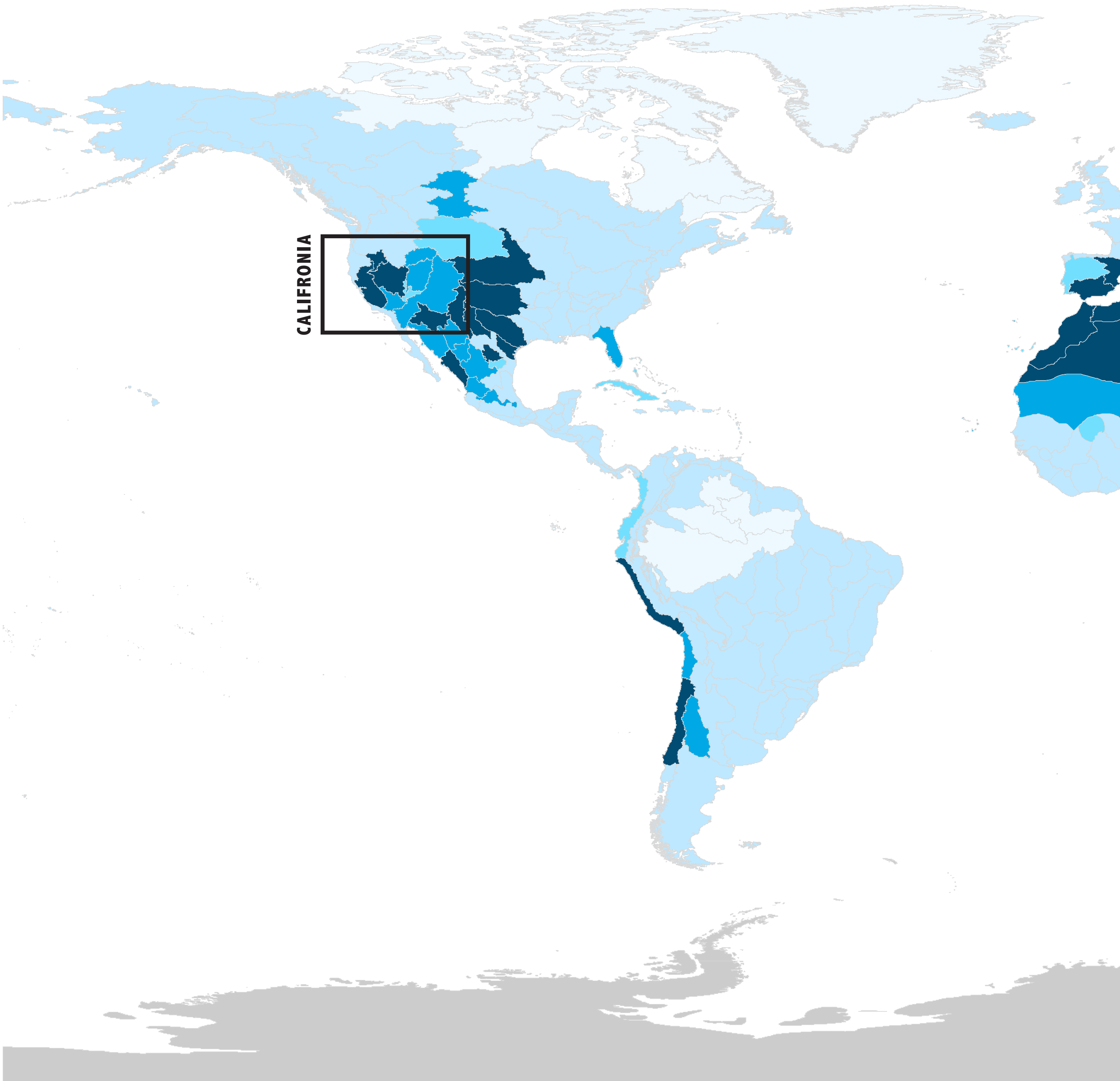
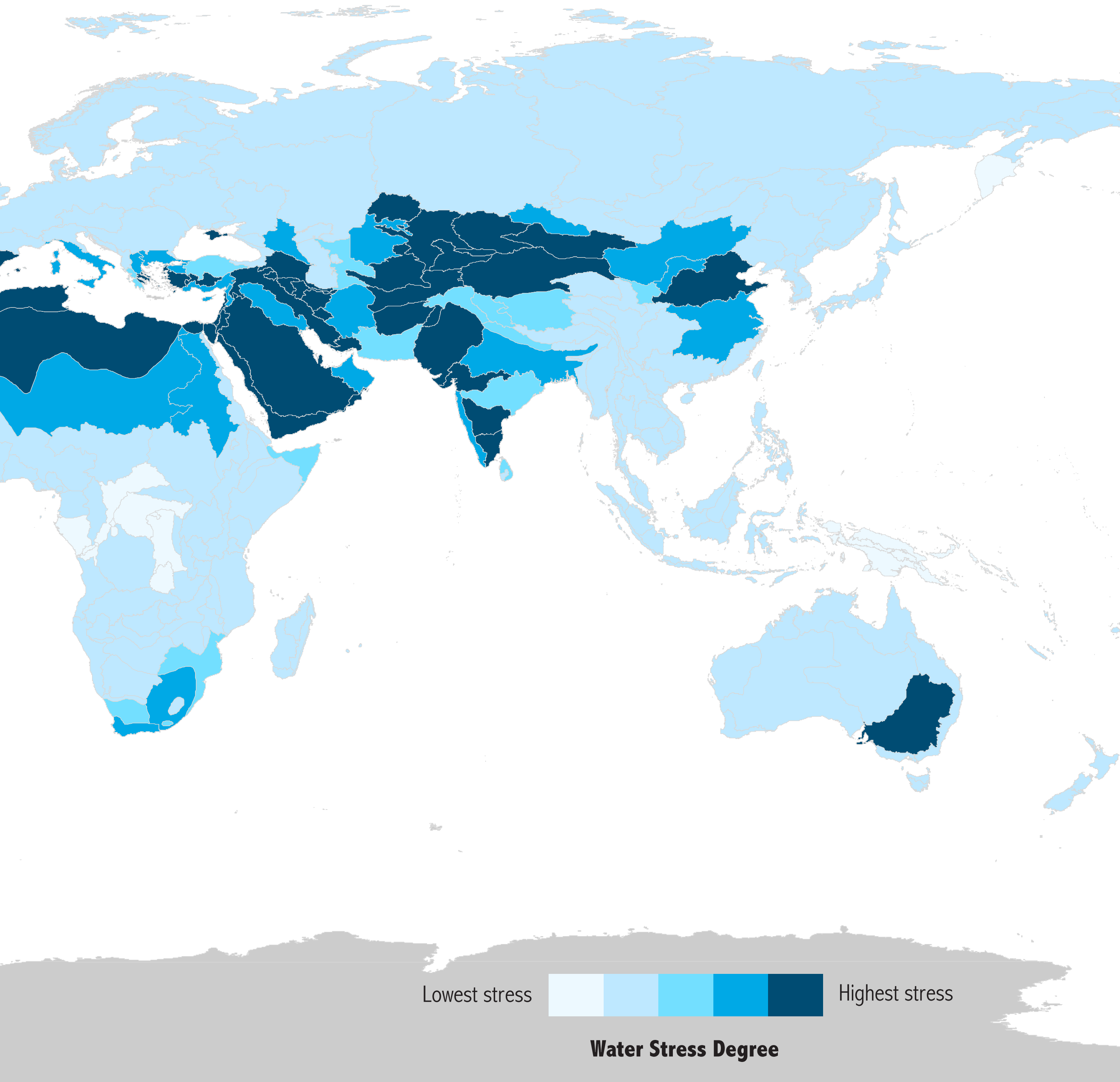


FIG.1.3: Global freshwater content comparison to global surface water content[3]

GLOBAL WATER STRESS

FIG.1.4: Map depicting degrees of water stress by ecoregion where human demand for water outstrips natural supply. Southwest United States is one of the largest water consuming regions globally.[4]




Lowest stress
Highest stress
Water Stress Degree

INTRODUCTION CONT.

Water security has always been a defining issue of the American West; and California is one of the western states that have long struggled with the management of its water resources since the first major Spanish settlement in the State in the 1760s.[5] In an area where aridness is a recurrent pattern of the local climate, water is a valuable resource and California has significantly altered its watersheds to satisfy its water demands. Over the past 5 years, California's water system was confronted with one of its biggest challenges. The golden state has been suffering from a "megadrought", the worst drought in almost 1200 years.[6] By the end of its first year, the drought had already placed 60% of California in an abnormally dry condition and by 2016, almost 70% of the State is under an extreme drought, affecting more than thirty million people living in drought stricken areas.[7] On January 17, 2014, California state governor Jerry Brown officially declared a drought state of emergency.[8] And in 2015, the governor also issued an executive order requiring California cities to cut their water use by 25% in a year.[9] Moreover, the drought is not only limited to California but the entire Southern Western America, meaning multiples states in the region would eventually vie for the same limited amount of freshwater.

FIG.1.5: Lake Oroville in August, 2014.

Although droughts and arid conditions have always been a part of the Western American climate, climate change has greatly intensified the duration, severity and frequency of extreme droughts.[10] Global warming is of course one of the most evident impacts of climate change and it is also the biggest contributor to the dire conditions of this drought. According to both the National Oceanic and Atmospheric Administration (NOAA) and The National Aeronautics and Space Administration (NASA), 2014 and 2015 were the two warmest years on record in California, with the rest of the drought years among the ten warmest years in two centuries.[11] In a study done by Stanford University in 2013, researchers suggested that this rise in temperature, both globally and locally, is the cause of an extreme atmospheric high pressure ridge over the North-eastern Pacific that had blocked the majority of winter storms and precipitation from California.[12] Multiple other studies from the scientific community also point out that record-breaking high temperatures are responsible for an accelerated loss of water into the atmosphere, when surface water is evaporated and moisture in vegetation is transpired at a heightened rate.[13]

FIG.1.6: California drought levels and runoff levels at different regions between 2011-2015

Finally, the warmer winters also cause the Sierra snowpack to melt earlier in spring. While normally western snowpack is at its greatest in April, the snow peak came earlier in the past winters and much of the scarce snow that did accumulate has already melted by March. Less snowmelt in later seasons would mean lower stream flows and water supply in the dry summer months.[16] Ultimately, this combination of unusually low precipitation, shrinking snowpack and shift in seasons have caused a significant drop in surface water runoff. Consequentially, many users in the state, especially farmers in Central Valley turn to the groundwater as an alternative source, but this only adds to the pre-existing groundwater overdraft issue. Almost 6 million people and much of the agriculture business in California depend on groundwater.[17] Groundwater is also a crucial reserve that helps prevent catastrophe during drought periods. However, groundwater withdrawal is poorly regulated in California, there is little guidelines and policies in place to track and control new wells constructions, leading to excess withdrawal in many areas.[18] (see fig.1.8) The problem is so serious that the drop in groundwater table brought about more than 1 foot of land subsidence per year.[19] Furthermore, groundwater overdraft is dangerous because it can take more than a hundred years for groundwater to naturally recharge and Californians are already exhausting this valuable resource at a much faster rate than it can be replenished.[20]

The hydrological cycle is a complex process not limited by physical or disciplinary boundaries and water is an element present in almost all aspects of life. Therefore water scarcity in California would impact every water user in the state. During these drought years, the state saw an alarming increase in wildfires fuelled by dry vegetation and low humidity in the atmosphere.[22] There has also been an alarming deterioration of natural habitats, especially aquatic habitats that pushed many native species close to extinction. Warmer waters have caused diseases to spread more easily in aquatic habitats and have prevented the reproduction of some endangered species. In a stretch of Sacramento River just downstream from the Shasta Dam, water released into the river was so warm that it virtually wiped out an entire generation of endangered winter-run Chinook.[23] The lack of water has also triggered problems beyond environmental concerns, causing direct decline in both agricultural and urban industries. Decrease in irrigation water meant significantly less crop production and more infertile saline soils in America's largest agricultural state.[24]

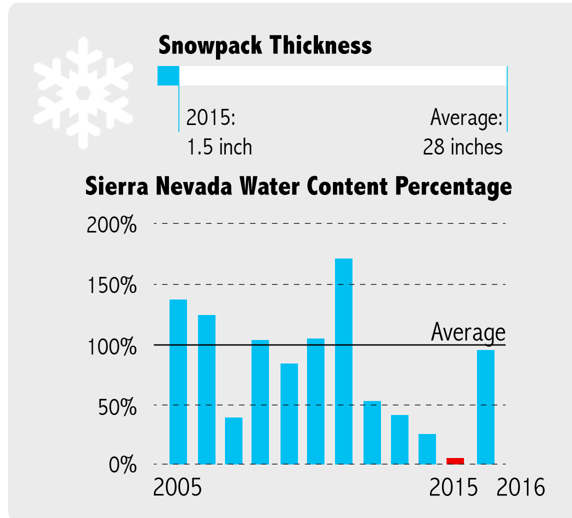


FIG.1.7: Sierra Nevada snowpack data chart showing snowpack water content at only 5% of historic average in 2015. Although there is a significant recovery in 2016, freshwater supply in the recent year was not able to counterbalance the severe drought impacts in previous drought years.[21]

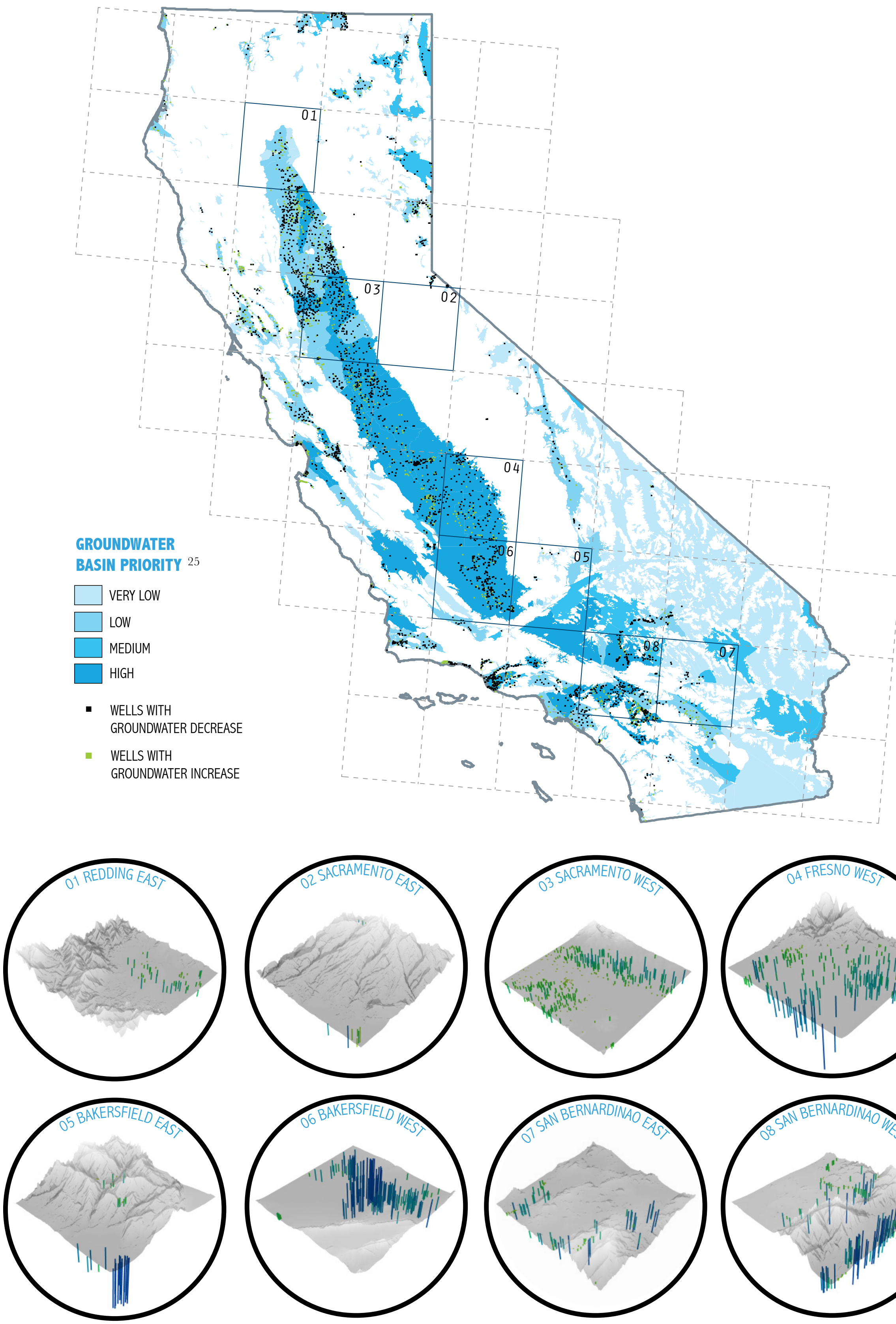


FIG.1.8: Groundwater basins priority map and groundwater wells depth at selected regions.[26]

Closure of many agribusinesses and the unemployment that followed has impacted economic, political and social systems on multiple levels, sometimes even extending its effect to foreign nations. Food prices in general have increased[27] and low-income families are struggling to afford the cost of water supply.[28] The constant drought also left streams, rivers and reservoirs with low water levels, posing immense stress on hydropower systems that depends on stable flows for energy generation.[29] A water crisis of such unprecedented severity is truly threatening every sector in the state and must be responded to with equally comprehensive and holistic solutions.

To fully comprehend the water issue in California, it is not sufficient to simply focus on climate change, because the situation in California is unique in a sense that it is amplified by other forms of human interventions. From the first day of Spanish settlement in California to the establishment of water rights, the infamous water wars to the development of the large-scale water projects and local water collection systems. Cultural, political and economic events throughout California's history have all contributed greatly to shaping the current water situation in the State. In the book *Sustainable Waters: Challenges and Solutions from California*, Allison Lassiter explains the intricate relationship between natural and anthropogenic causes of California's water issues, "The drought is a magnifying glass, revealing that California's water supply system is inflexible and brittle."[30] In the same book Peter Gleick points out that California's water disputes take many forms. "Cities, farms and ecosystems vie for limited supplies. Groundwater overdraft and uncontrolled and unmonitored pumping pit neighbour against neighbours. Water-exporting counties and watersheds have different perspectives from water importing areas. Senior water rights holders have far different worries from junior rights holders. And a mishmash of competing, overlapping, and confusing regulations, and organizations add to the mix."[31] Among these interrelated set of water issues, there are several problems that contributed to the current water stress more directly than the others. These include the state's highly stressed centralized water allocation system, cities' failure to reuse alternative water resources and finally the cultural barrier toward water conservation.

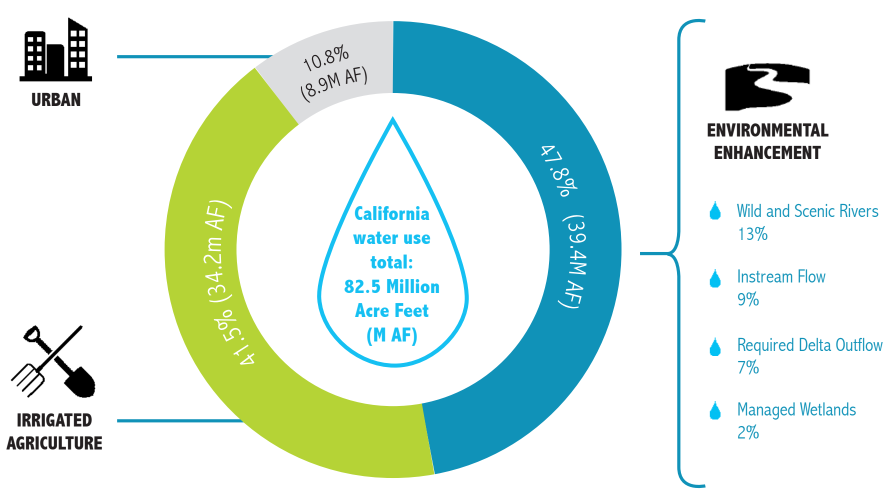


FIG.1.9: California water use percentage and volume divided among users. [32]

CONSTANT DROUGHT COULD WIPE OUT

18

NATIVE SPECIES OF FISH [33]

THE DUST BOWL EFFECT

INCREASING NUMBER OF DUST STORMS [35]

$2 BILLION worth of HYDROELECTRIC POWER LOSS between 2012-2015 [34]

FOOD PRICES MAY CONSEQUENTIALLY RISE BY

10%-15% [37]

$810 Million lost due to **564,000** Acres left unplanted/ idle in 2015 [36]

WILDFIRE OCCURANCE INCREASED OVER THE LAST 5 YEARS [38]

17100 FULL TIME PART TIME SEASONAL JOBS LOST [39]

MOST IMPACTED CROPS [40]:

RICE
ALFALFA
CORN

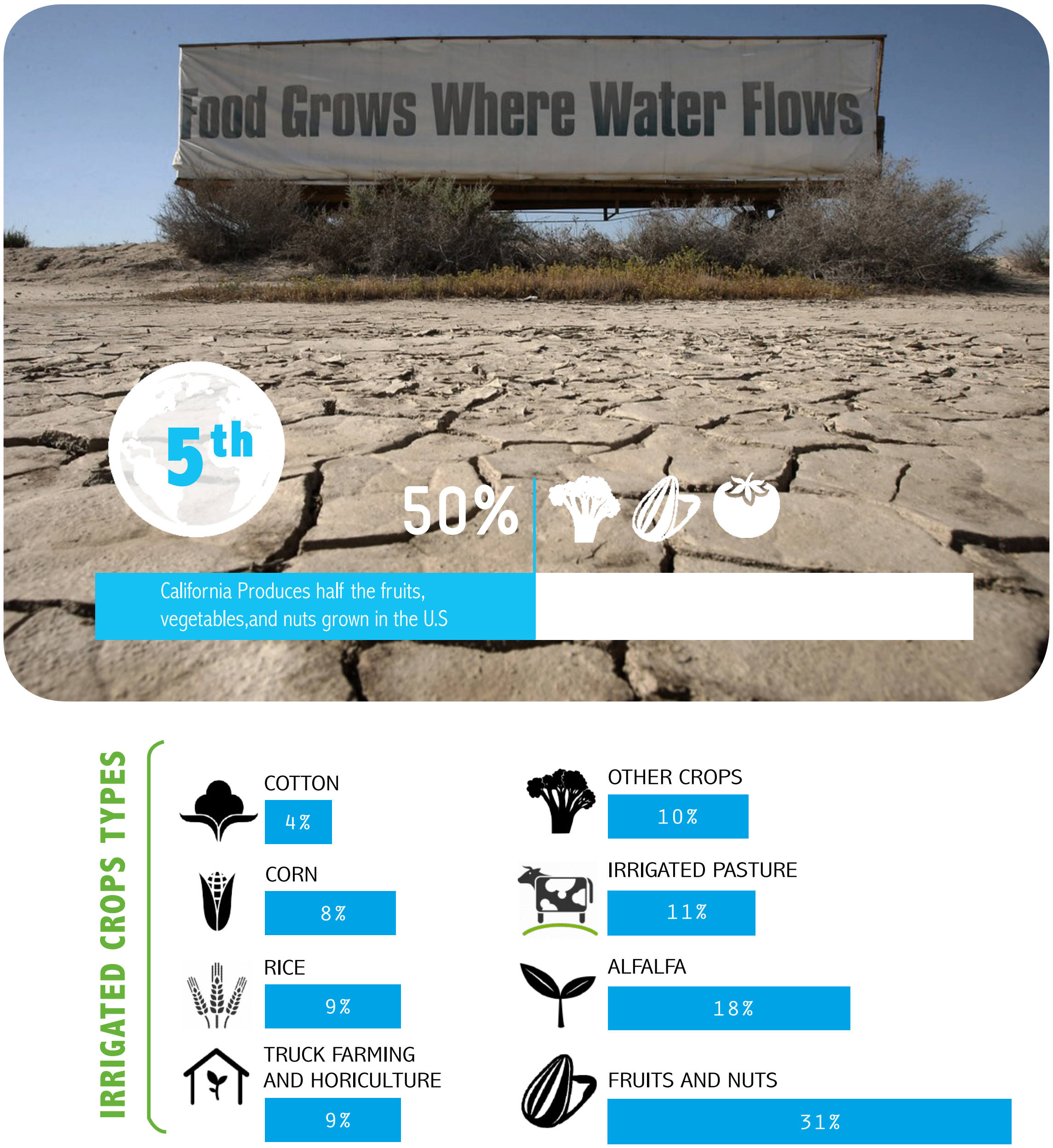


FIG.1.10: California Agri-business
California is the world's 5th largest supplier of food, cotton fibre, and other agricultural commodities.[41] While water is consumed in a range of agricultural processes, the highest water use is for irrigation of crops. Among all crops, fruit and nuts consumes the most water. The growing of nuts is particularly controversial during the drought as it considered a highly water-intensive crop.[42]

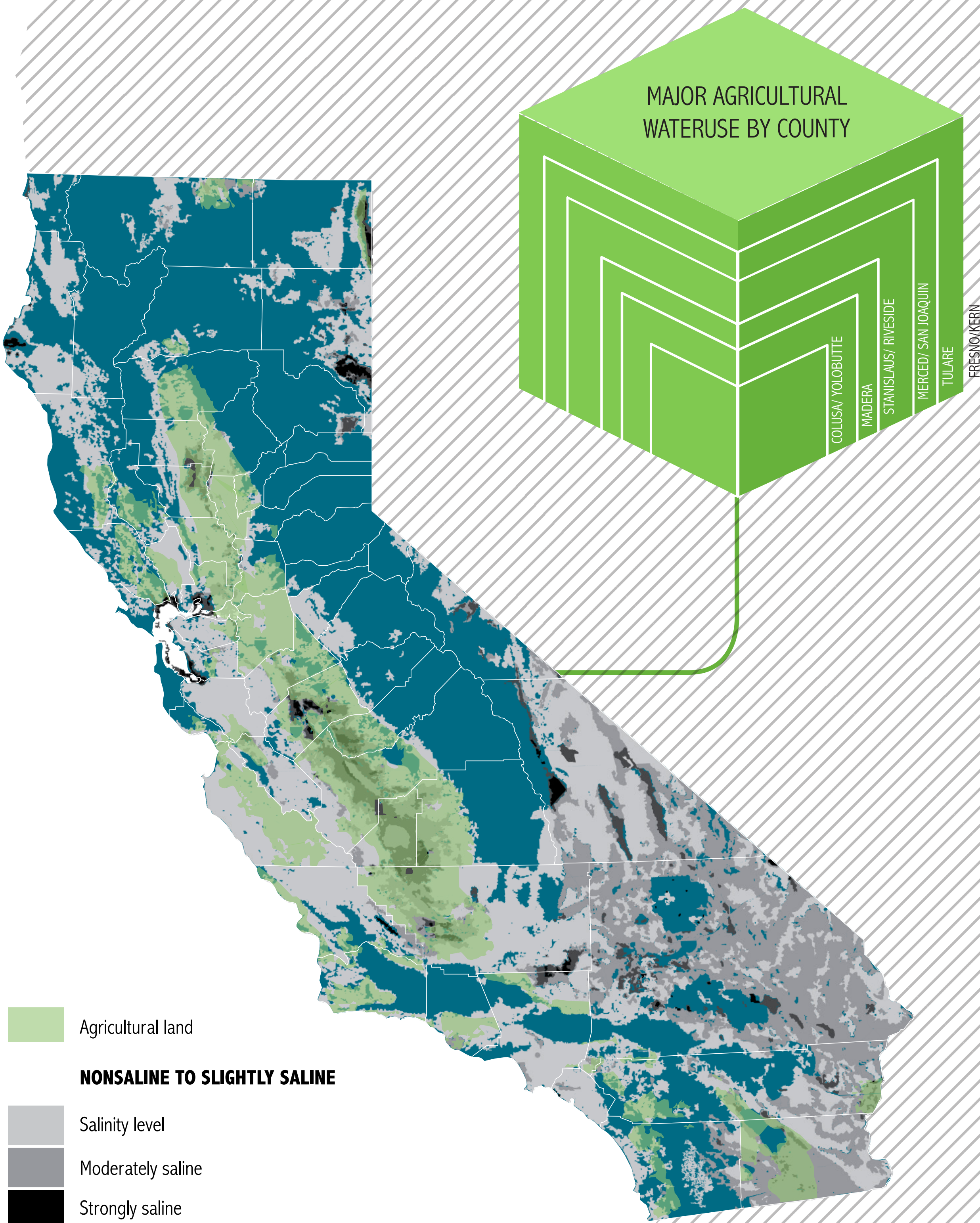
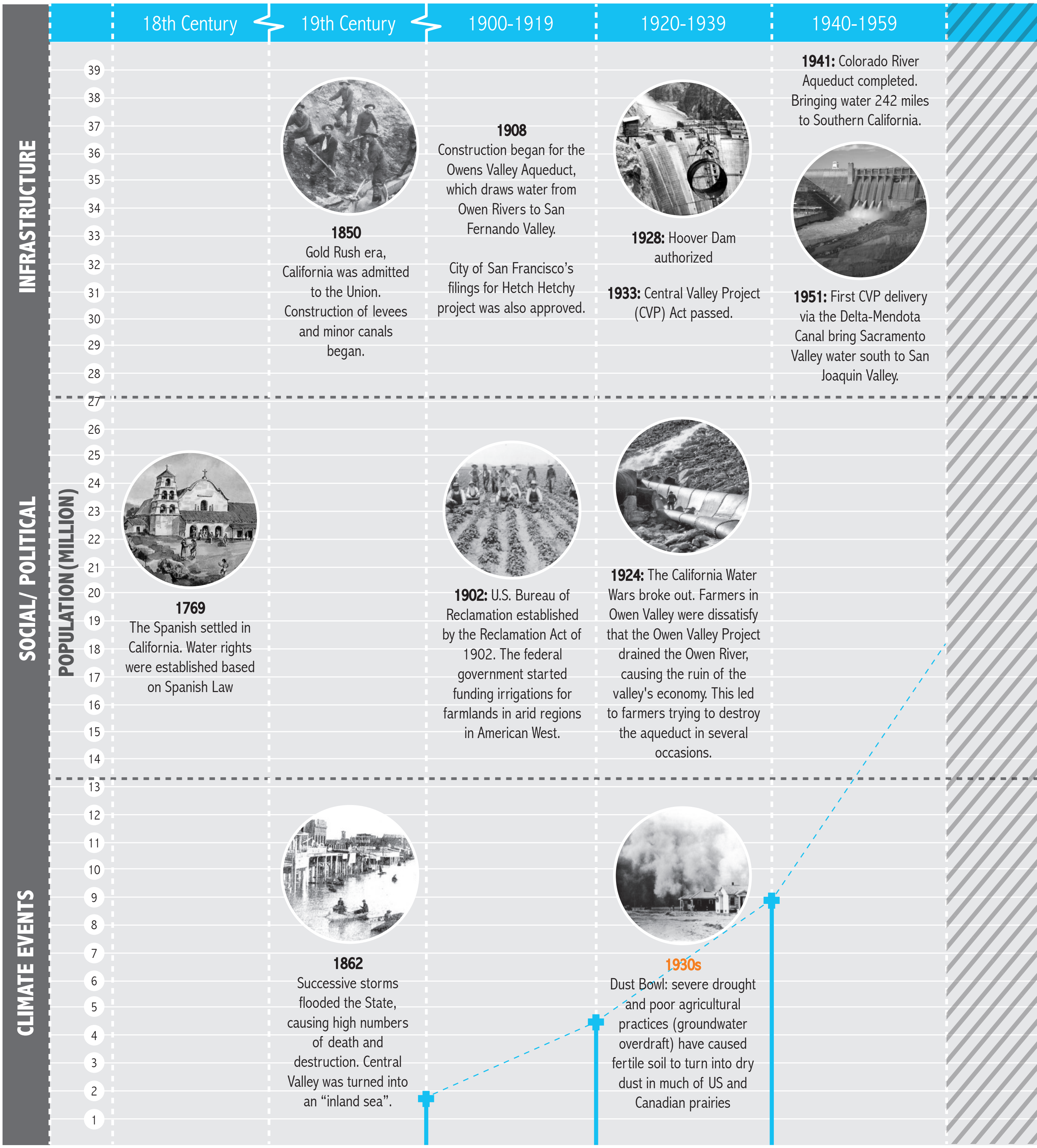


FIG.1.11: Map showing locations of major agricultural land in California vs. land impacted by different salinity levels. Increased salinity is caused by a combination of groundwater overdraft and accelerated evaporation, removing moisture and depositing salts in the process.[43]

CALIFORNIA WATER HISTORY

FIG.1.12: Series water events in California and in the United States that shaped the current water landscapes, together with population growth in the State. Years in orange represent drought- related events.[44]



1960-1979 | 1980-1999 | 2000s | 2010s

1960-1979

FIG.1.16

1960: State Water Project (SWP) authorized.

1971: State Water Project’s California Aqueduct began moving water from Northern California to Southern California

FIG.1.20

1972

Clean Water Act passes. It is a federal law governing water pollution in America. Around the 70s, there is a growing awareness and concern for controlling water pollution.

FIG.1.26

1976-1977

Two year severe drought in California. 1977 is the driest year on record.

1980-1999

FIG.1.21

1982

Rejection of the Peripheral Canal proposal. The canal is a recurring proposal to divert water from California's Sacramento River, around the periphery of the San Joaquin-Sacramento River Delta through an underground aqueduct.

1986

Drought in southeastern United States starts. It is one of the country's worst droughts. Its severity was unprecedented.

1987-1992

Six-year drought in California.

1997

The state’s second most devastating flood of the century.

2000s

2005

Update to The State Water Plan, identified the greatest opportunities to expand water supply from conservation, recycling, and groundwater management.

FIG.1.22

2008

Governor Schwarzenegger declared a statewide drought and emergency in nine counties across the state.

Bay Delta Conservation Plan initialed by the Department of Water Resource, a plan similar to the Peripheral Canal, which may further move the freshwater-saltwater interface inland in the Delta.

2010s

2013

Lake Oroville summer water level: 60%
Shasta Lake summer water level: 53%

2014

Lake Oroville summer water level: 35%
Shasta Lake summer water level: 34%

2015

Lake Oroville summer water level: 33%
Shasta Lake summer water level: 44%

2016

Lake Oroville summer water level: 65%
Shasta Lake summer water level: 78%

2017

Significant surface water recover across the State following multiple winter storms, but aquifers remain highly depleted.

2013: Governor Jerry Brown releases the Five-Year Water Plan that focus mainly on water conservation.

FIG.1.23

2014

Governor Jerry Brown declared a drought State of Emergency in January 2015 and imposed strict conservation measures statewide, including ordering cities and towns across California to cut water use by 25%

2015: The State ordered the largest cuts on record to farmers holding some of the state’s strongest water rights.

2010

Snowpack returns to content level according to Department of Water Resource.

2012

California’s snowpack found to be far below normal levels.

FIG.1.27

2015

Parts of San Jose River dried up

FIG.2.1: The Glen Canyon Dam was affected by the drought

WATER CHALLENGES OF THE AMERICAN WEST

WATER HIGHWAYS

FIG.2.2: Part of the California Aqueduct in Central Valley

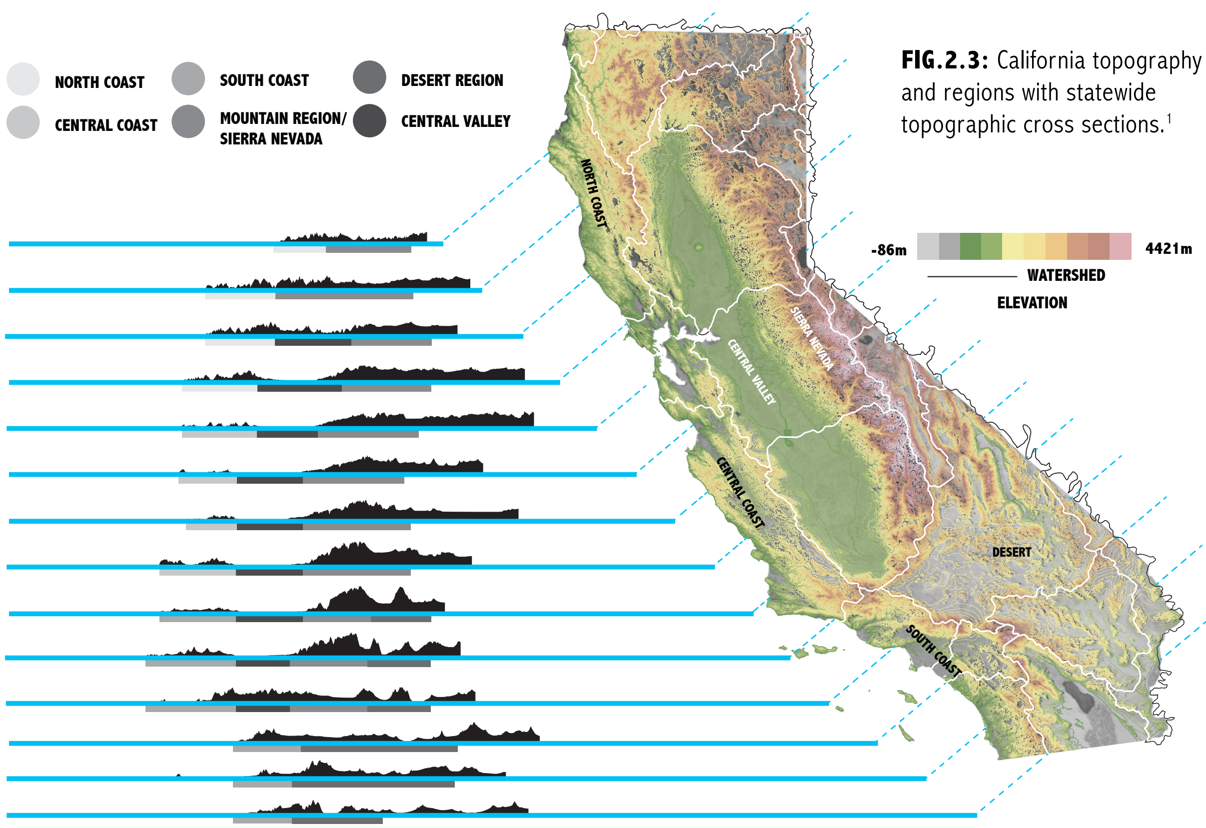


FIG.2.3: California topography and regions with statewide topographic cross sections.[1]

The building of large-scale water infrastructure in California began at the turn of last century and peaked during the Great Depression. Theodore Roosevelt, The President of the Great Depression era, believed that these projects could provide the much needed irrigation water for arid western lands, and serve as economic stimuli, generating employment, energy, and investment opportunities to restart the American economy.[2] Within a hundred years, there are already more than 1400 dams and 1300 reservoirs built in the nation, including the Hoover Dam, the Grand Coulee Dam, the Oroville Dam among others.[3] However, the most significant water infrastructural typology found in the state is the thousands miles of aqueduct and canals, essentially a network of water highways constructed to transfer water from one region to another for freshwater supply. These massive networks were initially constructed to overcome California's inherent water supply challenges created by the State's wide range of topography. The highest point of California is located at the northeast Sierra Nevada mountain ranges, and the lowest point of elevation is located at the Death Valley in the southern arid region.[4] With drastically distinct topography, each part of the State is exposed to very different microclimates and receives various levels of precipitation seasonally. Therefore freshwater in the state is mostly dependent on snowmelt from the Sierras that enters the watersheds. Lakes and major rivers such as the Sacramento River and San Joaquin River are also formed along these watersheds and become sources of freshwater.[5] Nonetheless, in areas such as the southern desert and Central Valley where climate and soil conditions do not allow for natural water accumulation, freshwater has to be imported from distant regions. This need for water importation eventually drove the development of massive water transfer structures such as the Central Valley Project and the State Water Project, the two largest centralized water deliveries systems that transfers water from the more water-rich Northern California to the South.[6] (see fig.2.6-2.10) Water is also imported from outside the State in some instances, such as the Colorado River Delivery System which supports 37% of Southern California's urban water use and 92% of the southern counties' farm irrigation water. The system draws from the Colorado River whose water resources is split between multiple South-western states.[7] These multiple federal, state and local water allocation systems certainly played an important role in the development of the state, allowing extensive urbanization in previously harsh and unlivable territories, and more importantly facilitating the rapid agricultural growth in the Central Valley. "Agriculture was California; there were no sprawling defense and aerospace industries, there was no Silicon Valley. To give it all up was unthinkable, even if it was the middle of Depression. The rescue project (Central Valley Project) which the legislation approved in 1933, was not only bold, it was almost unimaginable. If built, it would be by far the biggest water project in history. It would capture the flows not just of the San Joaquin River, which drained the southern half of the Sierra Nevada, but of the Sacramento, which drained the northern half and some of the Coast Range"[8] These massive water projects boosted the agricultural industry in the Central Valley, turning California into the most productive state

FIG.2.4: the California Aqueduct in the Mojave Desert near Palmdale CA

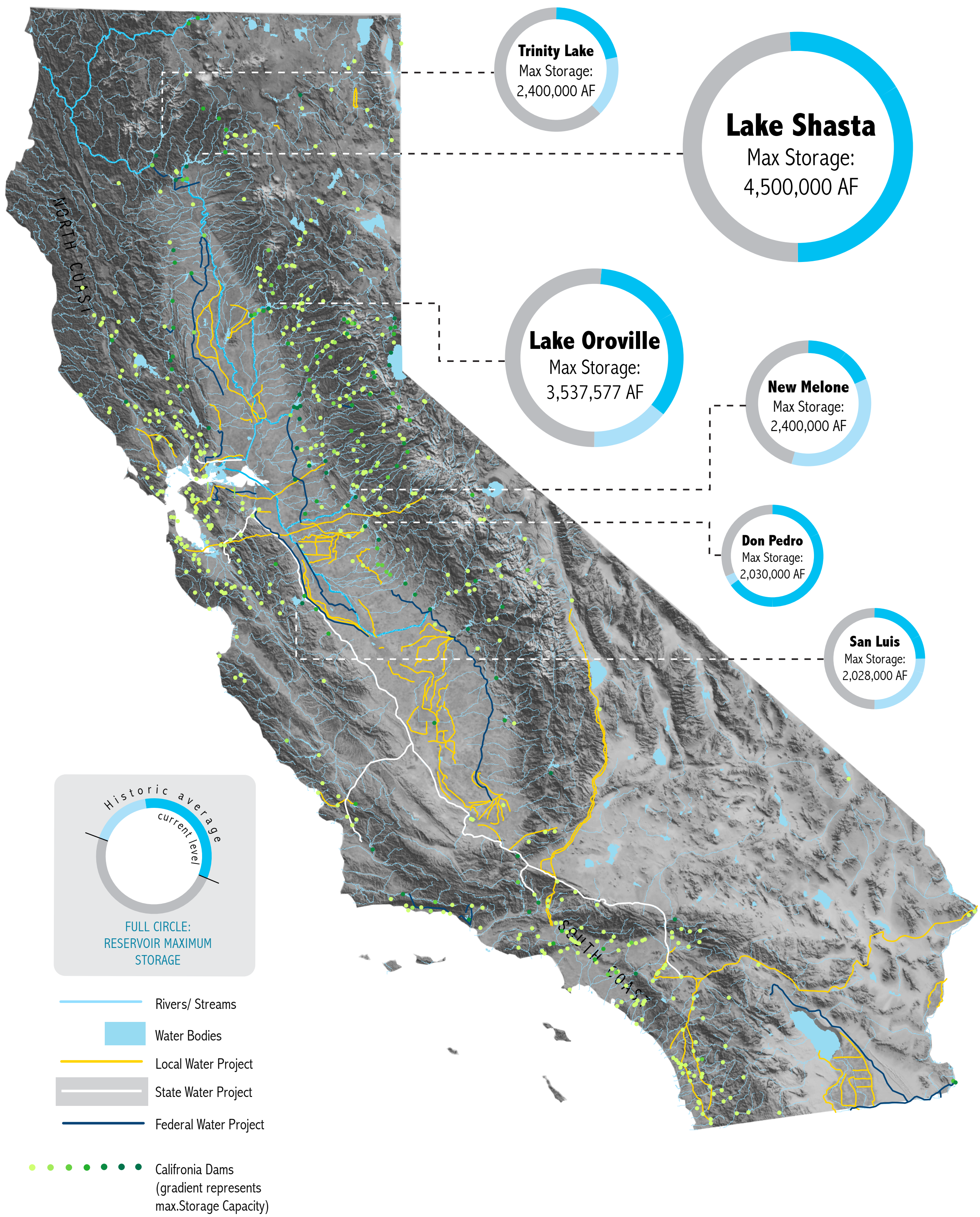


FIG.2.5: California water landscape map[9] and reservoir storage levels[10] as of summer 2016. Units in Acre-feet.

STATE WATER PROJECT

FIG.2.6: State Water Project (SWP) was constructed in stages from north to south. There is a total length of approximately 700 miles of canals and pipelines in the project and the total reservoir storage is approximately 5.8 million acre-feet of water. Lake Oroville is the main reservoir facility in the project, and the Oroville Dam is the tallest dam in United States. The California Aqueduct is the main water transfer infrastructure in the project and it is also shared with the federal Central Valley Project.[11]

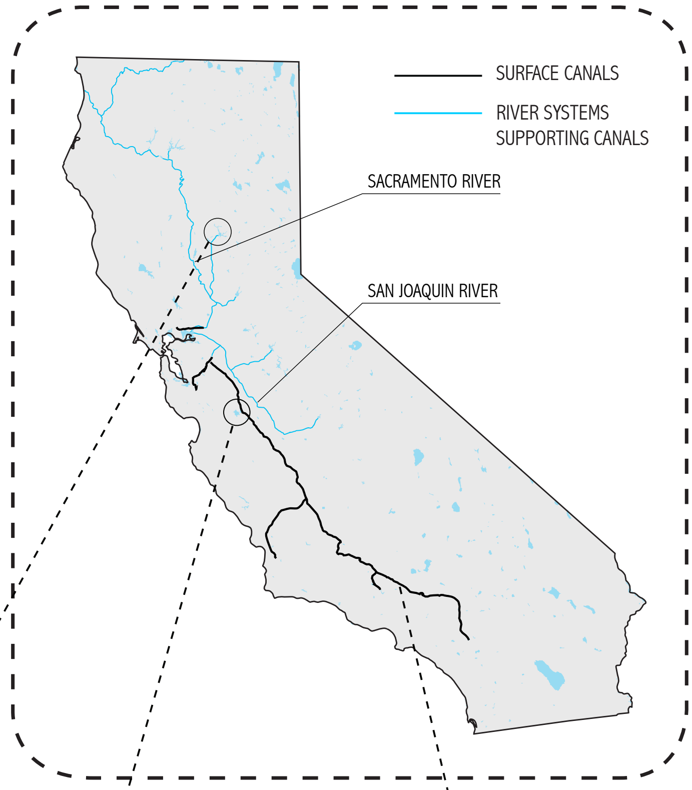


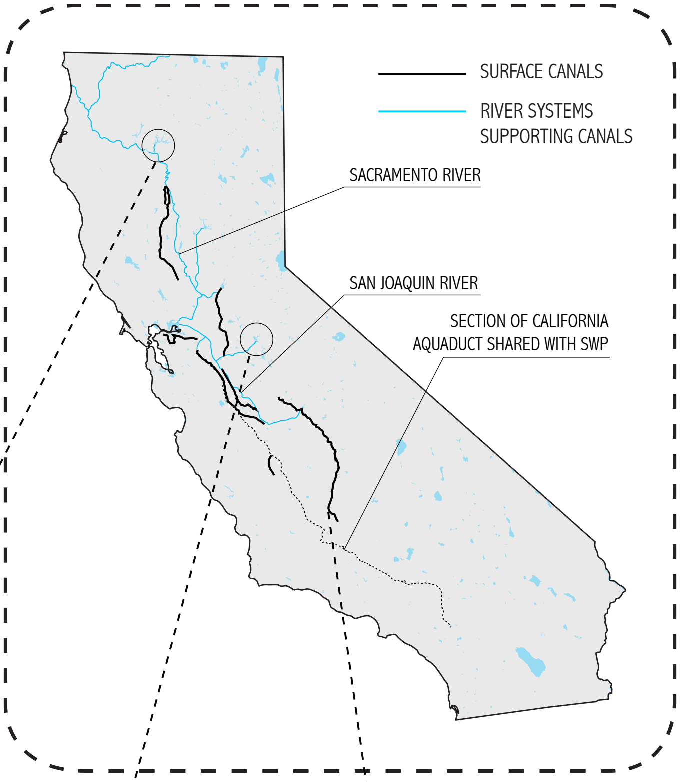
FIG.2.7: OROVILLE DAM SPILLWAY

FIG.2.8: SAN LUIS RESERVOIR

FIG.2.9: CALIFORNIA AQUEDUCT

CENTRAL VALLEY PROJECT

FIG.2.10: The Central Valley Project extends about 400 miles through California. It consists of a network of dams, reservoirs, canals, and hydroelectric power plants. Shasta lake is the main reservoir and The construction of the CVP began in 1938 with the construction of the Shasta Dam. Different from the SWP, the aqueducts in CVP are more distributed and depends highly on river systems as part of the water transfer process. Currently, the CVP delivers an annual average of 5 million acre-feet of water for farms, and 600,00 acre-feet of water for municipal and industrial uses.[12]



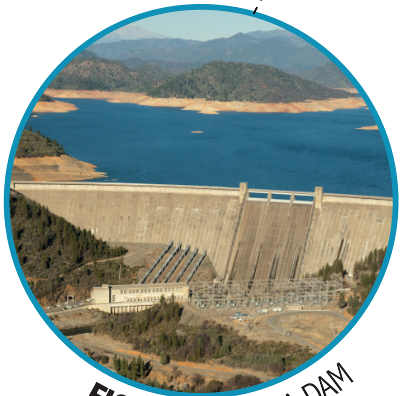


FIG.2.11: SHASTA DAM

FIG.2.12: NEW MALONES LAKE

FIG.2.13: FRIANT- KERN CANAL

WATER HIGHWAYS CONT.

in the nation and bringing major economic gain to the region. However, as population grew and arid conditions worsened, the shortcomings of these systems started to emerge. The deficiencies of centralized infrastructure systems is highlighted in Pierre Belanger's *Landscape as Infrastructure*, " If Roosevelt's dams and Eisenhower's highways represent the zenith of the civil engineering through the might of American presidents and federal public works, then their wear-and-tear, their breakdown, should reflect the impermanence of that might and warning of power…Today the externalities of the industrial economies of scale that underlie civil engineering practice are stress tests of centralized infrastructures showing signs of irreparable wear, hazardous risks, fiscal failures, and environmental spillovers."[13] In the book *Water 4.0: The Past, Present and The Future of the World's Most Vital Resource*, author David Sedlak looks more specifically into the water developments throughout history and compares the ancient Roman aqueducts with the modern California water system, a comparison that highlights the deficiencies in the Californian model. "Much of the knowledge that Roman engineers has acquired on subjects such as matching water sources to their ultimate uses, surviving droughts by establishing priorities for water deliveries among users, and separating wastes to facilitate more efficient recycling is forgotten in the rush to build bigger and better water systems. Perhaps the rediscovery of some of the Roman approaches will help us design Water 4.0."[14] (see fig.2.14) The major issue that exists within the California model is the single- purpose nature of most projects, often designed to serve a very particular group of users and lack the complexity to respond to changing needs. As a result, when natural water resource diminishes, water supplies that are highly dependent on these allocation systems become unreliable. On one hand, the withdrawal of water creates extra water stress at its original sources, damaging the ecosystem and stripping away access of water for population at the source location. On the contrary, regions on the receiving end continue their unsustainable patterns of consumption regardless of water shortage and become less adaptive to local hydrological changes. Given these limitations of centralized water systems, Californian agencies should move towards more localized systems under the current drought. Although there are a few examples of these smaller, localized systems, such as living machines[15] and water purification facilities[16], being implemented in selected cities. It is still very typical to see investments being poured into large and expensive infrastructural projects as drought responses. One controversial proposal is the peripheral canal supported by multiple California governors, a centralized underground pipeline that feeds water from the Sacramento-San Joaquin Delta to the existing California Aqueduct.[17] If built, the project could provide more water for the south, but the removal of large amount of freshwater at the Delta would interrupt the natural freshwater barrier and greatly intensify saltwater intrusion to inland aquifers, damaging local wetland habitats, salinizing regional farmland and displacing vital water sources for northern farmers.[18]

300 BCE

WATER 1.0

The earliest prominent water innovation, the aqueduct distribution system, was invented by the Romans. The gravity-driven piped water system and sewers model were replicated for centuries and served as inspiration to water systems in European cities during the age of industrialization and even the massive water systems in California today.

PRESENT/ FUTURE

WATER 4.0

Water 4.0 looks into the water condition in current society which is characterized by water scarcity. Water shortage have forced cities to look into alternative water supplies, including conversion of seawater into drinking water (Desalination) and purification of wastewater effluent. However, these systems alone are not going to solve the issue of water scarcity. The future of water requires even more innovative interventions, and maybe a reinvention of the existing urban water systems.

FIG.2.14: First generation of water infrastructure compared to current water challenges according to the book *Water 4.0: The Past, Present, and Future of the World's Most Vital Resource*[19]

DOWN THE DRAIN

FIG.2.15: Wastewater effluent discharged to California beaches

Despite the major role centralized water deliveries play in California's water issues, it is not the only cause of the high water stress. In a period where every drop counts, it is unfortunate to see water still being exploited and disposed carelessly, "Leading analysts of all the major domains- water, food, material resources and energy- tell us that our global industrial and financial models, based largely on the assumption of endless growth, are taking human society to the brink of a series of chronic shortages and insecurities."[20] Water shortages however could be more threatening than other resource shortages because there is no alternative to freshwater; there is no way to generate new water.[21] The closest processes to water generation is either desalination or water reuse. In 2015, North America's largest desalination plant opened near San Diego, California. The plant is capable of purifying tens of millions gallons of water per day, to support 7% of San Diego county's water demand.[22] While desalination may seem to be an ideal solution to the drought, desalination plants can often pose severe damage to coastal environments and are both uneconomical and energy intensive to operate. "Its (desalination plants) price tag is at least four times the cost of obtaining "new water" from conservation method… Desalination has substantial impact that many people have not recognized. The process requires lots of energy; each acre-feet (AF) produced requires from 2,500 to 29,500 kilowatt-hours of electricity. It takes about two gallons of seawater to produce each gallon of freshwater. Along with freshwater, a concentrated brine waste is generated."[23] Water reuse on the other hand maximizes the potential

of readily available water resources and avoids wasteful consumptions. As Davis Carle points out in *Introduction to Water in California*, “Consider how much water is, right now, within the bodies of millions of people-millions of small “reservoirs” that add up to amazing quantity of water. That urban water is in place, where it is needed. Through recycling, it can be reused again, again and again… Recycled water is a drought- proof source of supply, because it is already in hand and affected very little by weather cycles.”[24] Nevertheless, after many years of education and promotion in Californian cities, there are still a lack of public interest and effective water infrastructures to facilitate the capture and reuse of alternative water resources. Funding issues and inefficient bureaucratic processes also further sets back the implementations of water recycling projects.[25] High quality freshwater often enters into open-loop systems, and is discharged into natural water bodies after minimal use.[26] The disposal and waste of this runoff does not only seriously contaminate coastal environments, it also represents a valuable but missed opportunity to offset the severe drought conditions.

OUT OF SIGHT, OUT OF MIND

FIG.2.16: Soapy water flows into a drain at Divisadero Touchless Car Wash in San Francisco in 2015, a severe drought year.

The final issue surrounding California's water systems is the irresponsible water consumption culture fuelled by water importation. For much of the last century, water was viewed as a limitless resource, and centralized distribution systems have further created a false sense of water security that encourages unsustainable urbanization and agricultural practices. In *Something New Under the Sun: An Environmental History of the Twentieth-century World*, John Robert McNeill provide some interesting insights to the perception of water throughout history, "Churchill's outlook reflected the dominant approach to water in the Twentieth century. He saw it as a resource, and it irked him to see that resources unexploited. Its development, he thought, promised better future… A great deal has changed in the hydrosphere because of men who felt much the same way Churchill did. Lenin, Franklin Roosevelt, Nehru, Deng Xiaoping and a host of lesser figures saw water in much the same way, and encouraged massive water projects…They did so because they all lived in an age in which states and societies regarded adjustments to nature's hydrology as a route to greater power and prosperity. And they had unprecedented technological means at their disposal. Since 1850, hydraulic engineers and their political masters have reconfigured the planet's plumbing."[27] With these massive water transfers structures in place, users are both psychologically and physically removed from their sources of water. This caused many to believe that water sources at some remote location could provide cities with endless supply of water, allowing them to live a lifestyle characterized with mindless consumption and quick disposal. This 'out of sight, out of mind' behaviour has contributed to the destruction of many precious natural habitats in the nation, with the most notorious example being the drainage of Owens Lake. Throughout the 1920s, Los Angeles had withdrawn water from The Owens Valley.[28] Constant development and excess water importation in city had ultimately drained the 108-square-miles lake entirely. The dried lake basin is a poster

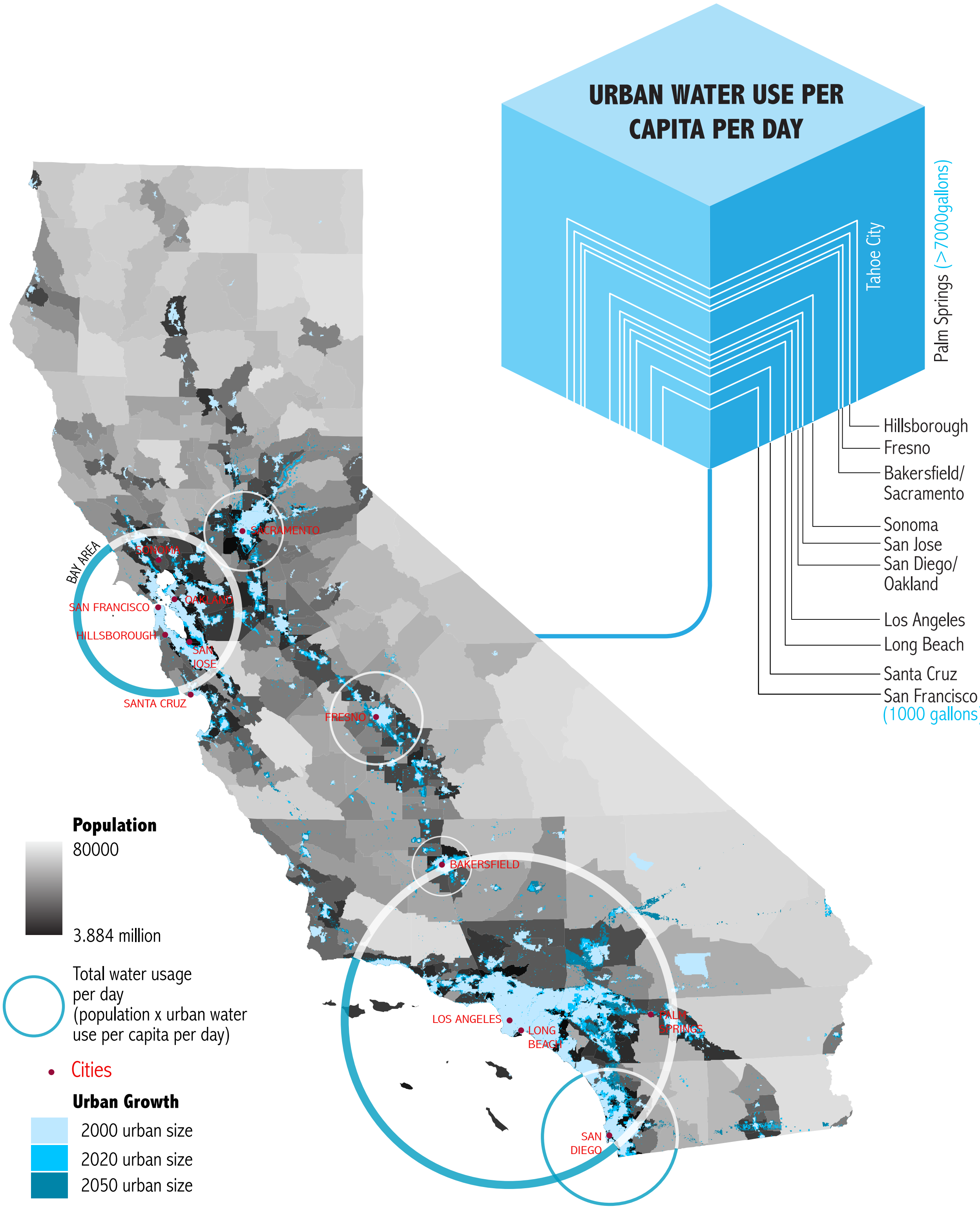


FIG.2.17: California urban water use map.[29] While per capita use is highest in Central Valley cities, population[30] is much higher in urban zones[31], so regional urban water use remain highest along the coast.

FIG.2.19: Dust storm in the dried up Owens Lake

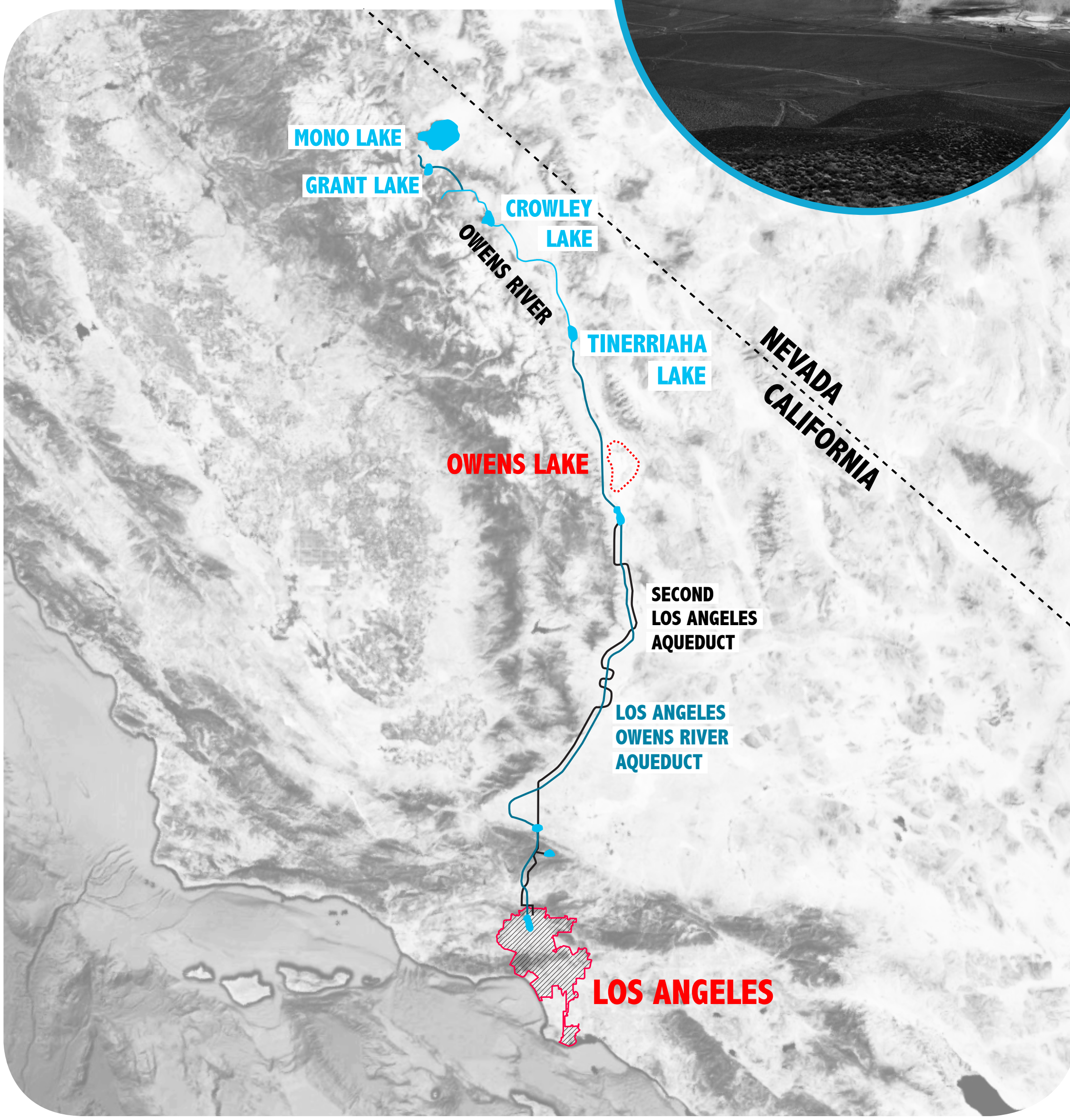


FIG.2.18: Map of the Los Angeles Owens Lake Water System and the location of the previous Owens Lake.[32] Photo at the corner shows the dried up Owens Lake lake bed, the largest source of dust pollution in the nation.[33]

OUT OF SIGHT, OUT OF MIND CONT.

child for dramatic ecological mismanagement and still remains as the largest source of dust pollution in America till this day.[34] (see fig. 2.18)

In addition to the disconnection from water source, citizen's disconnect from their waste is also problematic. In *Fetishizing Urban Technological Networks*, Maria Kaika and Erik Swyngedouw highlight the flaws in modern urban water systems and discuss how has that contributed to current water issues, "Urban networks in the contemporary city are largely hidden, opaque, invisible, disappearing underground, locked into pipes… It is exactly this hidden form that renders the tense relationship between nature and the city blurred, that contributes to severing the process of social transformation of nature from the process of urbanization."[35] Infrastructural water systems including urban sewer systems are often reduced to a subterranean "invisible city"[36] hidden from the mass population. Users, especially ones in urban areas, are never confronted with the consequences of their unsustainable consumptions. A portion of people are also skeptical of the use of alternative water sources, believing recycled water is unhygienic and all urban processes must be supported by potable water. This combination of disconnection and misinformation provides citizens little incentive to conserve and recycle water. Under the immense pressure from the drought, it is clear that water systems in California would require a revolutionary transformation; one that liberates water infrastructure from their strictly utilitarian nature and starts forming connections with users to create the necessary paradigm shift in water consumption culture.

FIG.2.20: Water mains normally hidden underground were exposed only during system upgrade and repair.

FIG.3.1: Aerial view of the California desert region and agricultural fields

REINVENTING THE WESTERN WATERSHEDS

DECENTRALIZATION, DIVERSIFICATION & VISIBILITY

FIG.3.2: Aeration tanks in the San Francisco Southeast Wastewater Treatment Plant

The current California drought signifies an extremely critical point in the history of the State and the nation. Policy makers and designer could either adopt more "band-aid" solutions to provide temporary relieve and continue their unsustainable development pattern; or they can start tackling the core weaknesses in conventional water infrastructures and formulate effective, long-term solutions. A couple major federal and state policies in the past decade have started to point water management in a more sustainable direction. For instance, the Water Conservation Act of 2009, also known as "20x2020", sets a goal to reduce 20% of urban water use by the end of year 2020. In 2012, the Rainwater Capture Act was passed to make it legal for individuals to collect rainwater for certain non-potable uses. In 2013, the California Plumbing code was also modified to better facilitate greywater reuse in households. Finally, during the severe drought years, the California Water Action Plan proposed by the Governor also laid out more key actions for water management in the following years.[1] These laws and policies show the state's desire to improve the current water infrastructure system and ensure California's water security. However without the appropriate implementation methods, these radical policies would remain unrealized. Combined with more advanced technologies and global collaboration, a sustainable form of water management that focuses on decentralization, diversification and the integrated water cycle would be the key to realizing some of these policies and attaining the conservation goals.

Decentralization is one of the most current strategies in the field of infrastructural design. For years infrastructure development is defined by enormous

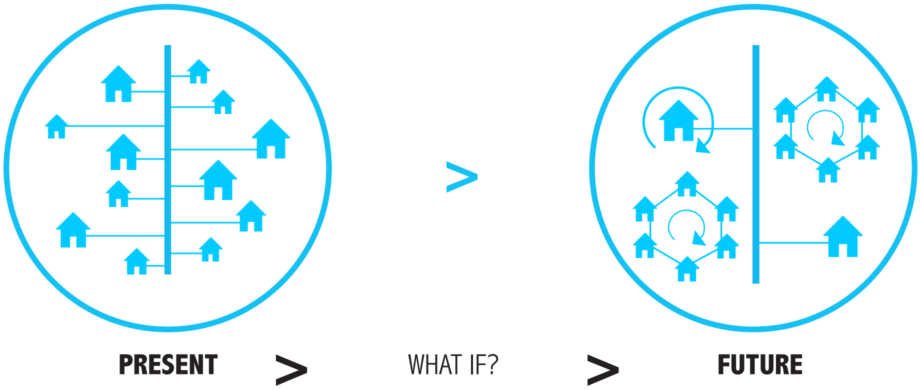


FIG.3.3: Present and potential water infrastructure development framework

systems and engineering fleets that involves huge alteration to watersheds. However, many water experts in the last decade are starting to recognize and promote the strength of smaller, more dispersed systems and one of the these voices is David Sedlak. In *Water 4.0: The Past, Present and The Future of the World's Most Vital Resource*, Sedlak points out: "Perhaps the best long-term solution to our water problem will be to abandon centralized water systems altogether. At first glance, this approach seems as if it would create more problems than it solves. But if we can figure out ways to meet our water needs with local resources, to safely treat our wastes close to where they are produced, and to drain the streets without a centralized storm sewer system, we might break free of the cycle of costly investments and environmental damage that currently

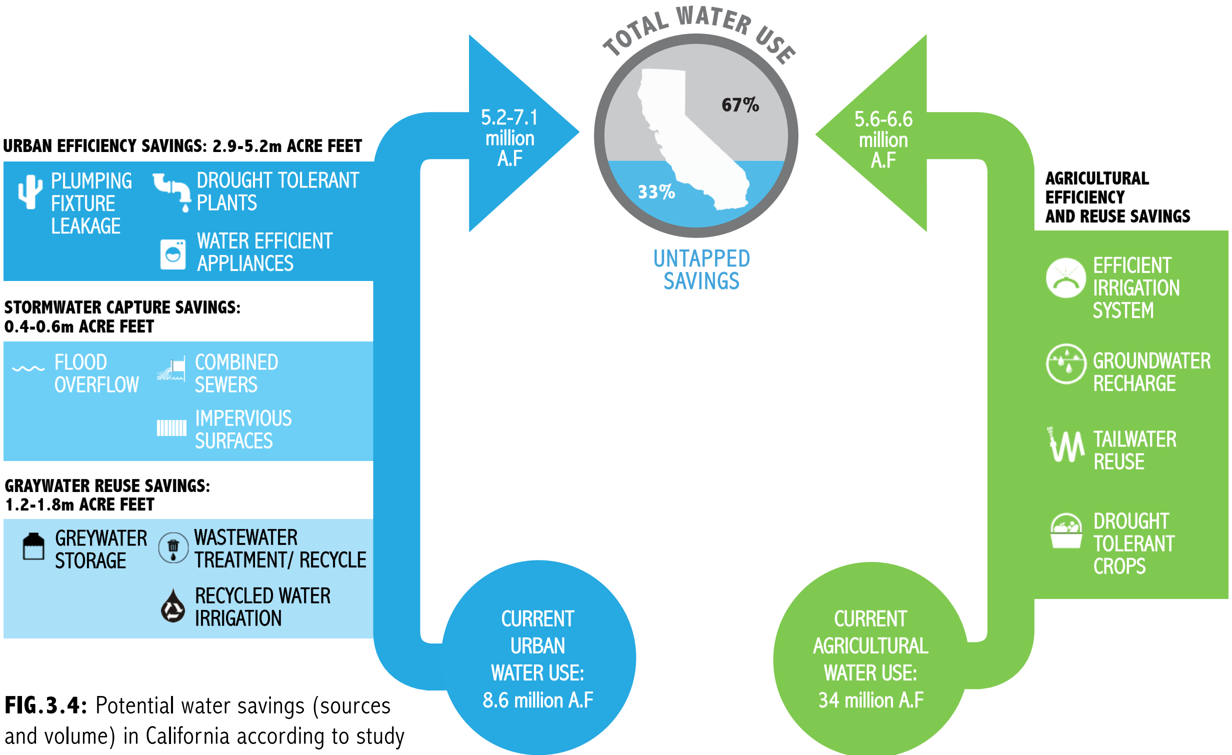


FIG.3.4: Potential water savings (sources and volume) in California according to study conducted by The Pacific Institute.[2] Units in million-acre-feet.

plague our water and wastewater systems."[3] Decentralization could help maximize local sustainable resources and in turn not only provide higher project feasibility, but increase general resilience and adaptability of the water systems because their smaller-scale would allow them to adjust easily to environmental changes. Higher independence from the imported supplies also means these systems could function and continue to service the public even if the larger system breaks down. One real-life example of a small-scale, decentralized water system is the living machine. First proposed by biologist John Todd, the living machine is a local sewage treatment system based on processes of a natural tidal wetland.[4] The system passes water through multiple vegetated treatment cells and disinfection mechanisms small enough to fit inside urban buildings. Living machines essentially allow buildings to become their own wastewater treatment facility to return treated water for non-potable water use and significantly cut back freshwater usage.[5] (see p.38)

The idea of decentralization is strongly tied to another key water management method, water diversification and recycling. Compared to decentralization, water diversification and reuse have long been recognized as an effective strategy to respond to water shortage. In a report conducted by the renowned Pacific Institute: "California could be saving up to 14 million acre-feet of untapped water – providing more than the amount of water used in all of California's cities in one year – with an aggressive state-wide effort to use water-saving practices, reuse water, and capture lost stormwater."[6] Under this historic drought, Californian cities must look toward creating a more diverse portfolio of water supplies by investing in technologies and infrastructures that capitalize on these alternative water resources. The most direct way to do so is through the switch from an open-loop to close-loop system, where stormwater, greywater and wastewater are treated then returned for future processes. The strength of water diversification

DECENTRALIZATION
PRECEDENT: **Living Machines**

FIG.3.5: Large-scale indoor living machine prototype in Emmen Zoo, The Netherlands.

Introduced by Dr. John Todd, the living machine is a small-scale, decentralized typology for treating wastewater. There are four steps in the system for cleaning the water. Wastewater first enters the primary treatment and equalization tank, where it goes through a sedimentation process to remove the larger waste particles. The second step is the treatment of wastewater in the tidal wetland cells. Under the plants, tidal wetland cells are filled with gravel coated with a biofilm, a micro-organism coating, and the waste in the water would be consumed by these micro-organisms and the plants above. Step three is a repetition of step two to further remove any waste in the water. And in the final step, the bio-filtered water undergoes UV treatment or chlorine addition for disinfection. The treated water could support any non-potable local water demands without the complex processes in municipal wastewater treatment plants.[7]

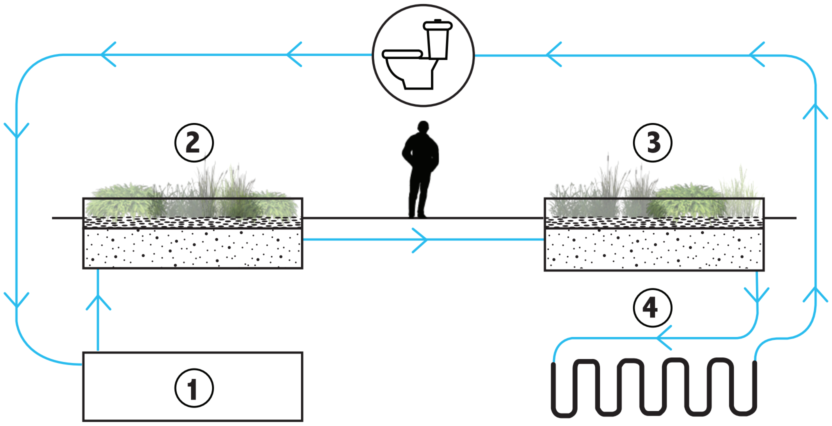


FIG.3.6: Living machine system process:
(1) Primary and equalization tank
(2) Stage 1 tidal flow wetland cell
(3) Stage 2 tidal flow wetland cell
(4) UV and chlorine disinfection

FIG.3.7: The San Francisco Public Utilities Commission has installed living machines in their headquarter in San Francisco and the system is able to treat and return up to 5,000 gallons of wastewater per day for non-potable water use in the building. The photos above show the outdoor (left) and indoor(right) wetland cells of the living machine.[8]

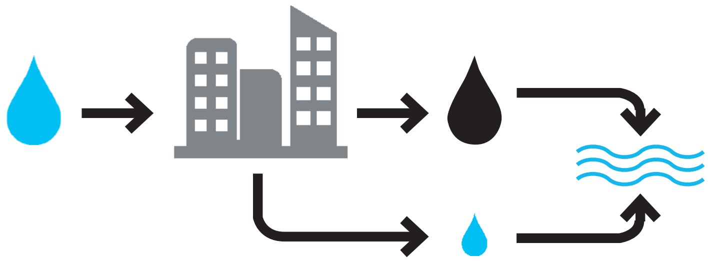


FIG.3.8: Open-loop: Water enters system, delivered to end users and is disposed into ocean or water bodies.[9]

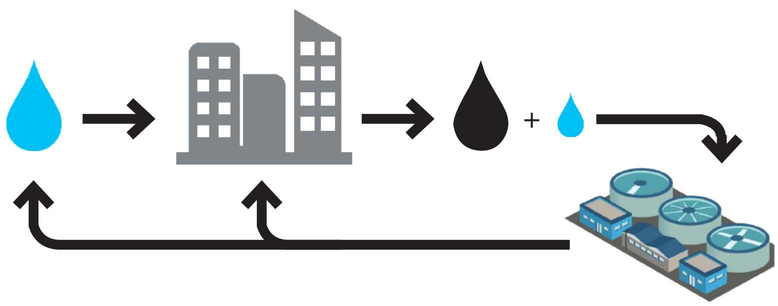


FIG.3.9: Close-loop: Water enters system, delivered to end users, but is filtered and treated to be returned for new processes.[10]

also comes from the fact that it can be achieved through systems across multiple form or scales and of different budgets. It can range from state-sponsored programs such as a non-potable water purification facility[11] (see p.40) to simply a residential rain barrel[12]. These systems would mean all members of society could contribute to the solution in their own ways. In California, the implementation of such recycling systems is still hindered by out-dated regulations, redundant bureaucratic processes and at times the lack of public support. But the concept of water diversification and recycling is still proven to be achievable given enough public and political support. For instance, the strategy is already widely adopted in some other countries, including Israel which recycles up to 86% of their domestic wastewater.[13]

Finally, returning to the notion of cultural impacts on the water crisis, the corresponding infrastructures to decentralization and water diversification must also break from the "invisible city"[14] model to promote a higher level of consciousness towards water consumption and encourage the acceptance and usage of alternative water resources. As Dana Cuff explains in her piece *Architecture as Public Work*, "Most people don't even know what infrastructure serves them until it breaks down, and because of that, their water and food supply, for example, becomes opaque. The next generation of infrastructure should be indexed above ground so that people can see how the city works."[15] Regardless of the its size or form, water infrastructure should no longer be categorized purely as engineering projects, but designed as visible, integral parts of the urban fabric and as systems that welcome the participation of the public. (see p.41-42) This approach will be key to rebuilding the lost connections between infrastructure and their users, help citizens understand the potentials of recycled water resources and furthermore help improve living quality in urban areas.

DIVERSIFICATION

PRECEDENT: **Silicon Valley Advanced Water Purification Facility** by Santa Clara Valley Water District

Silicon Valley Advanced Water Purification Facility is one of the few facilities in California that treats water to a level that reaches and exceeds California drinking water standards.[16] The facility provides an additional process after wastewater is treated in municipal wastewater treatment facilities. The process is similar to a desalination process, however due to the significantly less amount of dissolved solids in wastewater effluent compared to seawater, the process is more affordable and less energy-intensive.[17] The facility began operation in 2014 and in 2015, the Santa Clara Water District and City of San Jose have completed a South Bay Water Recycling Strategic Master Plan in hopes of expanding the facility and its water deliver by 2019. This project is one of the most innovative methods of water diversification, tapping into previously overlooked water resource as new water supplies.[18]

FIG.3.10: Tanks outside the facility for storage of purified water.

Before entering the purification facility, wastewater must be treated first in the municipal wastewater treatment plant to reach wastewater effluent levels.

In the first step of the purification process, wastewater effluent is passed through polypropylene hollow fibres, similar to straws, with tiny holes in the sides that are 0.2 micron in diameter, to filter out any large waste particles.

In reverse osmosis, water is forced through reverse osmosis membranes, made of plastic, under high pressure, removing dissolved chemicals, viruses and pharmaceuticals in the water.

Water is exposed to high-intensity ultraviolet (UV) light with hydrogen peroxide (H_2O_2) to disinfect and to destroy any trace organic compounds that may have passed through the reverse osmosis membranes.

The process is able to purify water to a level that exceeds all drinking water standards in the State. However, the purified water is still not allowed for drinking purposes under law, but is redelivered for agricultural and industrial purposes.

FIG.3.11: Wastewater purification process in the Silicon Valley Advanced Water Purification Facility[19]

VISIBILITY AND ENGAGEMENT

PRECEDENT: **Poreform** by Water Pore Partnership

Poreform is an urban surface, a flexible fabric of pores invented by WPP. The smart fabric allows for quick absorption of water and slow release into adaptable infrastructure below the surface. The project also proposes a flood control network for Las Vegas. The network incorporates several water detention basins covered with poreform to effectively capture urban runoff and flood water. Besides their functions in water management, the water tanks and their porous urban surfaces also create alternative opportunities for urban activities and interactions. Below the surface, the water tanks has its own circulation path, floatable platforms, and hydroelectric generating light buoys that converts the water tanks into an architectural space. The tanks are designed to serve as a place of education and leisure when the water level is at its average.[20] This design brings audiences into the water infrastructure and closer to their water sources, encouraging users to understand and appreciate urban water processes from a different perspective.

FIG.3.12: Render of the interior of the water storage tank

FIG.3.13: Storage tanks are designed to allow human occupation and event hosting. The strategy brings people into the typically isolated water infrastructure and allow audiences to interact with their water resources in a new way.

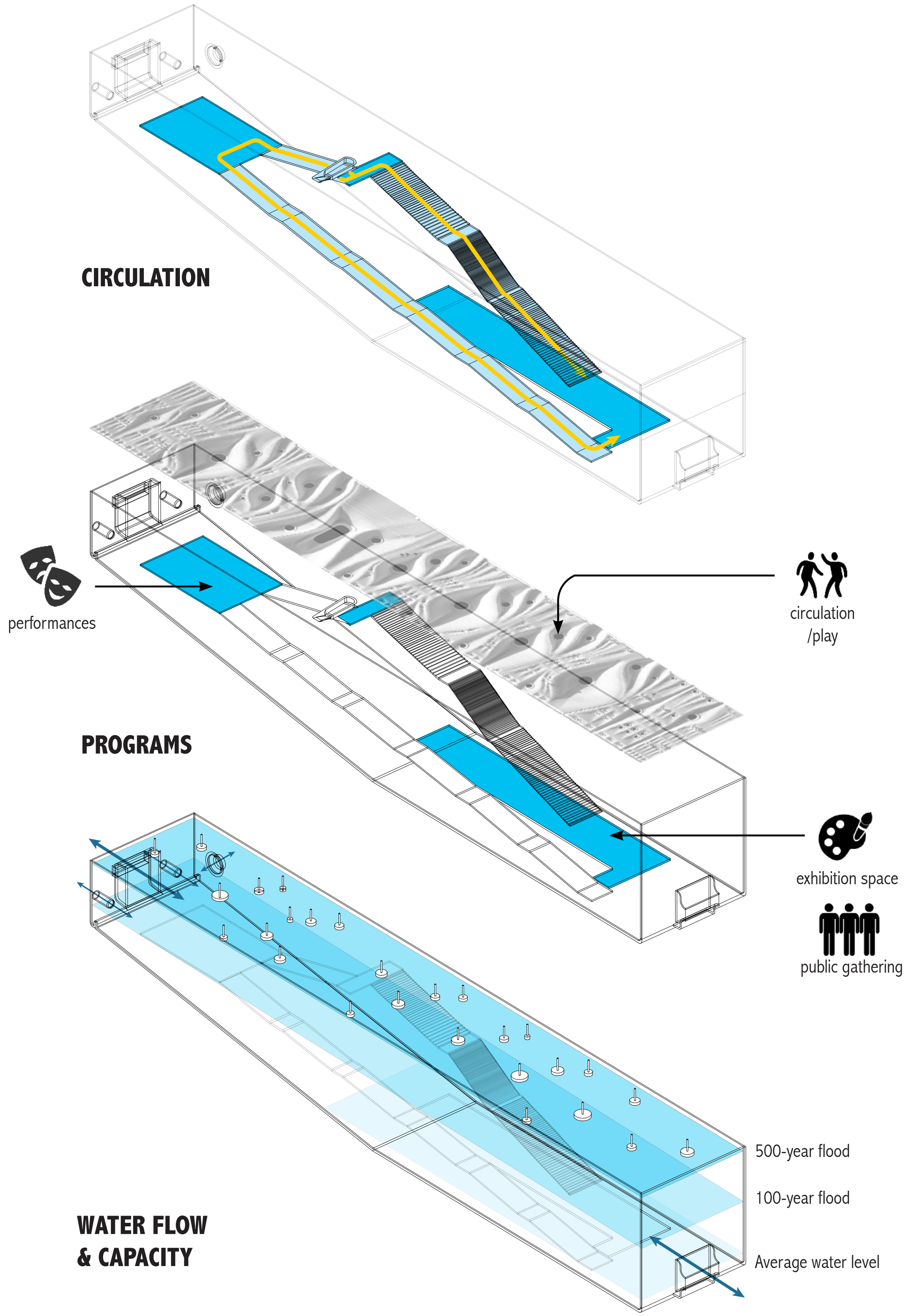


FIG.3.14: Analysis of storage tank structure and programs

INTEGRATED WATER MANAGEMENT

FIG 3.15: Dried mud and the remnants of a marina at the New Melones Lake reservoir

The next significant water management strategy to counter the California drought is the integrated water resource management. This approach is highly regarded in the water research community as one of the most practical and comprehensive responses to various twenty-first Century water issues. In the book *Out of Water: Design Solutions for Arid Regions*, the integrated water cycle is defined as "a transition from an extremely utilitarian, single-purposed system to integrated hybrid systems that are multi-functional, a kind of opportunism by a large number of interactions at multiple and nested scales. (Material, building, site, area, region and inter-regions.)"[21] The success of the approach also lies in its emphasis on a couple of crucial water system design principles.

1. Effectiveness over efficiency, a system should not simply focus on promptness but optimization of all water processes and potential resources. (see p.45)

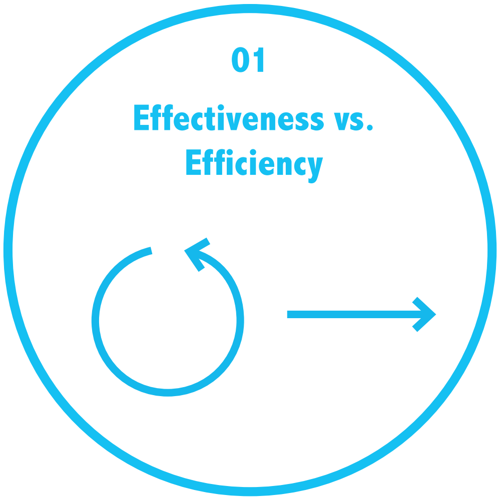
2. Interconnectedness between agencies because corporation and participation of all stakeholders in society can ensure higher productivity and performance. Interconnectedness of water system including urban and natural systems is also necessary to ensure a healthy development of the full hydrological cycle. (see p.46)

3. Water systems must become **multi-objective**, meaning that they should be seen as social-cultural, economic and ecological extension of a city and serve multiple functions. (see p. 47)

4. Resilience through diversity, which means the adaptation of a wide range of expertise, perspectives and typologies in multiple scales to enrich the systems and increase resiliency. (see p.48)

5. Adaptability and flexibility such that water systems are designed to respond to a range of climatic conditions and varying water demands, so any emergencies or environmental changes can be easily accommodated. [22] (see p.49-50)

In evaluating the existing Californian water system through the five objectives, most water infrastructures are essentially out-dated and inadequate. Existing water systems are only complex in terms of their large quantities, but not in terms of their functionalities, resiliency and adaptability. The continual addition of inflexible massive water import systems has only created more competition for limited resource and hence conflicts and division between stakeholders in the state. Therefore, to truly revolutionize water infrastructures of the coming generations, water system planners must start embracing the water management strategies and objectives outlined above. Water resource management would also benefit greatly from an integration with other disciplines, among those the knowledge and expertise of architects and urban planners. The union of infrastructure and urbanism could be the vital step that may guide water development in a more progressive and sustainable direction.



PRECEDENT: **Growing Water** by Urban Lab

In Chicago, wastewater is currently disposed into Lake Michigan after little treatment. Urban Lab's Growing Water project proposes a series of "Eco-boulevards" in Chicago that facilitates water filtration and treatment with constructed landscapes and aquatic and wetland ecological processes. This strategy may not be as quick as the typical treatment processes in a municipal wastewater plants, but it creates a closed- loop water system within the city, to recycle wastewater, increase city water supply and minimize water disposal impacts on Lake Michigan. The green infrastructure also provide a network of open spaces and conservation land that naturally manage stormwater and simultaneously encourage community engagement in the conceptualization, design and upkeep of the greenway system.[23]

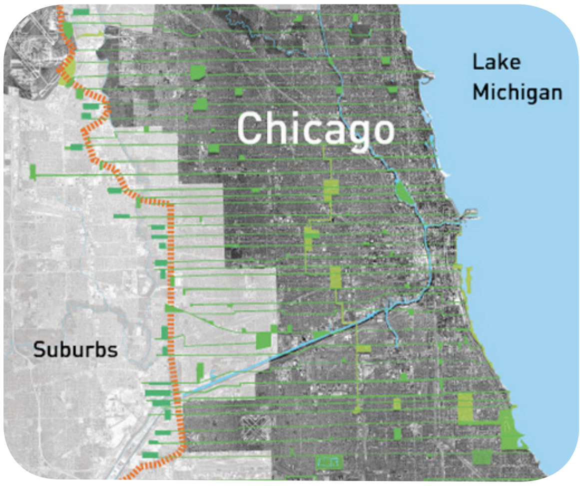


FIG.3.16: Eco-boulevards treat wastewater before its disposal

FIG.3.17: Terminals parks are formed along the eco-boulevards

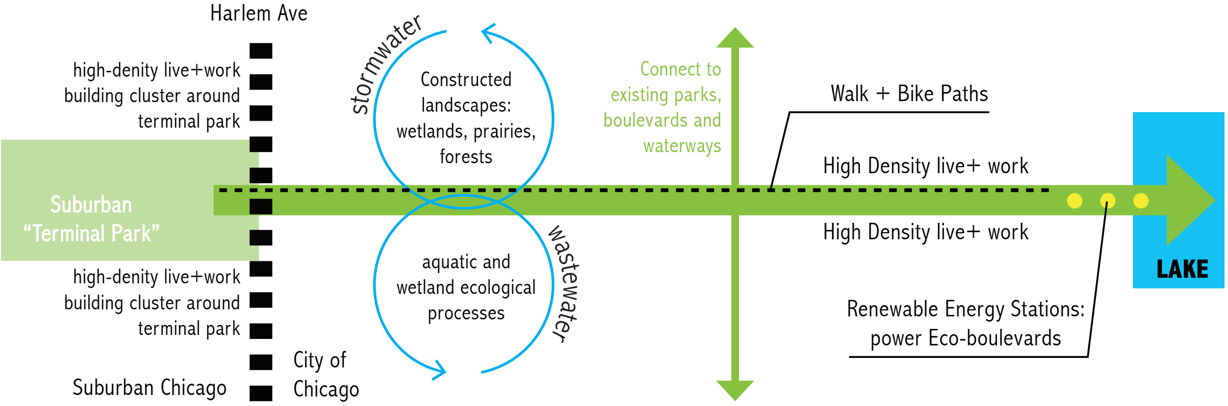


FIG.3.18: Eco-boulevards anatomy, re-illustrated from project drawings.[24]

PRECEDENT: **Watersquare Benthemplein** by DE URBANISTEN

Located in Rotterdam, the Watersquares Benthemplein are a series of stormwater retention basins that also double as public open space. These squares allow for different activities to take place depending on the water conditions in the basins. De Urbanisten architects led a participation programme that enabled local residents, students and entrepreneurs to provide input and share their opinion during the design process of the square. The local cooperation is then supported and funded by the municipal government, the water management departments and other innovative subsidies. The combined efforts allow the architects to eventually design a public space that caters to the needs of the local community.[25]

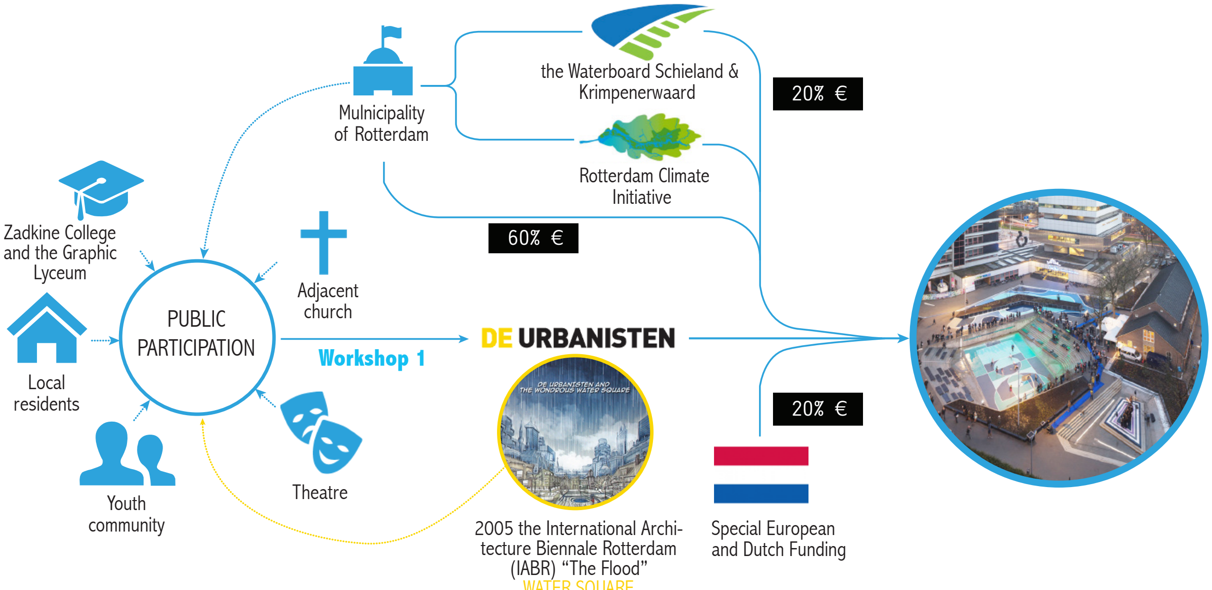


FIG.3.19: Watersquare Stakeholder involvement[26]

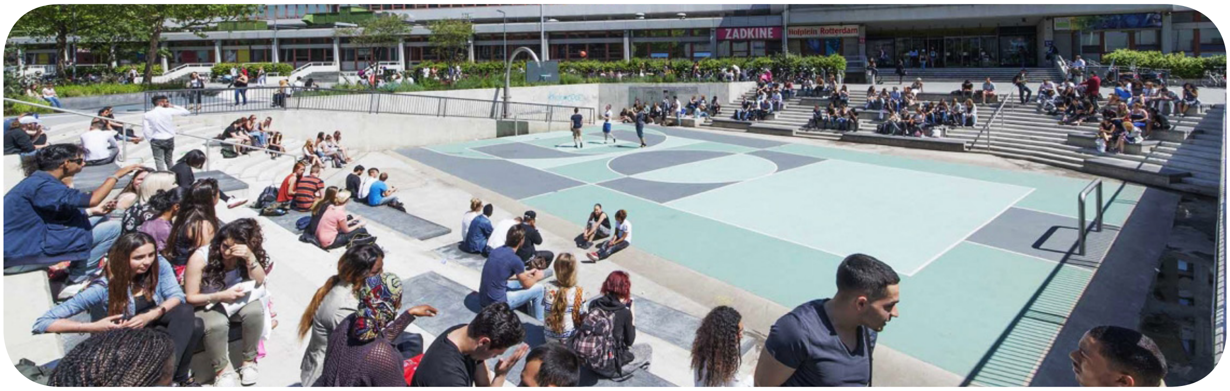
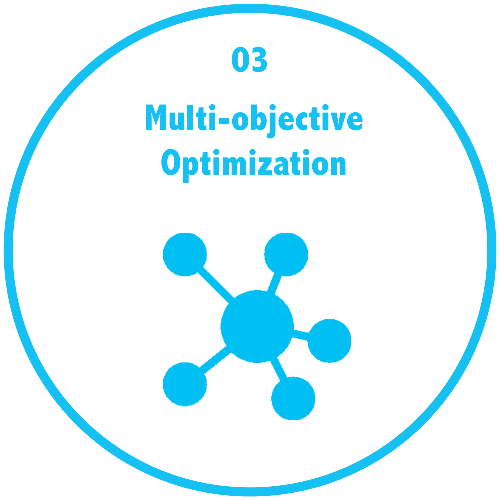


FIG.3.20: View of the Watersquare in dry conditions.



PRECEDENT: **Floodcourt Gowanus**

by Tamara Maric, Branko Palic, Krešimir Renic, Josip Zaninovic

Flood Court Gowanus is the winning project of the Gowanus by Design Water Works competition in 2013. The design combines the idea of a community center with a water retention facility. A main feature of the design is the pool on the roof, which can be transformed to accommodate a multitude of community activities depending on different seasons and weather conditions. Other than the provision of urban activities, the design also allows for rainwater accumulation on the deck and water storage below the deck. The water gathered is then reused in the building.[27] The strength of project is that it sees water as more than a resource but also an urban design element. It demonstrates that water infrastructure can serve multiple purposes in the community.

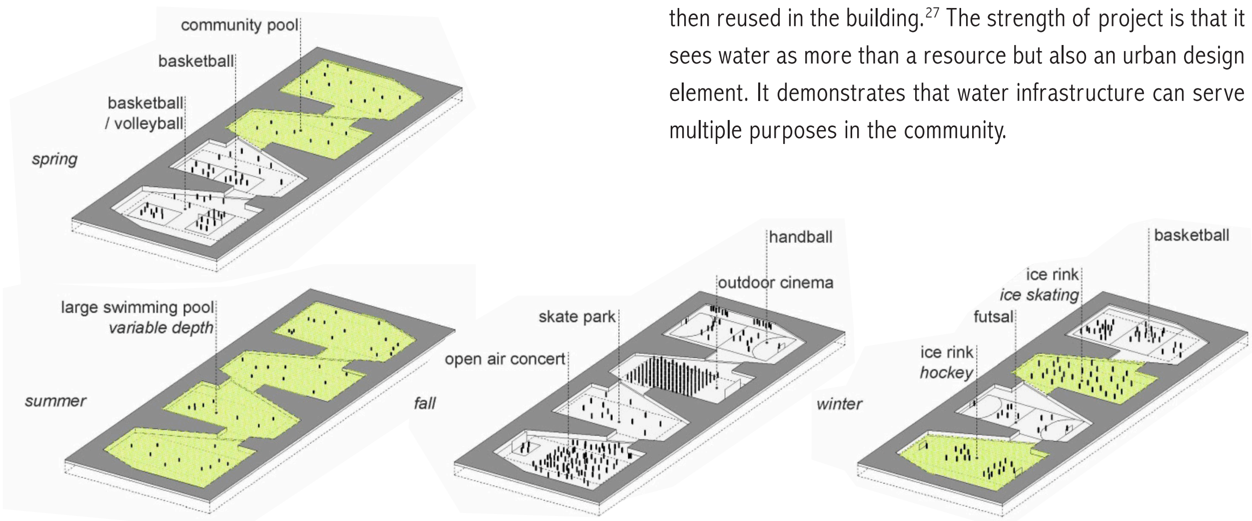


FIG.3.21: Flood Court Gowanus was designed to accommodate different activities in different seasons and changing weather conditions.[28]

FIG.3.22: A render of the roof after a storm event, rainwater fills the sunken areas and forms pools for the community.

04

Resiliency through Diversity and Repetition

PRECEDENT: **WaterShed**
by Lorcan O'Herlihy Architects

In this speculative project by LOHA, designers propose a new model for urban regeneration that transform the traditionally overlooked residual spaces in Los Angles to different water handling typologies. The system is composed of interventions at multiple scales, combining living, public space and water-based infrastructure into a new hybrid system that captures, recycles, purifies, loops, and reconnects ground and stormwater back to local aquifers. Some of these typologies include the sponge house (fig. 23), the water tower house (fig. 24), the river bridge cap (fig. 25) and so on.[29] This project demonstrates that there can be a range of solutions to a water issue, the combination of all these typologies maximizes the effect and collectively they form a more resilient system.

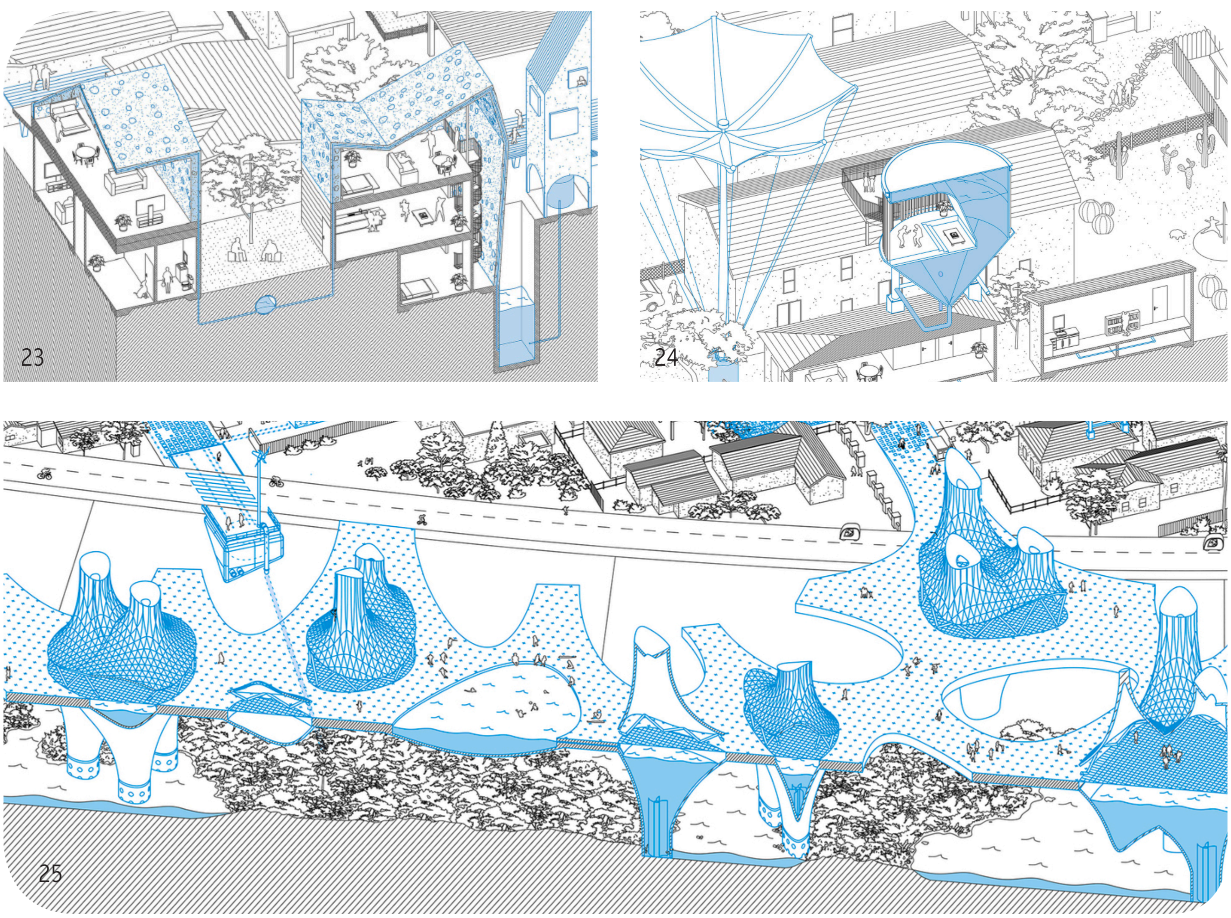


FIG.3.23-25: A range of speculative typologies proposed by LOHA to reimagine the water storage and handling systems in Los Angeles

PRECEDENT:
by Arturo Vittori

Warka Water tower is a portable fog harvesting structure designed to collect extra water resources in regions with unstable water supply, especially villages in remote area. Warka Water towers rely only on natural processes such us gravity, condensation & evaporation and doesn't require electrical power. The structure is also designed to be owned and operated by the villagers so it can be easily built and maintained without the need of scaffolding or electrical equipment. The structure is resilient because it can operate independently from the water supply or electrical grid, so its function would not be affected by deficiency in the larger system.[30] The ease of construction and maintenance also means it can be applied to different locations around the world and adapt to a range of weather, social, economic conditions. A prototype tower have already been tested in both Italy and Ethiopia, and was well-received by locals residents.

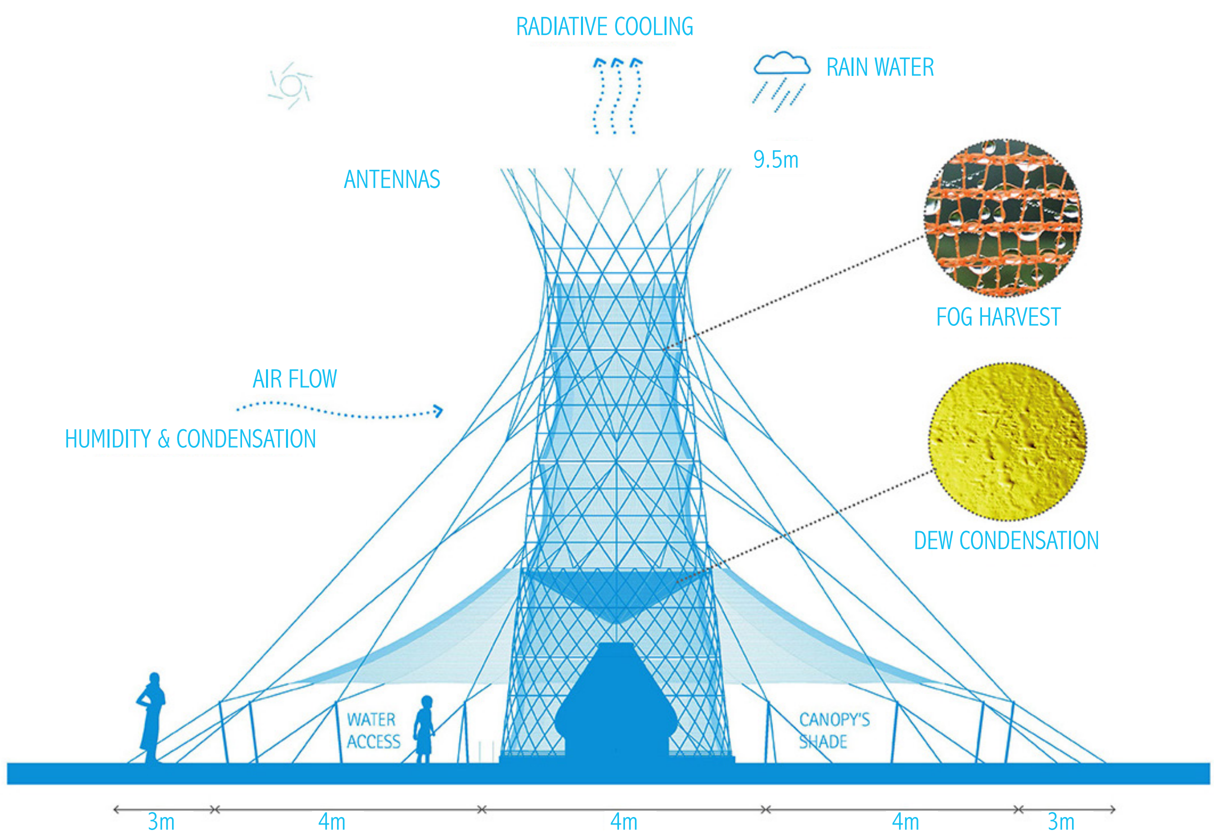


FIG.3.26: Warka Water Tower fog harvesting process

FIG.3.27: Warka Water Tower test sites

FIG.3.28: Warka Water Tower in Italy

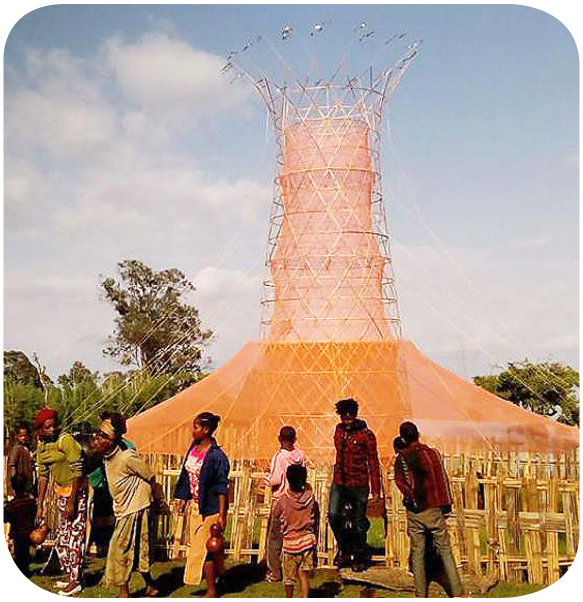
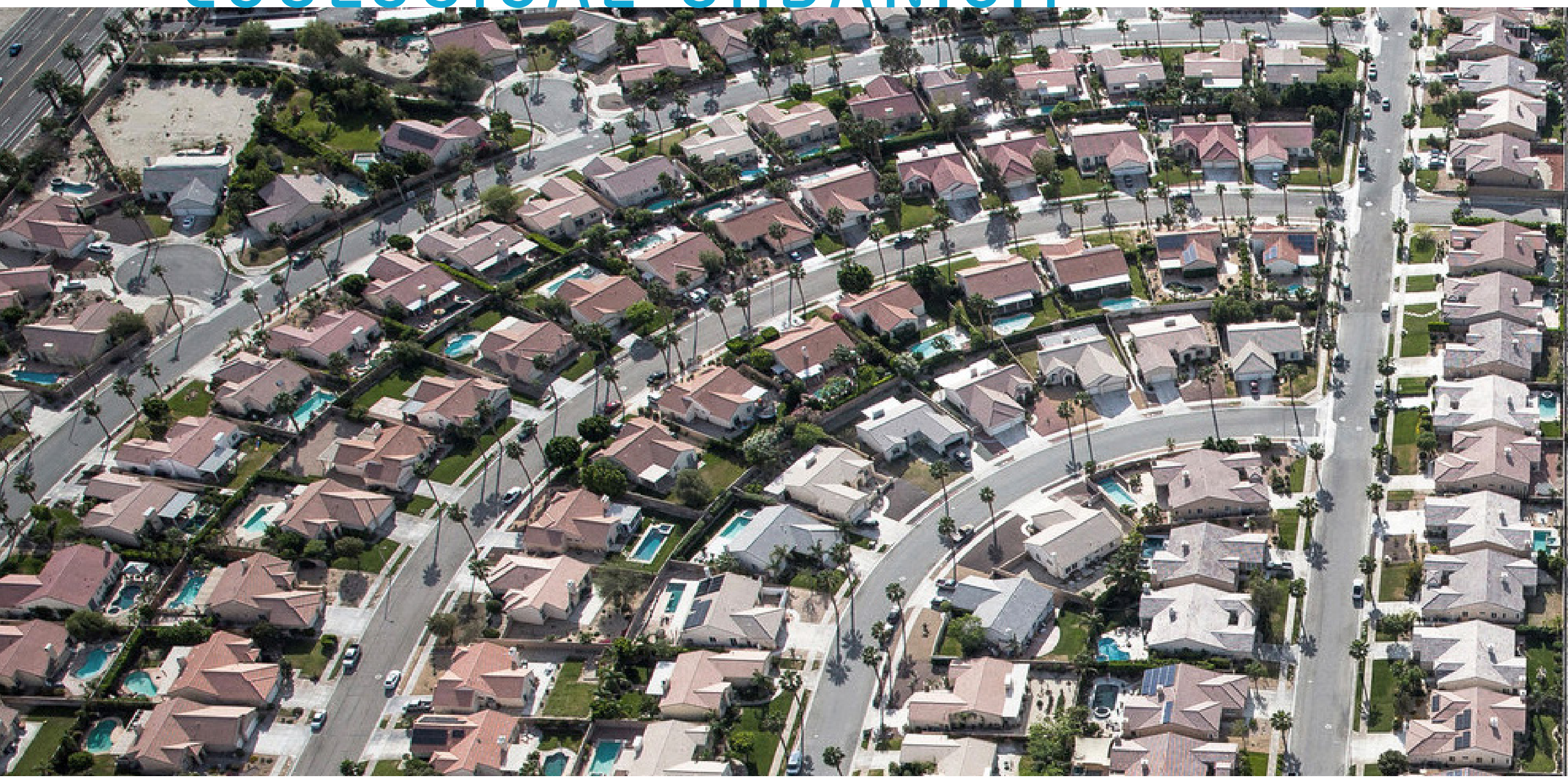


FIG.3.29: Warka Water Tower in Ethiopia

ECOLOGICAL URBANISM



Urbanism has always been a joint product of natural and human forces, a discipline that has long functioned as one of the most direct responses to changes in the natural environment. To the contrary, urbanization has also contributed greatly to climate instability and furthered the destruction of natural watersheds at the same time. According to Marc Reinsner in *Cadillac Desert*, the iconic commentary on western water developments, it is exactly the competition and ambition to develop the American West that drove the water crises at the first place, "in the West, it is said, water flows uphill toward money. And it literally does, as it leaps three thousand feet across the Teachable Mountains in gigantic siphons to slake the thirst of Los Angeles; as it is shoved a thousand feet out of Colorado River canyons to water Phoenix and Palm Springs and the irrigated lands around them… In a hundred years, actually less, God's riverine handiwork in the West has been stood on its head. A number of rivers have been nearly dried up. One now flows backwards."[31] The recent shifts in the hydrological cycle has further intensified some of these existing water issues in California and exposed the defects in the conventional forms of infrastructural and urban development. As a major participant in the urbanization process that devastated the hydrological cycle, urban planners, designers and architects have to re-evaluate their current urbanization models and participate more actively in the resolution of this pressing issue.

The need for a new form of urbanism can be understood as a response to the rapid changes in the world in the past century. Among the many

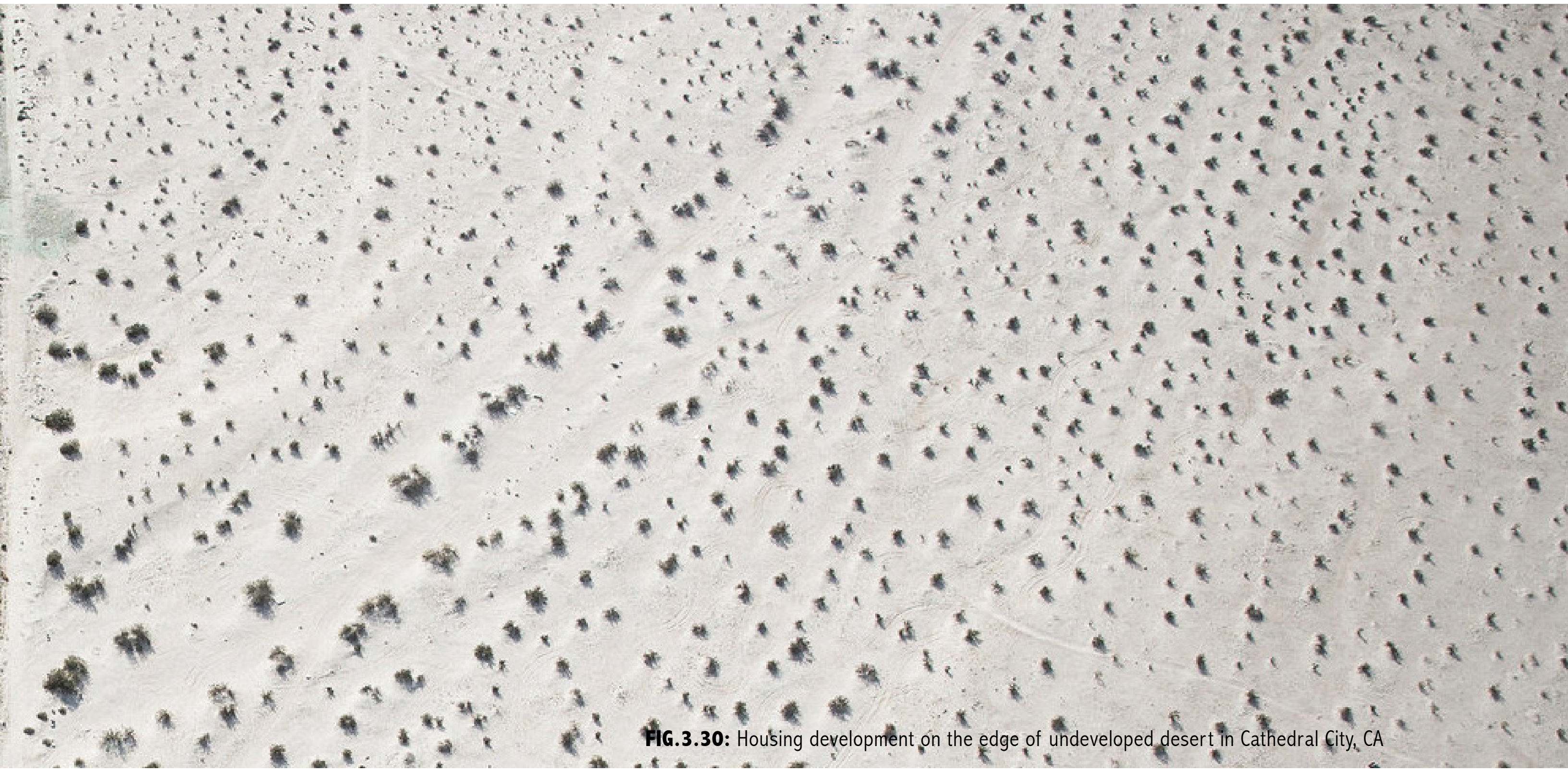


FIG.3.30: Housing development on the edge of undeveloped desert in Cathedral City, CA

factors that affect urban development, population growth and climate change are the two leading concerns.[32] It is important to point out that the two factors are essentially connected in a paradoxical relationship. While the growth in population signifies a higher demands for resources from the natural system and environment, climate change destabilizes natural processes and diminishes resources available. This relationship has become

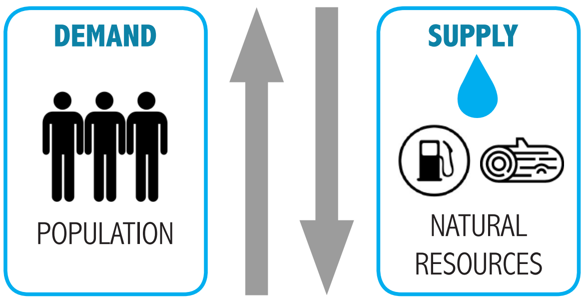


FIG.3.31: Population rise threatens natural resource supplies

one of the most studied themes in the field of architecture and urbanism today. Various new models and theories of urbanism proposed in recent years do not only address this topic, but adopts it as a core question in their model. Although these models may not have provided a specific solution to the problem, they provided the design community a new understanding of sustainability and also new strategies to develop future cities through sustainable designs. Among the multiple urbanism models, Ecological Urbanism proposed by Mohsen Mostafavi[33] is perhaps the most relevant for drought stricken California. This is because the theory's emphasis on a trans-boundary, interdisciplinary and multi-scalar approach closely resembles the comprehensive nature of the hydrological cycle.

In his revolutionary work, Mostafavi

FIG.3.32: Sietch Nevada, Architect's Render

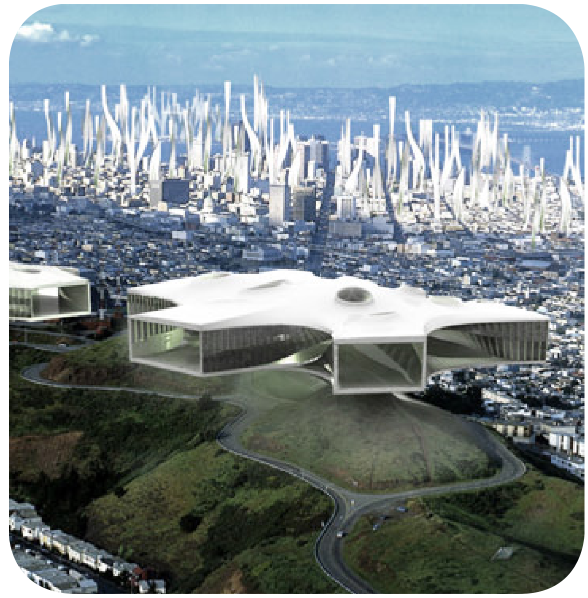


FIG.3.33: Hydronet San Francisco, Architect's Render

Sietch Nevada by Matsys and Hyrodnet San Francisco by IwamotoScott are two speculative projects designed based on projected future climate conditions and corresponding social, political structures in Southwestern America. In both projects, water is considered a rare and valuable resource that is central to the design. These projects blurs the division between reality and fiction. Although not all ideas in the projects area realizable at the moment, they serve as important precedents for the design community, providing a innovative directions for potential future scenarios.

suggested that although stresses on the planet's resources have posted threats to our society, these catastrophic moments, such as the Californian drought, have also provided the architectural and planning community an intriguing opportunity to generate innovative, speculative designs that break away from the conventional solutions limited by technical legitimation.[34] He also argues that urban designers should become more engaged in the sustainability movement. Despite the aggressive effort from multiple disciplines to respond to Western water issues, urban planners and designers still play a rather marginal role in this solution process.[35] This circumstance is largely due to several major stigmas in the field. First of all, the idea that sustainability is only supplementary to design excellence has hindered the advancement in sustainable architecture and urbanism. "Sustainable architecture itself rudimentary, often also meant an alternative lifestyle of renunciation, stripped of much pleasure… There remains the problem that the moral imperative of sustainability and, by implication, of sustainable design, tends to supplant disciplinary contribution. Thus sustainable design is not always seen as representing design excellence or design innovation. This situation will continue to provoke skepticism and cause tension between those who promote disciplinary knowledge and those who push for sustainability."[36] To certain extent this passivity towards sustainability has also led to another stigma in the industry, the lack of inter- disciplinary collaboration. Based on French philosopher Felix Guttari's *The Three Ecologies*, ecology is essentially a combination of multi- disciplinary knowledge: social-economic-political struggles, environmental conditions and human interactions.[37] To design with an ecological mind frame, urban designers would have to be aware

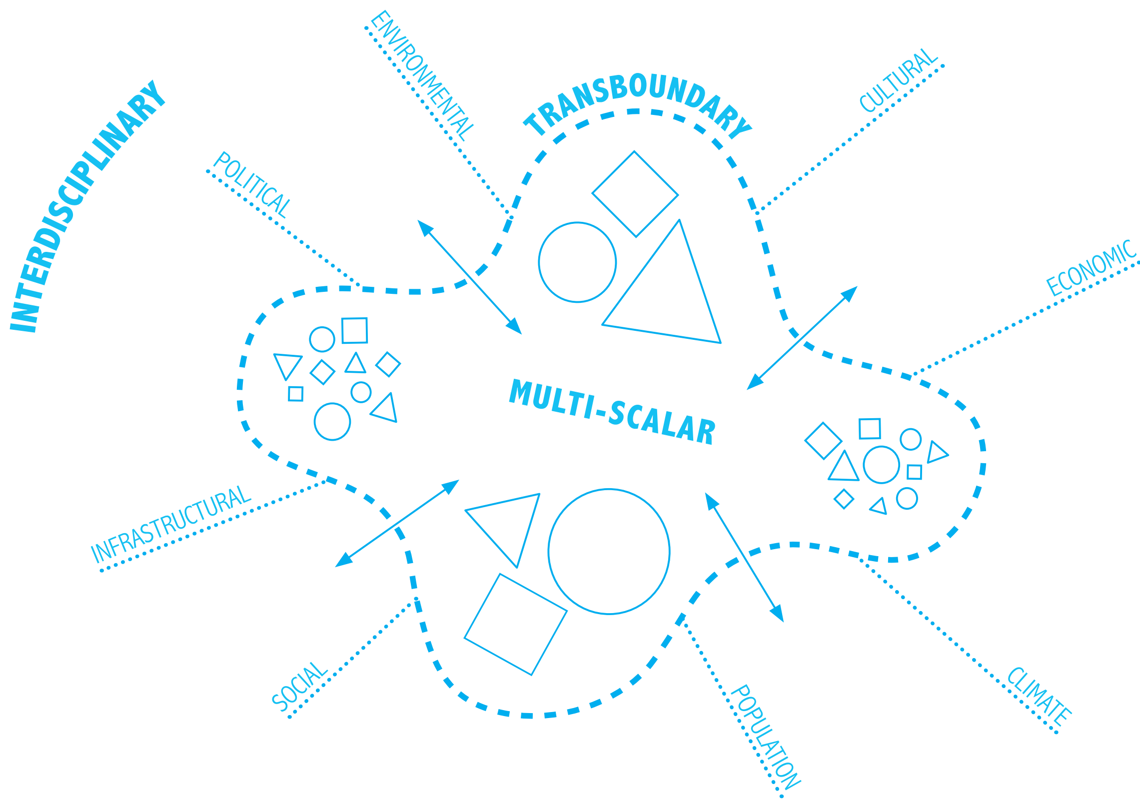


FIG.3.34: Diagrammatic representation of the core ideas of Ecological Urbanism.

of these parameters and forces at all time. Furthermore, it is also necessary for designers to adjust the current scale and scope of urban projects in order to achieve more comprehensive responses to current environmental problems. Mostafavi points out in his book *Ecological Urbanism* that "Much of the work undertaken by sustainable architects has been relatively limited in scope…but because of the challenges of rapid urbanization and limited global resources have become much more pressing, there is a need to find alternative design approaches that will enable us to consider the large scale differently than we have done in the past."[38] He later then discusses why ecological urbanism could be the answer to this issue. "Key characteristic of ecological urbanism is its recognition of scale and scope of the impact of ecology, which extents beyond the urban territory. The city, for all its importance, can no longer be thought of only as a physical artifact; instead, we must be aware of the dynamic relationships, both visible and invisible, that exist among the various domains of a larger terrain of urban contingencies can lead to uncertainties and contradictions- calling for unconventional solutions. This regional, holistic approach, with its consequent national and global considerations, demonstrates the multi-scalar quality of ecological urbanism."[39] The California drought is a classic example of the extremely complex environmental issue mentioned, it affects so many sectors and parties locally, national and globally that it blurs both physical and disciplinary boundaries. It is only through the departure from traditional architectural and urban design theories, and an aggressive integration of interdisciplinary knowledge, that designers could truly provide fertile means of addressing the Western hydrological challenges.

LANDSCAPE INFRASTRUCTURE

FIG.3.35: The Liupanshui Minghu Wetland Park in China

Ecological Urbanism has provided the fundamental framework and a reformative manifesto for sustainable development in the 21st Century. However, its full fruition would have to be accompanied by the redefinition, and reinvention of several major components in the urban territory. Landscape design and infrastructural development are two major aspects of urbanism, but they were traditionally viewed as somewhat unrelated disciplines. While landscape design is often associated with natural environment and seen as a way to elevate the urban condition, infrastructure is typically seen as unpleasant artificial systems that should be isolated from urban living. Therefore, the field of architecture has always been reluctant to embrace design opportunities embedded in infrastructural systems, causing their design to fall solely into the realm of engineering.[40] However in the last few decades, the concept of infrastructural urbanism started to gain traction, questioning the conventional isolation of infrastructure from the field of design. In his essay *Infrastructural Urbanism*, famous architect and theorist Stan Allen encourages architects and urban designers to depart from the representation model, that the profession started to explore and reclaim infrastructures as part of their practice. "A building was once "an opportunity to improve the human condition;" now it is conceived as an opportunity to express the human condition" Rethinking infrastructure is only one aspect of a larger move away from the representational model, one of the many implications of architecture understood as a material practice… They do not work primarily with images or meaning, or even with

FIG.3.36: Core principles guiding the design portion of the thesis, an integration of ideas from multiple disciplines: ecology and landscape, infrastructure and architecture and urbanism

FIG.3.37: View of Qunli Stormwater Wetland Park in Harbin, China. The Park designed by Turenscape received multiple awards for this innovative approach to manage and clean storm water with a restored wetland. The park is also successful in bringing more population to the area and driving residential development in the region.[41]

objects, but with performance: energy inputs and outputs, the calibrations of forces and resistance. They are less concerned with what things look like and more concerned with what they do."[42] With the significance of performativity being brought to attention, urban designers become open to the potentials of infrastructure. Conversely, such integration also challenges the traditional definition of infrastructure and help renegotiates their forms, performance and their identity in the city.[43] The emphasis on performance in the urban territory is nonetheless not a brand new idea in the discipline of landscape architecture and design. In fact landscape architects have long embraced this idea, evaluating the performative quality of ecological cycles and examining if natural processes could be adopted to enrich the urban landscape.[44] This process gives landscape architecture its strength and ability to mimic and maximize natural processes, while minimizing human impact. In such sense, there has always been a parallel between landscape and infrastructure design. Regardless of the specific method, performance is key to both disciplines and this shared awareness ultimately leads to the overlap of landscape and infrastructural design to form landscape infrastructures. Urban projects such as the Qunli Wetland Stormwater Park in China[45] (see fig.3.37), Wadi Hanifa Wetlands in Saudi Arabia[46] (see p. 58) are just two of the many successful real-life examples of landscape infrastructures that transform natural features and plants into water treatment machines, allowing ecological processes to support and even replaces some of the traditional functions of water infrastructure. One added benefit

LANDSCAPE INFRASTRUCTURE

PRECEDENT: **Wadi Hanifa Wetlands** by Moriyama & Teshima Planners Limited

Similar to the Urban Lab's Growing Water project and the Qunli Storm water park, the Wadi Hanifa wetlands is a new form of water infrastructure that uses constructed landscapes, especially wetland species and processes to treat water naturally. The Wadi Hanifa is the longest and most important valley near Riyadh, Saudi Ababia, and a natural water drainage course for an area of over 4,000 square kilometres. The natural environment of the valley was however heavily destructed throughout the last decades. Therefore, the new wetland is designed to support multiple functions including water filtration and reclamation, habitat restoration, industrial clean up and also the development of recreational areas for the citizens. This successful example of landscape infrastructure has received multiple awards, including the prestige Aga Khan Award for Architecture.[47]

FIG.3.38: View of the swales in the Wadi Hanifa Wetland

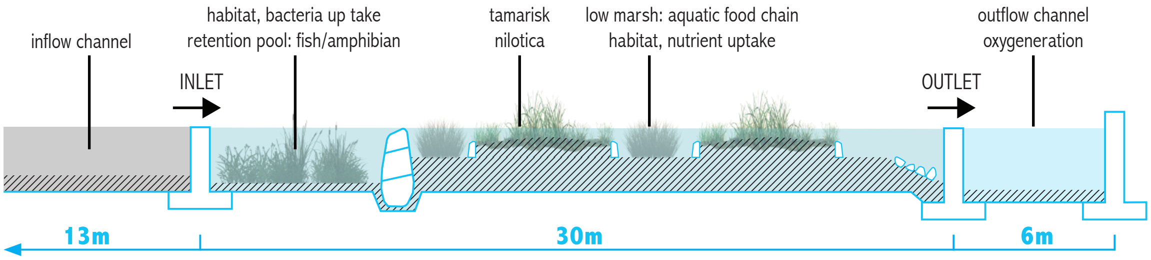


FIG.3.39: Section of a bioremediation cell, reillustrated from the book Out of Water.[48]

FIG.3.40: Aerial View of the Wadi Hanifa Wetland. The site is separated into 2 areas, bioremediation cells on the west and wetlands/ swales on the East.[49]

of combining the two disciplines is the introduction of the concept *Terra Fluxus* to infrastructure design. *Terra Fluxus* is a concept brought forth by landscape designer and theorist James Corner.[50] It calls for a form of urbanism that recognizes dynamic relationships and anticipates temporal changes, a concept that is often lacking in the design of traditional water infrastructures in the West, " We have yet to understand cultural, social, political, and economic environments as embedded in and symmetrical with the "natural" world. The promise of landscape urbanism is the development of a space-time ecology that treat all forces and agents working in the urban field and consider them as continuous networks of inter-relationships…The entire metropolis is a living arena of processes and exchanges over time, allowing new forces, and relationships to prepare the ground for new activities and patterns of occupancy."[51] The ineffectiveness of the centralized water networks in the west is perhaps resulted largely from the lack of this sensibility in their design at the first place. The two biggest centralized water system in California, The Central Water Project and the State water project, were built in 1930s[52] and 1960s[53] respectively. During those times, California's water availability, state population and water demands were far different from the current conditions. Centralized systems designed largely based on the climate and social-political contexts at the time are incapable of responding to the rapid changes in recent years. "In all, these hydrological impacts undermine the foundation of the state's hydraulic empires. As Maurice Roos, California's State Hydrologist, observed: "By and large, reservoirs and water delivery systems, operating rules have been developed from historical hydrology on the assumption that the past is a good guide to the future. With global warming that assumption may not be valid."[54] The merge of landscape and infrastructure signified the first step towards recovering some of that awareness in the design process. Additionally, it also respond to the idea of sustainability in a truly ecological manner by allowing a new generation of infrastructure to embrace ephemeral characteristics such as growth, succession, spontaneity, and even decay.[55] This recognition and acceptance of changes through time could help create modern water infrastructures that are flexible and resilient.

In *Landscape as Infrastructure*, Pierre Belanger suggests, "As an integrative and horizontal discipline that transcends disciplinary boundaries, landscape practice stands to gain momentum, widening its sphere of intervention to include the operative and logistic aspects of urbanization. Tough they may seem banal; these aspects can bridge the current divide across the economic-ecological gap. The engineering of basic elements such as topography, hydrology and biomass as a system can be instrumental in the amplification of invisible yet fundamental processes that support urban development."[56] As the landscape infrastructure strategy becomes more widely adapted in urbanization processes, including the design and implementation process of water infrastructure systems. The approach would be fundamental to the construction and realization of some extremely powerful and truly sustainable alternatives to the conventional, utilitarian water infrastructure in the West, especially when the strategy can be extended to the scale of a neighbourhood, city or even an entire region.

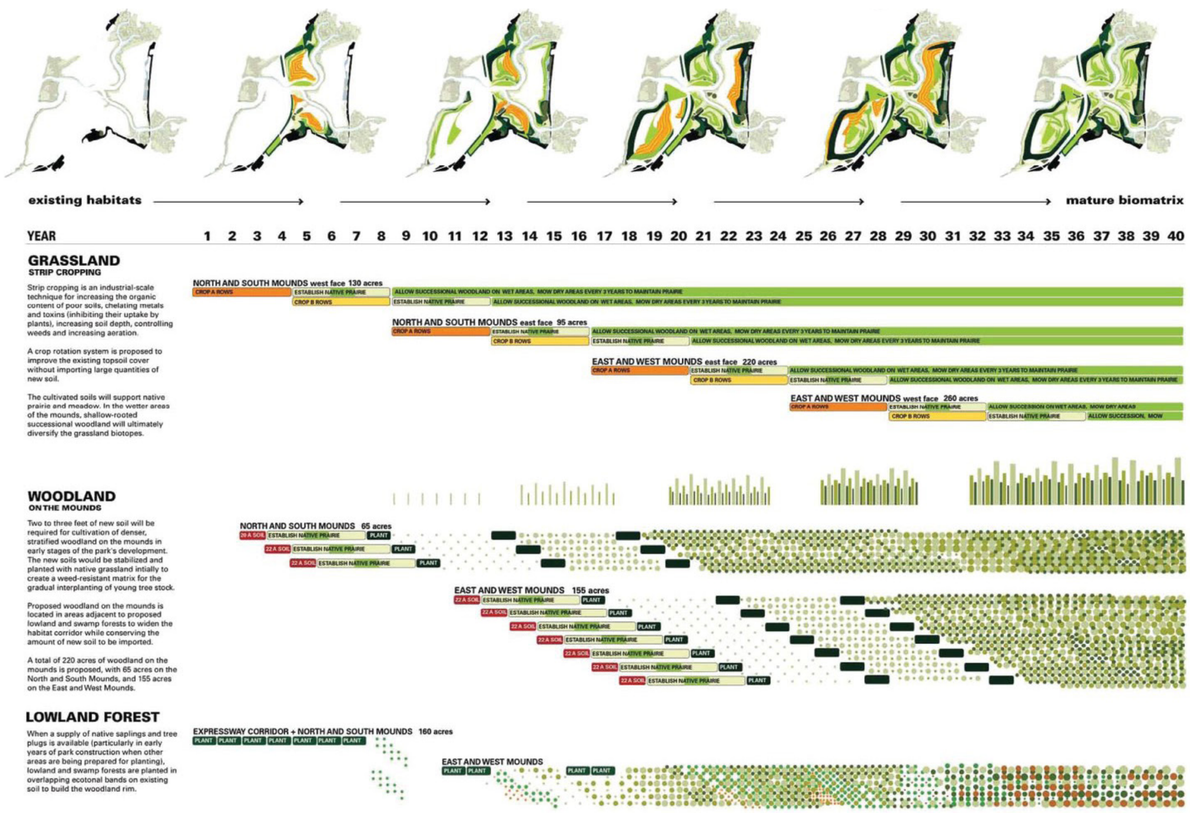


FIG.3.41: James Corner's Fresh Kills Park Project implementation timeline, the landscape architect's most famous project demonstrating the anticipation of growth and changes in the landscape.[57]

A NEW FORM FOR WATER INFRASTRUCTURE

In the attempt to resolve the California drought from the perspective of architecture and urbanism, it is also essential to recognize that aside from the traditional audience, humans; we are designing for various water processes, including local water collection, filter, recycling and distribution. Much of the challenge in designing for water processes of course lies in the fluid physical nature of the element and its fluctuating quantity throughout the seasons, but the various quality of water produced from different human activities also adds to the complexity of the design. In other words, a successful urban water system would need to accommodate multiple water processes simultaneously and maximizes the range and quantity of water it holds, all while responding to a host of networked physical and nonphysical variables. In order to development such system, it is necessary to rethink the form and organization of the current water systems, to move away from the linear supply structure and engage the concept of a field or composite network. In one of Stan Allen's most acclaimed piece *Field Conditions* in the book *Points+ Lines*, the author provides two interesting interpretations of a field that could be particularly useful to urban water systems design. First of all, a field can be understood as the repetition of local elements forming a flock or a crowd, "defined by precise and simple local conditions, and relatively indifferent in form and extent. Because the rules are defined locally, obstructions are not catastrophic to the whole. Variations and obstacles in the environment are accommodated by fluid adjustment."[58] This first interruption echoes James Corner's understanding of the Field in *Terra Fluxus*, where he states that a field is predominantly a phenomenon of horizontal surface but is essentially governed by "an organization that lends legibility and order to the surface while allowing for the autonomy and individuality of each part, and remaining open to alternative permutation over time."[59] The second interruption in Stan Allen's piece then begins to depart from the planar perspective of a field and discusses the potential of overlapping multiple fields to form composite networks and create certain intensified moments within the overlapping fields, "What these field combinations seem to promise in this context is a thickening and intensification of experience at specific moments within the extended field of the city… The new institution of the city will perhaps occur at moments of intensity, linked to the wider network of the urban field, and marked not by demarcating lines but by thickening surfaces."[60] The above interruptions of a field condition provided a new way to envision and reimagine the form and organization of urban water infrastructures and a framework to develop systems consist of independent components separate from the centralized water deliveries. Instead of depending solely on a single source of imported water, cities can switch to a model that harvest locally available water resources by combining multiple fields, each composed of repeated typologies to maximize certain water capture and reuse processes. Through the overlapping of these typologies layers with other context layers, opportunities may also emerge for larger, community-scale water infrastructure. If these infrastructures are designed to include

programs beyond its water handling functions, they can potentially grow into new institutions in the city and contribute to the overall urban experience. Ultimately, the advantage of approaching water infrastructure with the field organization strategy is the ability to form systems that can functions as both an integrated network and as individual parts. This would greatly increase the flexibility of the water systems and their resiliency to constant environmental, social-political changes. “More than a formal configuration, the field condition implies an architecture that admits change, accident, and improvisation. It is an architecture not invested in durability, stability and certainty, but an architecture that leaves space for the uncertainty of the real.”[61]
(see p. 63-66)

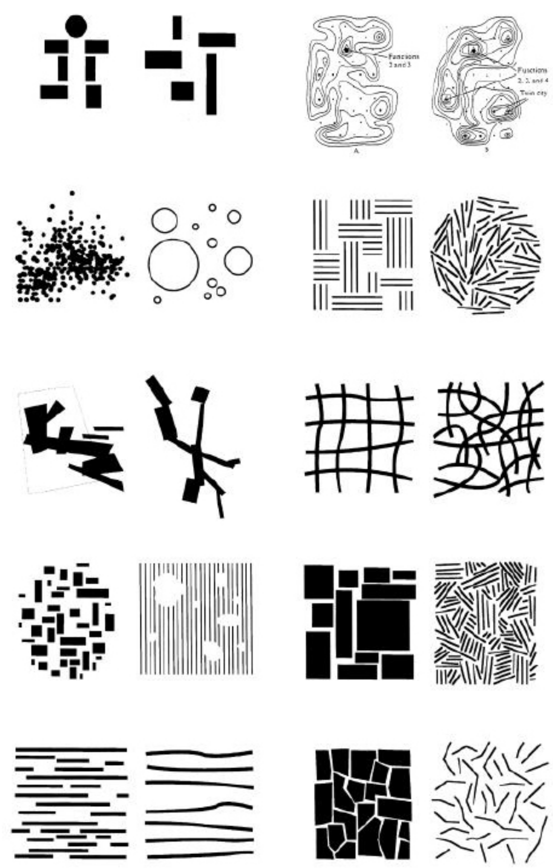


FIG.3.42: Stan Allen’s field conditions diagrams

FIELD AND LAYERS

PRECEDENT: **Sietch Nevada** by MATSYS

Located in the arid Nevada desert area, Sietch Nevada is a conceptual underground waterbank city that makes the storage, use, and collection of water an essential part in the forming to the performance of urban life. The context of the project also aligns closely to the conditions in parts of California which makes it a valuable precedent. The project essentially consists of a field of cellular-shaped pods connected by a network of underground canals. The cellular-shaped pods in the project is an example of an individual element within a field. Each pod includes spaces dedicated to residential, commercial and civic programs and a field is created by the repetition of these pods to form a cohesive underground neighbourhood.

The overlapping of fields and the thickened layers is another important strategy in Sietch Nevada. Each individual cellular pod is essentially constructed as a series of offset rings layered over each other and the city as a whole is formed through the layering of multiple programmatic layers. Programs are organized by the different layers and the offset of layers allow for activities to happen on each layer surfaces. Besides programmatic organization, each layer also function as a different parts of the water system to guide, collect, allocate and store water in the city.[62] (Fig.3.45)

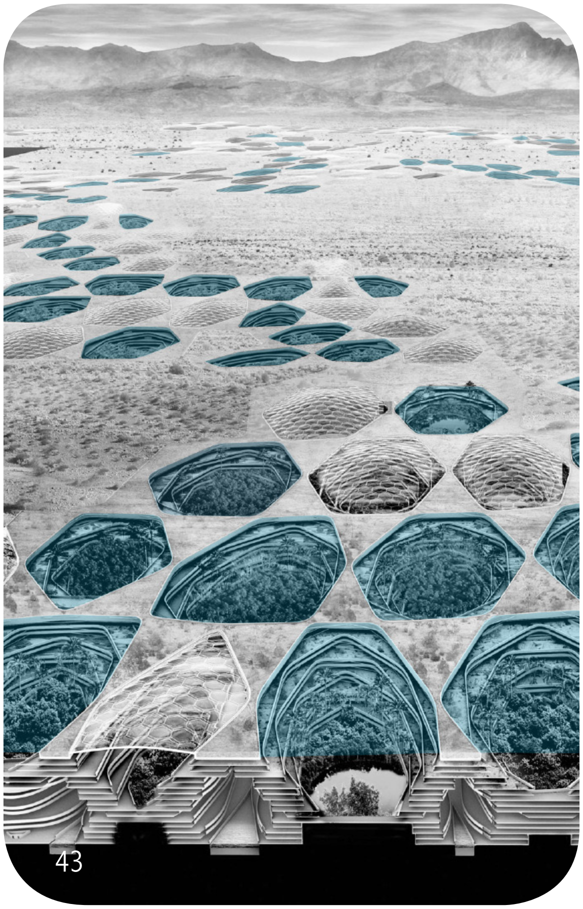


FIG.3.43-44: Architect's render of the Sietch Nevada City in the Nevada Desert.

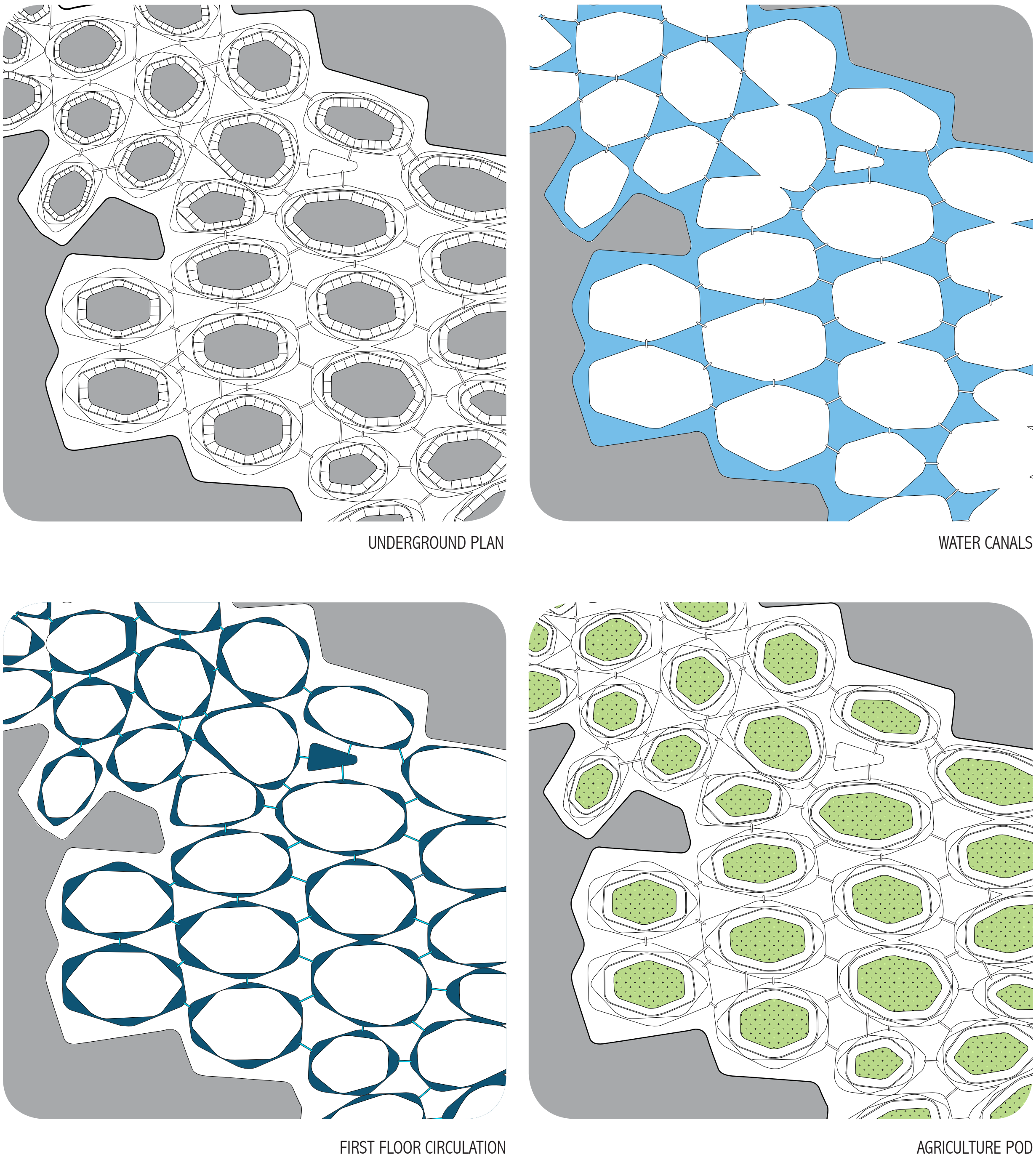


FIG.3.45: Fields conditions in the Sietch Nevada City.

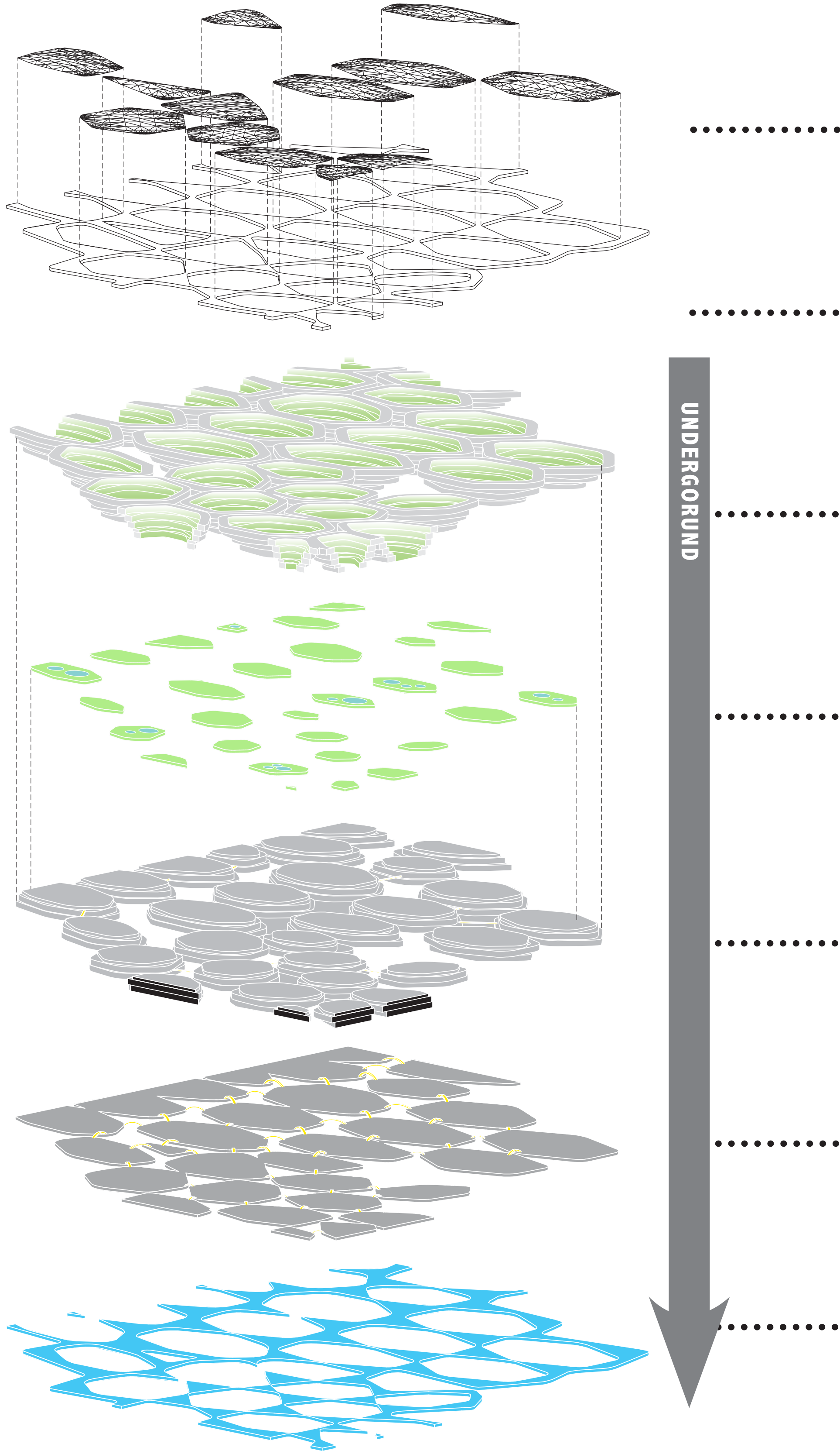
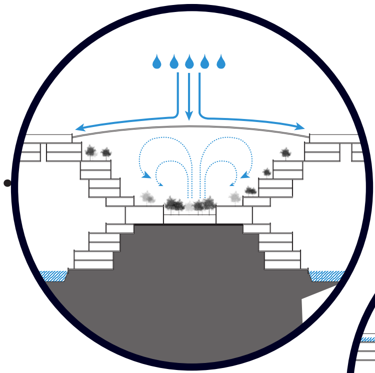


FIG.3.46: Sietch Nevada Underground City layers.[63]

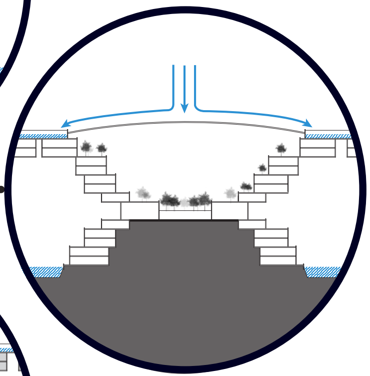
1/ Canopies

Located at selected areas, the glass canopies guide precipitation to ground level and prevents water lost through evaporation



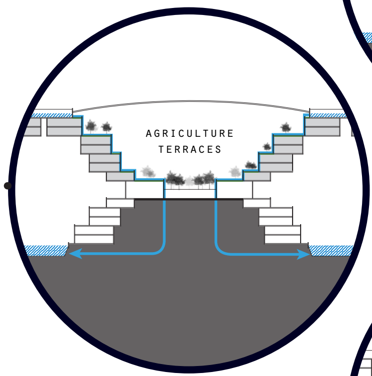
2/ Ground Level

Ground surface acts as absorption basin to collect water from precipitation

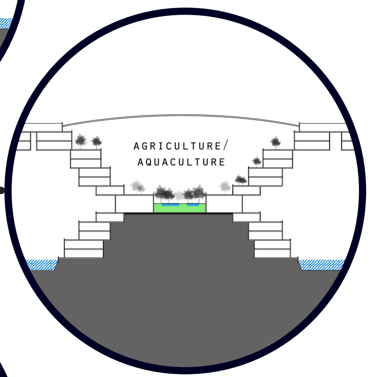


3/ Residential & Agriculture

The top layers of pods are residential zone with agricultural terraces on the interior of cell. Water is guided by terraces to underground aquifers. Green represent surfaces of agricultural terraces and gre represents residential zones

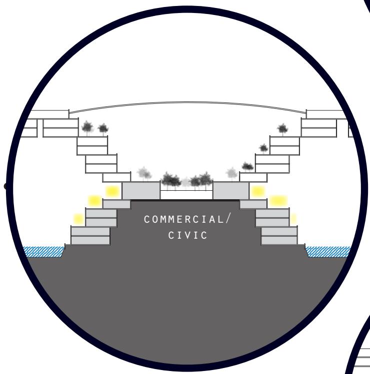


4/ Agriculture & Aquaculture



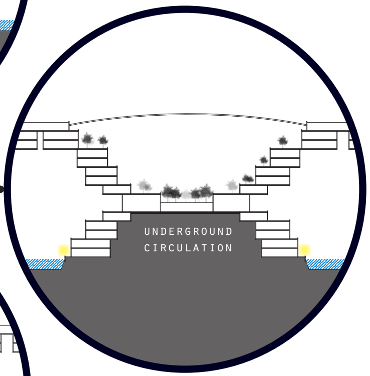
5/ Commercial & Civic

The lower layers of the cell pods are reserved for public programs such as commerical and civic programs as the terrace on these layers allow for public pedestrian circulation



6/ Pedestrian Circulation

Lowest level of cells pods is used for pedestrian circulation. Pods are connected the each other wi bridges



7/ Water Canals/ WaterBank

Underground water canals act as major water storage for the city and they also allow for water traffic through the site

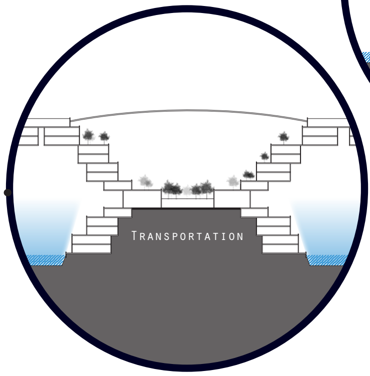


FIG.4.1: A dried section of Bernal Heights Park in San Francisco

THE GOLDEN GATE

WATER DEMAND AND HETCH HETCHY

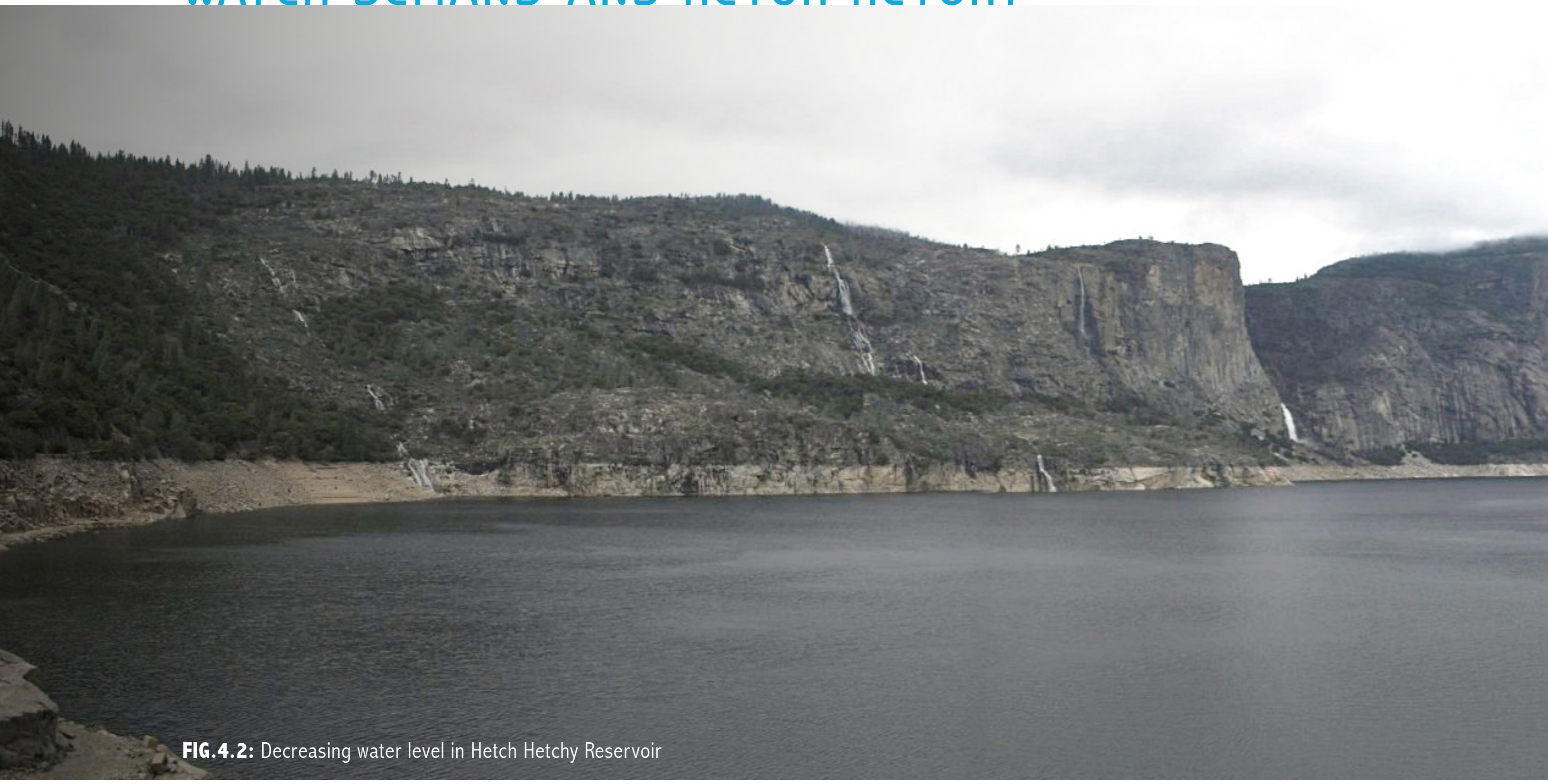


FIG.4.2: Decreasing water level in Hetch Hetchy Reservoir

A collection of 58 counties and 482 municipalities[1], California is the third largest[2] but most populated state in America.[3] Similar to the diverse landscape of the state, every California city is characterized with very different rates of urbanization and development. While the population of the state is spread along the coastal region and the Central Valley, the most urbanized regions are concentrated in the South Coast and the Bay Area in Northern California.[4] In order to contextualize and study the potential of a new generation of urban water infrastructures, San Francisco, a city located in the Bay Area is selected as a test site for AquaCalifornia, an urban water system design proposed in this thesis.

Influenced by the tech-industry boom in the last decade, the Bay Area has become the fastest growing region in the entire California.[5] The forming of the Silicon Valley in the region has attracted population from around the globe, and greatly increased the reach of urbanized zones in the nine counties that make up the Bay area[6]. Based on a report from the Center for Continuing Study of the California Economy, Bay area population have grown by 6.1% between 2010 and 2015, in comparison to the state-wide average of 4.6%.[7] By 2016, there is a total of 7,654,870 people residing the region and 805,235 people in San Francisco city alone[8]. This rapid population growth and urbanization also signified a corresponding increase in water demand, adding pressure to the Hetch Hetchy Water system, a centralized water supply system owned by the city of San Francisco. The 117-billion-gallon Hetch Hetchy reservoir currently

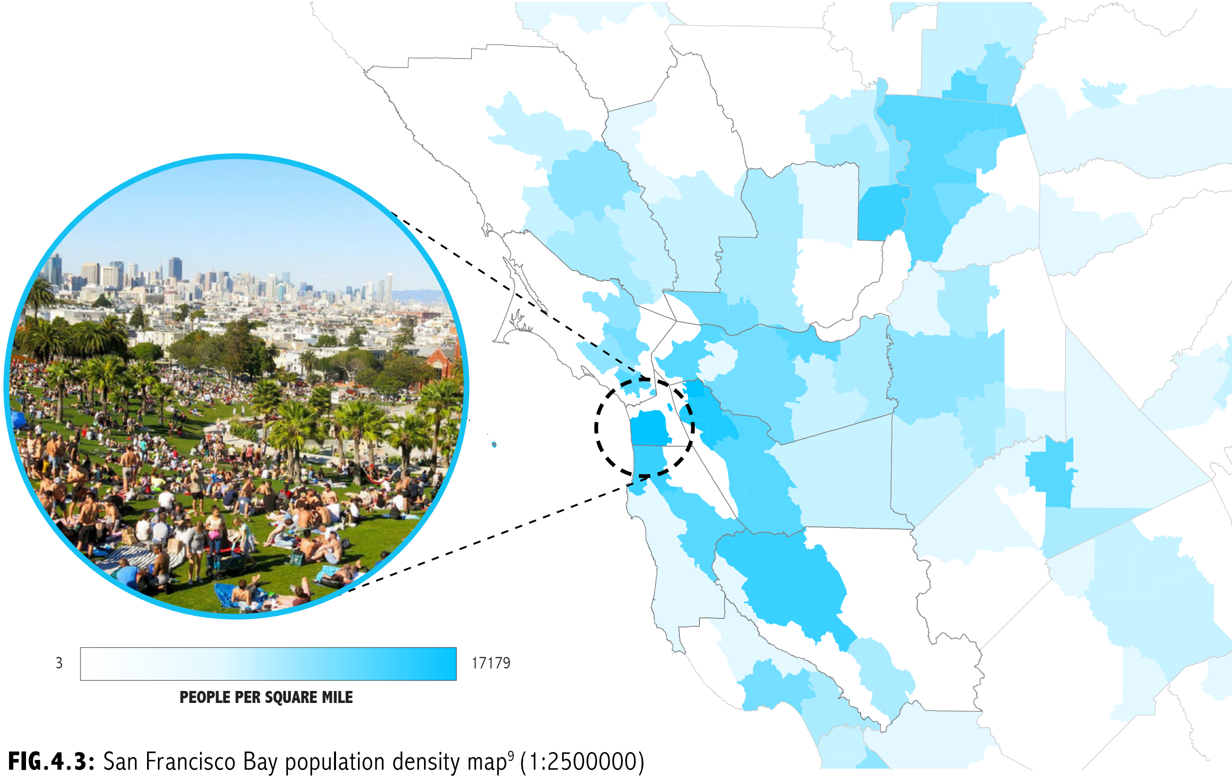


FIG.4.3: San Francisco Bay population density map[9] (1:2500000)

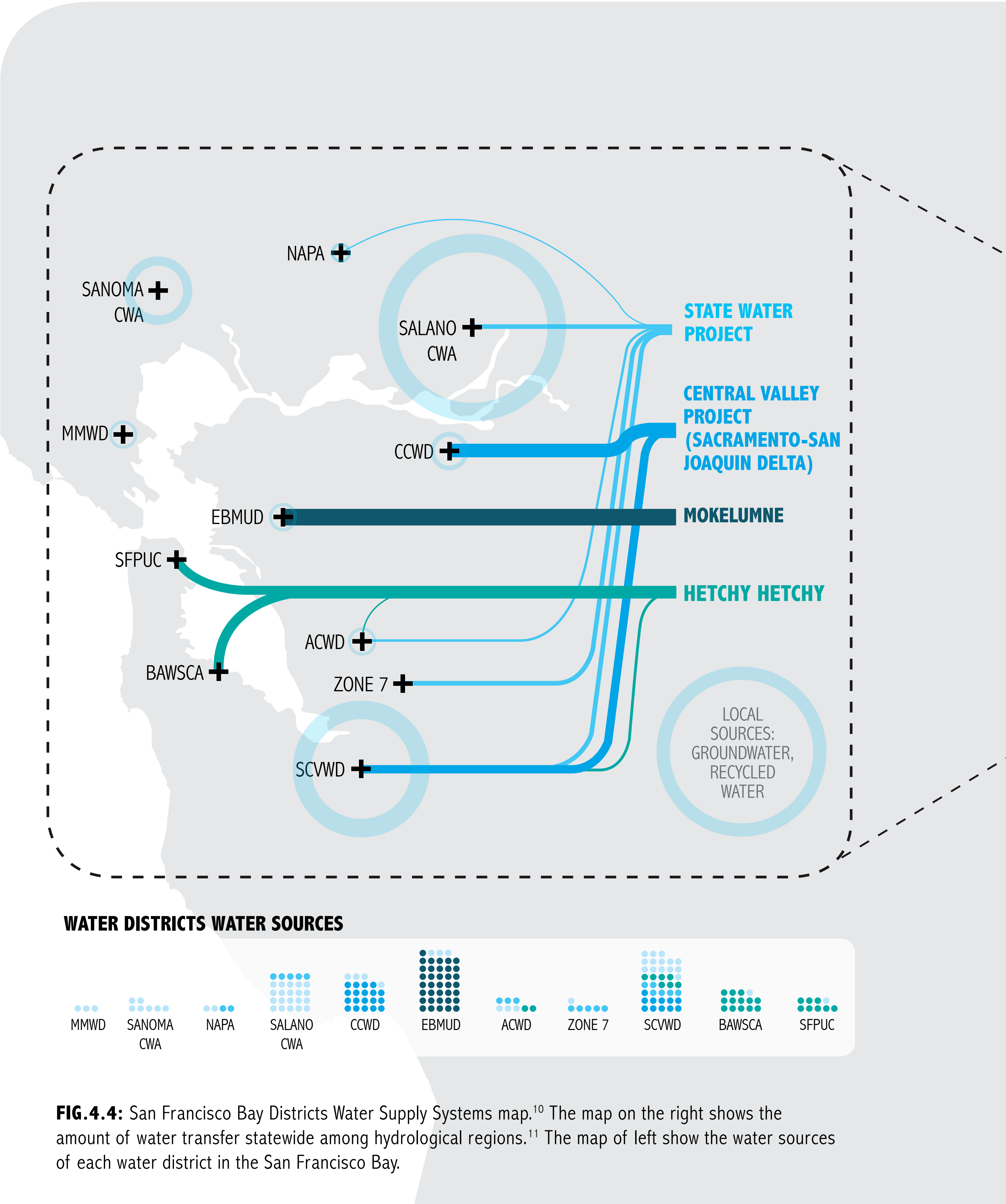
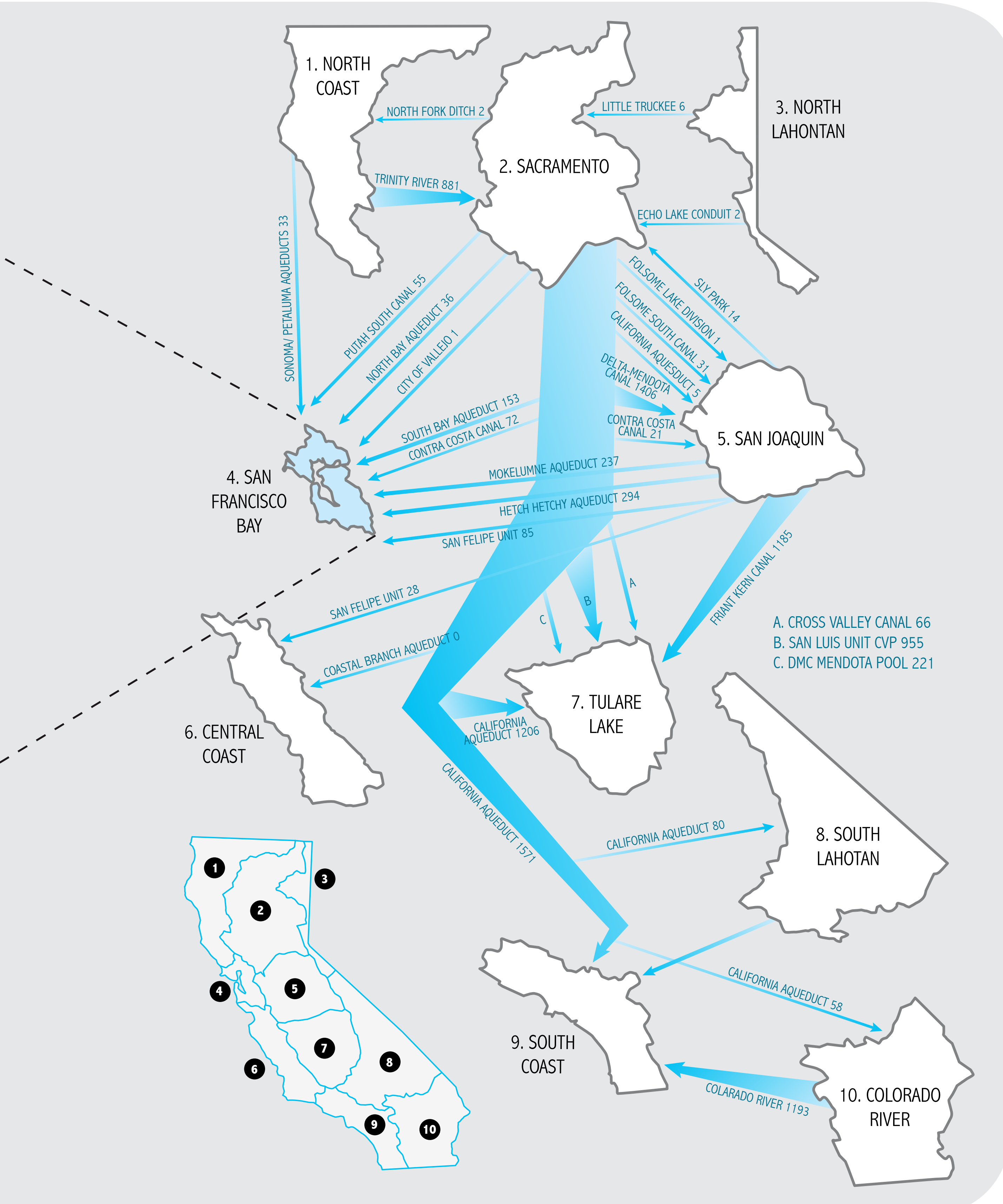


FIG.4.4: San Francisco Bay Districts Water Supply Systems map.[10] The map on the right shows the amount of water transfer statewide among hydrological regions.[11] The map of left show the water sources of each water district in the San Francisco Bay.


1. NORTH COAST
2. SACRAMENTO
3. NORTH LAHONTAN
4. SAN FRANCISCO BAY
5. SAN JOAQUIN
6. CENTRAL COAST
7. TULARE LAKE
8. SOUTH LAHOTAN
9. SOUTH COAST
10. COLORADO RIVER
NORTH FORK DITCH 2
LITTLE TRUCKEE 6
TRINITY RIVER 881
ECHO LAKE CONDUIT 2
SONOMA/ PETALUMA AQUEDUCTS 33
PUTAH SOUTH CANAL 55
NORTH BAY AQUEDUCT 36
CITY OF VALLEJO 1
FOLSOME LAKE DIVISION 1
SLY PARK 14
FOLSOME SOUTH CANAL 31
CALIFORNIA AQUESDUCT 5
DELTA-MENDOTA CANAL 1406
CONTRA COSTA CANAL 21
SOUTH BAY AQUEDUCT 153
CONTRA COSTA CANAL 72
MOKELUMNE AQUEDUCT 237
HETCH HETCHY AQUEDUCT 294
SAN FELIPE UNIT 85
SAN FELIPE UNIT 28
COASTAL BRANCH AQUEDUCT 0
FRIANT KERN CANAL 1185
A
B
C
A. CROSS VALLEY CANAL 66
B. SAN LUIS UNIT CVP 955
C. DMC MENDOTA POOL 221
CALIFORNIA AQUEDUCT 1206
CALIFORNIA AQUEDUCT 1571
CALIFORNIA AQUEDUCT 80
CALIFORNIA AQUEDUCT 58
COLORADO RIVER 1193
1
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10

supplies pristine drinking water to 2.4 million Bay Area residents and industrial users. As for San Francisco, almost 90% of its water comes directly from the Hetch Hetchy system.[12] Freshwater in this system originates from the Tuolumne River, then travels west, passing through the San Joaquin Valley to the coastal area. In this process, the water also passes through tunnels leading down to a series of powerhouses that generates electricity.[13] When the water eventually arrives in San Francisco, it is guided into the ten in-City reservoirs for temporary storage before distribution to all users. These reservoirs for potable water storage are constructed at high points of the city to take advantage of the city's hilly topography for gravity fed water delivery. They are also constructed in bedrocks to make them more resilient to regional seismic activity.[14] In fact, the idea of the Hetch Hetchy aqueduct and reservoir was initially proposed as a response to the historic1906 earthquake and fire that devastated San Francisco, when the city realized its need to strengthen its insufficient water supply.[15] In 1913, the proposal was officially approved and construction of the O'Shaughnessy Dam and the Hetch Hetchy reservoir began in the Yosemite National Park.[16] The water supply system has remained controversial throughout the century, mainly due to the Valley's historical and environmental value, and the fact that it is the only reservoir inside a national park. Since its construction, preservationists such as John Muir started campaigning against the system, calling for the decommissioning of the reservoir and the restoration of the natural Hetchy Hetchy Valley.[17] The latest group leading the campaign is Restore Hetch Hetchy, who has been vocal in their support for a dam removal project.[18] Contrary to the position of Restore Hetch Hetchy, many residents, NGOs and government bodies in San Francisco and Bay Area cities argued that the reservoir must remain an integral part of the water system to secure water supply for the area.[19] According to the San Francisco Public Utilities Commission (SFPUC), the Hetch Hetchy system is one of the more successful centralized water systems in the state. The reservoir remained one of the least impacted during the severe drought and it is key to providing affordable energy and high quality water to its users.[20]

These countering perspectives actually makes San Francisco a very compelling test site for a new form of urban water infrastructure. Considering the increasing pressures from the drought, a projected trend of lower precipitation and high temperatures in the coming years, the SFPUC agrees that it is necessary for the city to invest in more alternative forms of water resources. While a localized urban water systems would also signify less dependence on the Hetch Hetchy Reservoir. Essentially, a water system that focuses on water diversification would not only function as a crucial step to ensure the general resiliency of San Francisco, but also helps bridge the divide between different agencies in the city.

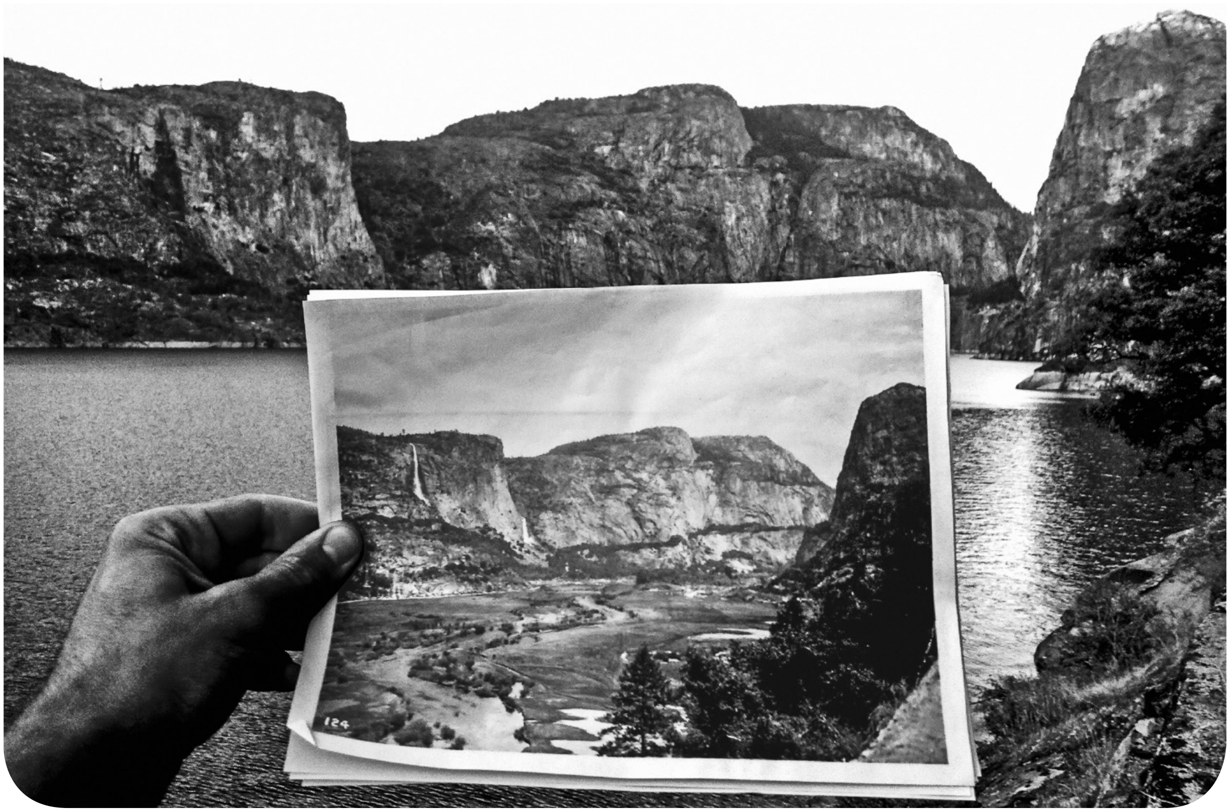


FIG.4.5: Hetch Hetchy Valley before and after the O'Shaughnessy Dam was constructed to form the Hetch Hetchy Reservoir

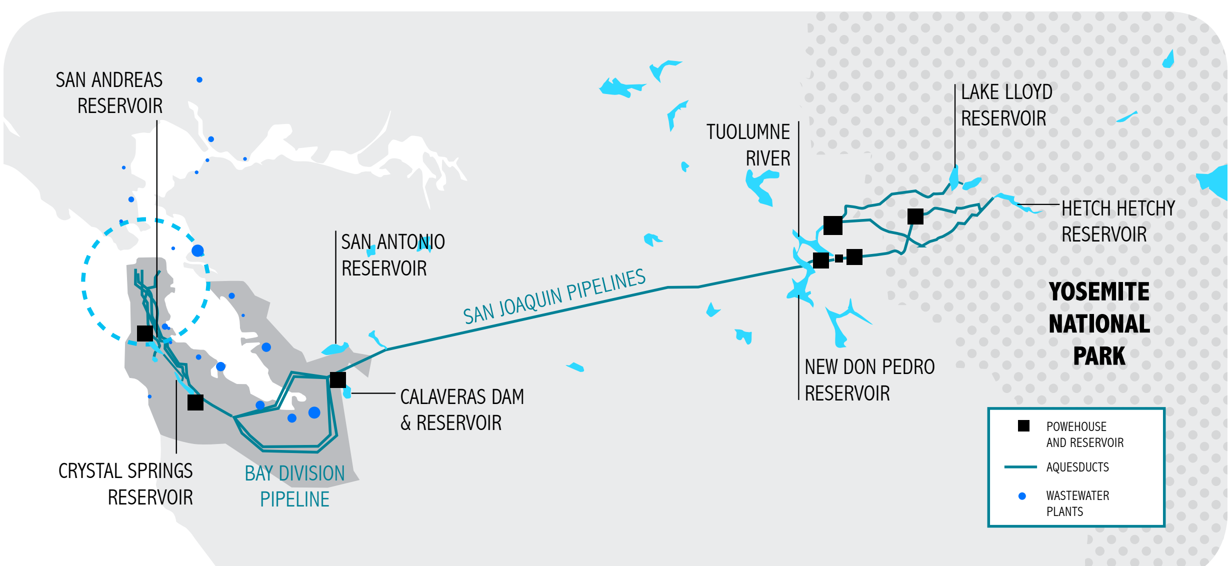


FIG.4.6: Hetch Hetchy Water Delivery system map.[21]

DISAPPEARING WETLANDS AND WATER POLLUTION

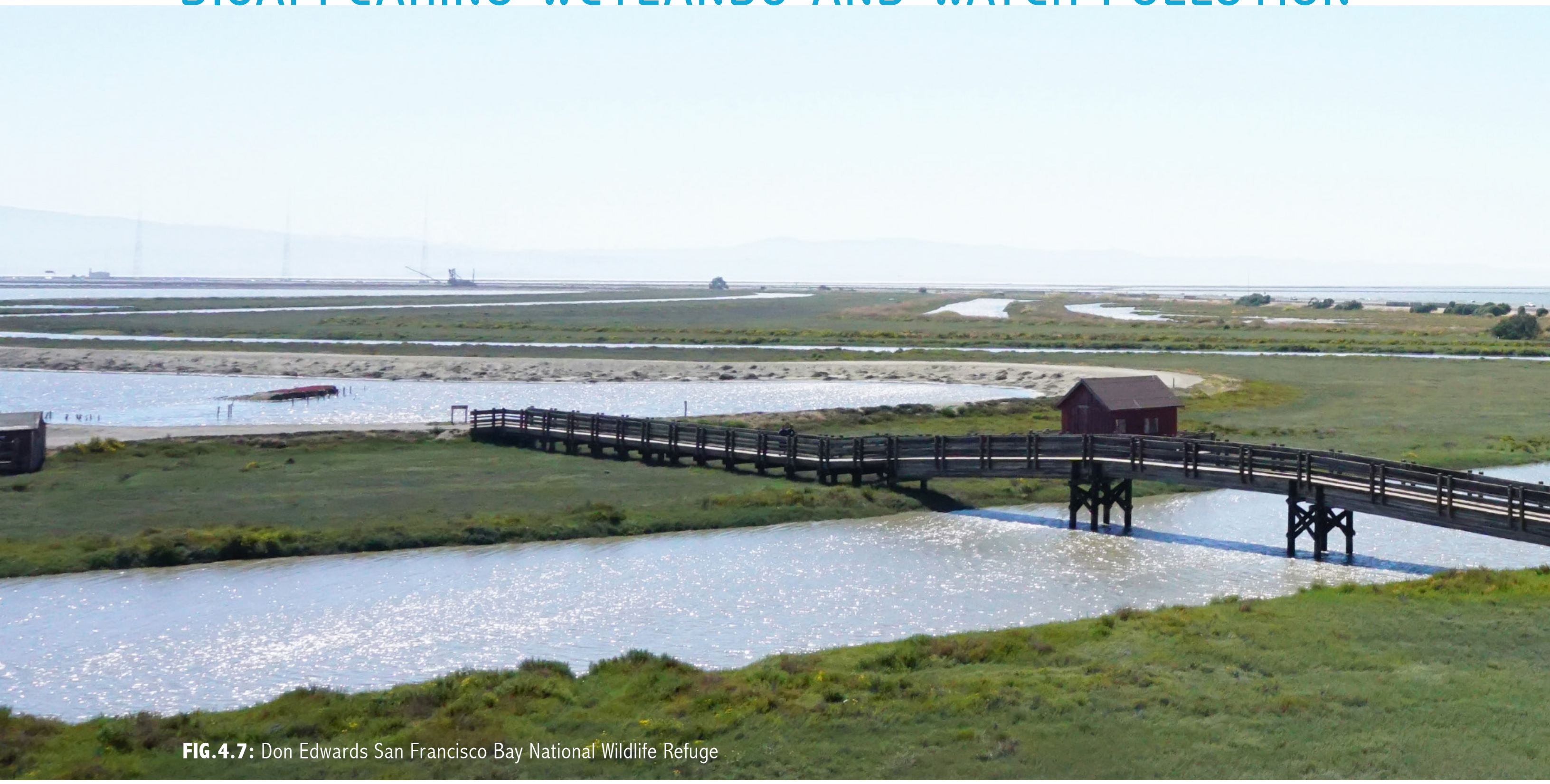


FIG.4.7: Don Edwards San Francisco Bay National Wildlife Refuge

The Sacramento- San Joaquin Delta located inside San Francisco Bay is one of America's most important wetland habitats. Water from the Delta spreads into almost 700 miles of channels to form the largest estuary on America's west coast.[22] However, much of the wetland and marshes have been replaced by landfills in the last century due to rapid urbanization in the region. The Delta once supported 345,000 acres of seasonal tidal marshes but is now down to only 8000 acres.[23] This lost of wetlands habitats is extremely concerning as they support a range of migratory and residents bird, fish and plant species.[24]

In addition to the lost of tidal marshes and wetlands, the San Francisco Bay ecosystem is also threatened by heavy pollution. Surrounded by nine highly urbanized counties, the Bay is one of the most polluted water bodies in California. The Bay drains water from almost 40% of the State, including flows from both the Sacramento River and San Joaquin River.[25] The waters from these two rivers often carry a large amount of agricultural runoff, which contains pollutants such as pesticides and nutrients.[26] The water quality issue of the Bay is further worsened by the constant discharge of urban runoff from the surrounding counties. The pollutants contained in these urban discharge, such as pharmaceuticals, heavy metals, mercury, organic matter and so on, are proven to be extremely damaging to ecosystem health and could post serious threats to aquatic life.[27]

In most Bay area cities, urban runoff is typically separated into two drainage systems, the stormwater drainage and wastewater drainage

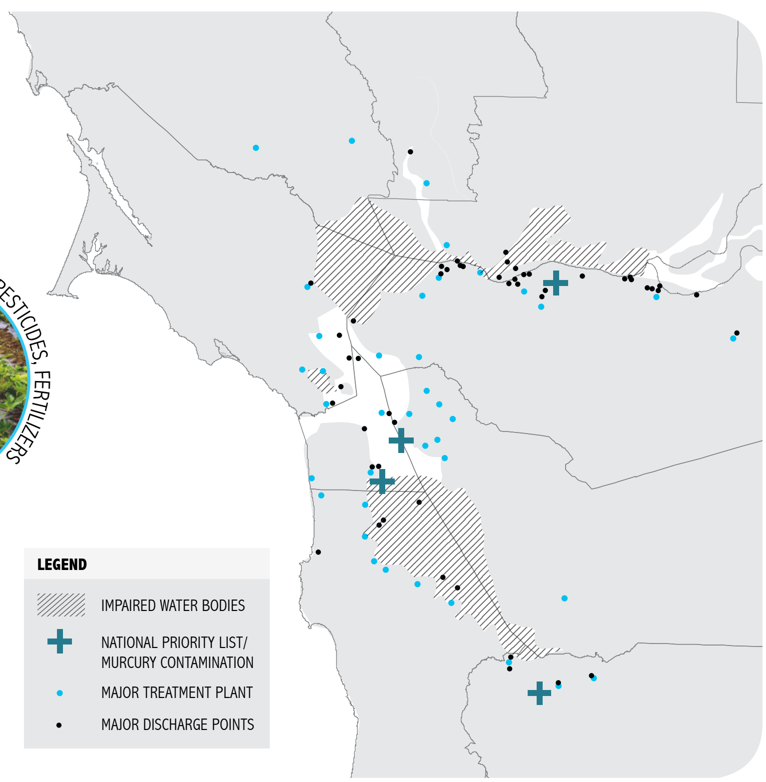


FIG.4.8: San Francisco Bay water pollution map[28] (1:1300000)

FIG.4.9-11: Wetland and Marshes in San Francisco Bay.
9 Don Edwards San Francisco Bay National Wildlife Refuge
10 Seasonal wetlands at Baylands Wetland Park in Sunnyvale
11 Restored tidal wetlands along the coast of Palo Alto

FIG.4.12-14: Chrissy Field Marshes, the remaining and restored wetland In San Francisco.

DISAPPEARING WETLANDS AND WATER POLLUTION CONT.

FIG.4.15: Flooded areas in Los Angeles during a storm event

FIG.4.16: Winter months are the wet season of the year

system. Although both types of water contain forms of pollutants, stormwater is comparatively clean. Therefore stormwater is directed into natural water bodies with little treatment, while wastewater must undergo tertiary treatment before being discharged.[29] Nonetheless, in San Francisco, one of the most populated cities in the Bay, the two discharge processes are jointed through the combined sewer system. In this system, stormwater, greywater and wastewater are all collected into one set of sewers and are directed to a treatment plant before disposal. The initial concept was to provide adequate treatment to all water before it is discharged.[30] However, at a time where any potential water resources should be maximized, the system becomes wasteful as it contaminates the valuable stormwater resource. On a day with heavy precipitation, the system is even more problematic. Although California is under a drought, the El Nino effect does bring forth occasional heavy rainstorms to parts of the State, especially the coastal regions. In a hyper-urbanized area like San Francisco, the water produced from these storm events would have difficulty infiltrating through the concrete-covered streets and is directed straightly into the combined sewers. The heavy stormwater flow combined with the increased wastewater produced by a larger population overwhelms the sewage system and causes sewage overflow, where excess untreated water would be released into the Bay or the ocean when the sewage system is at its full capacity.[31] In spite of the SFPUC's effort to gradually separate the drainage systems in newly developed areas, San Francisco is still predominantly supported by combined sewers.[32] In order to prevent any wasteful disposal and capitalize potential water recourses, San Francisco must study ways to reinvent the combined sewers and invest in new systems capable of handling different water types separately.

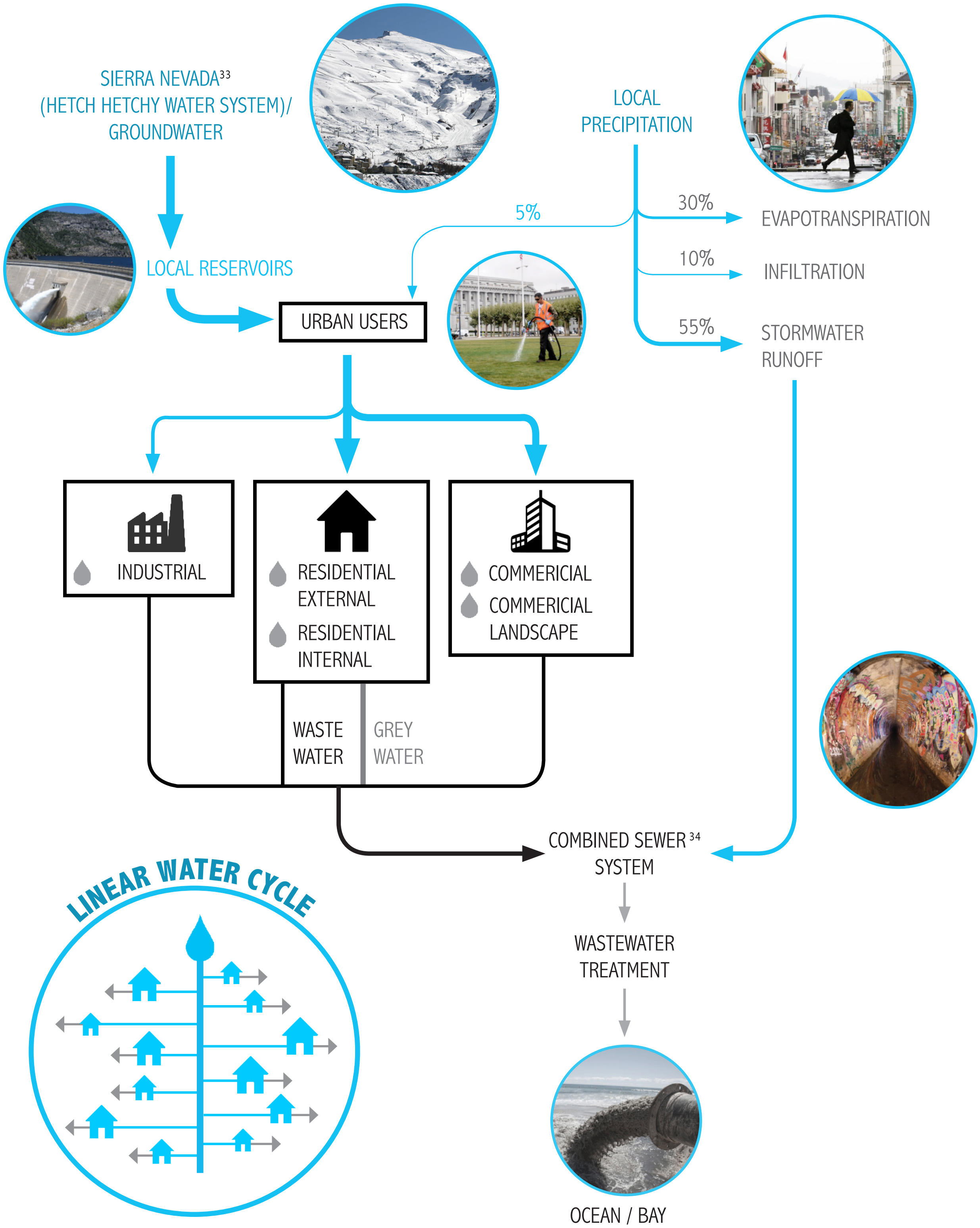


FIG.4.17: San Francisco existing urban water cycle

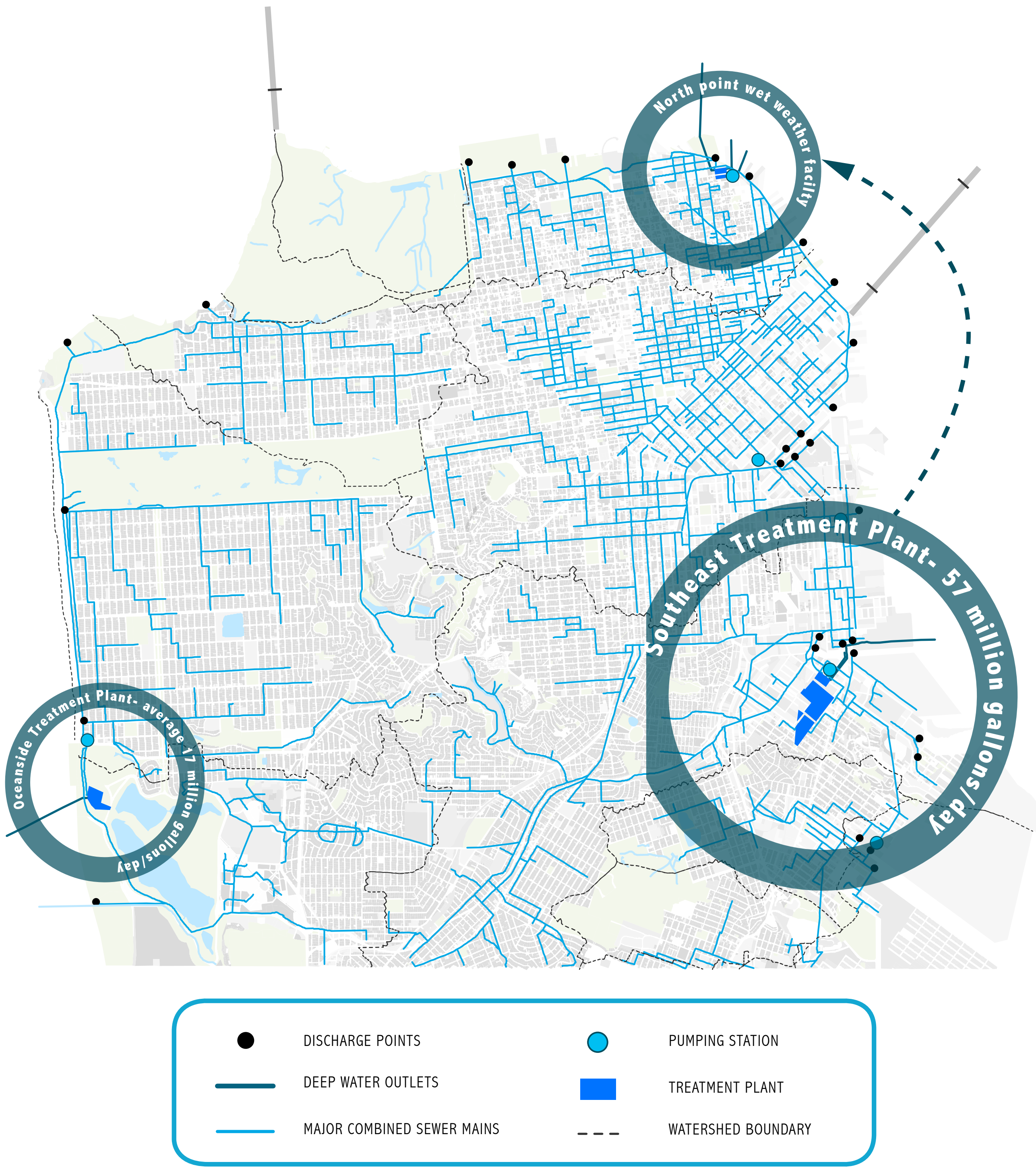


FIG.4.18: San Francisco Combined Sewer System Map[35] (1:80000)
This shows the location of combined sewer mains and the three municipal wastewater treatment plant in the city. The Southwest Treatment Plant and the Oceanside Treatment Plant operates daily throughout the year, and the Northpoint Treatment plant only operates when the Southeast Treatment Plant exceeds its maximum capacity. Wastewater effluent is then disposed through the deep water outlets into the Ocean or the Bay.

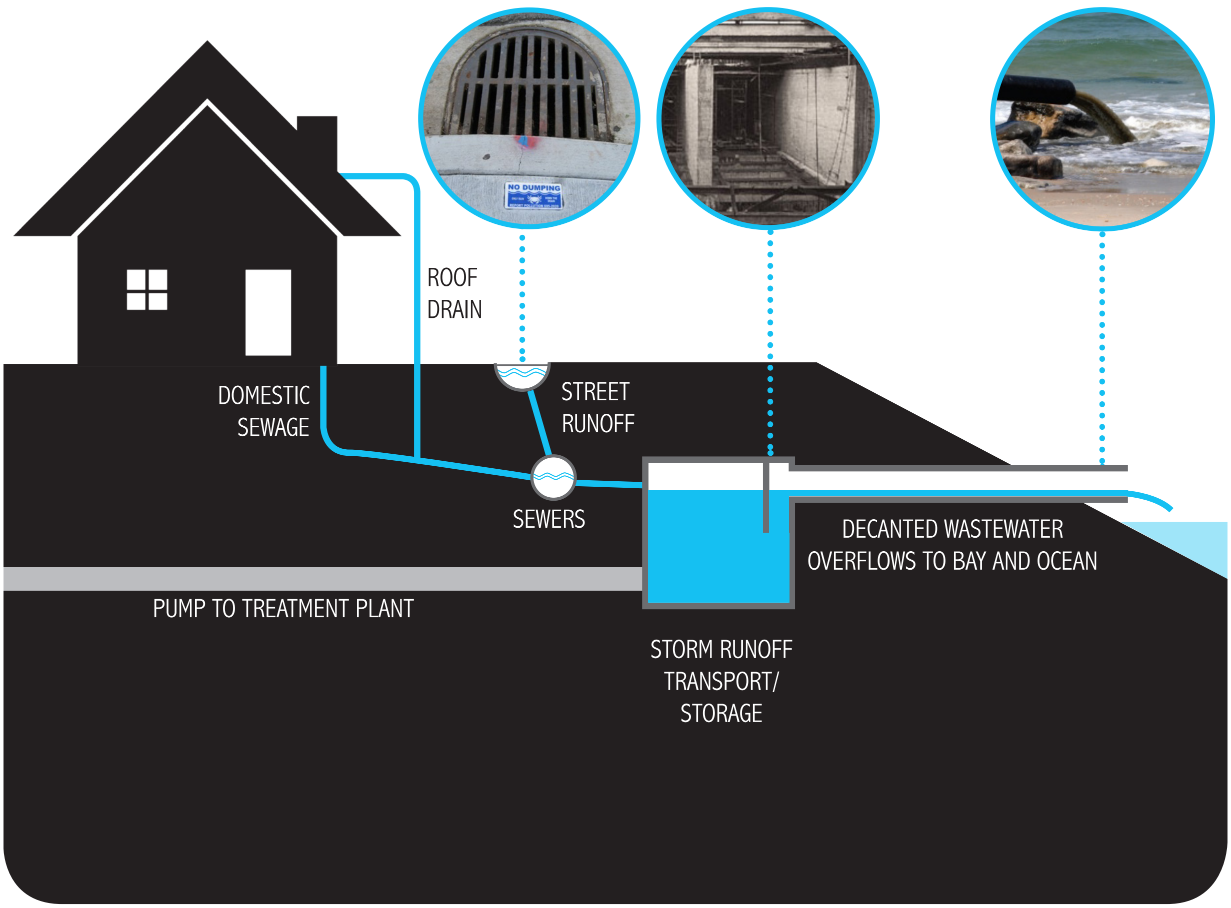


FIG.4.19: San Francisco combined sewer process[36]

CULTURAL-POLITICAL FORCES

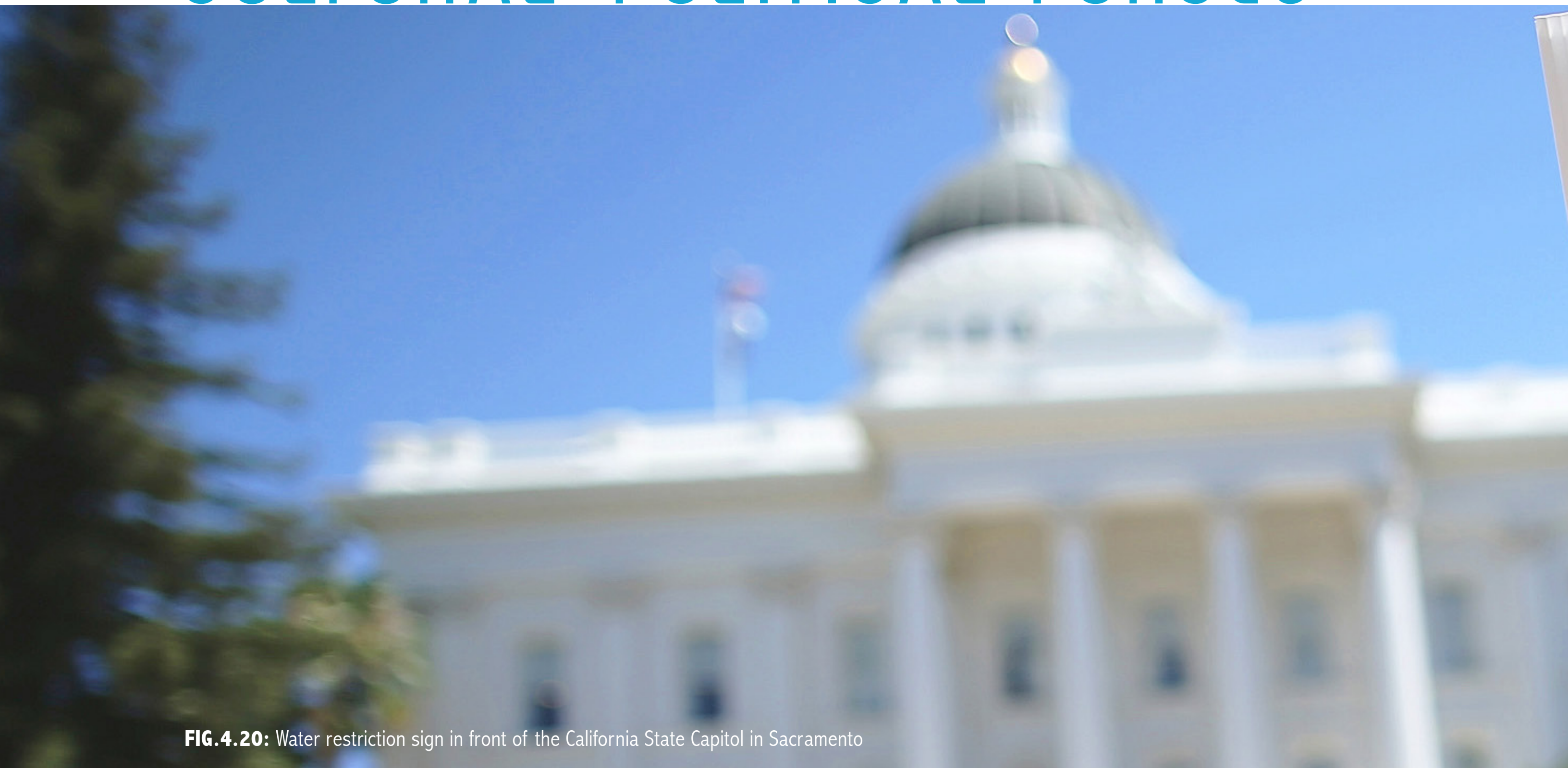
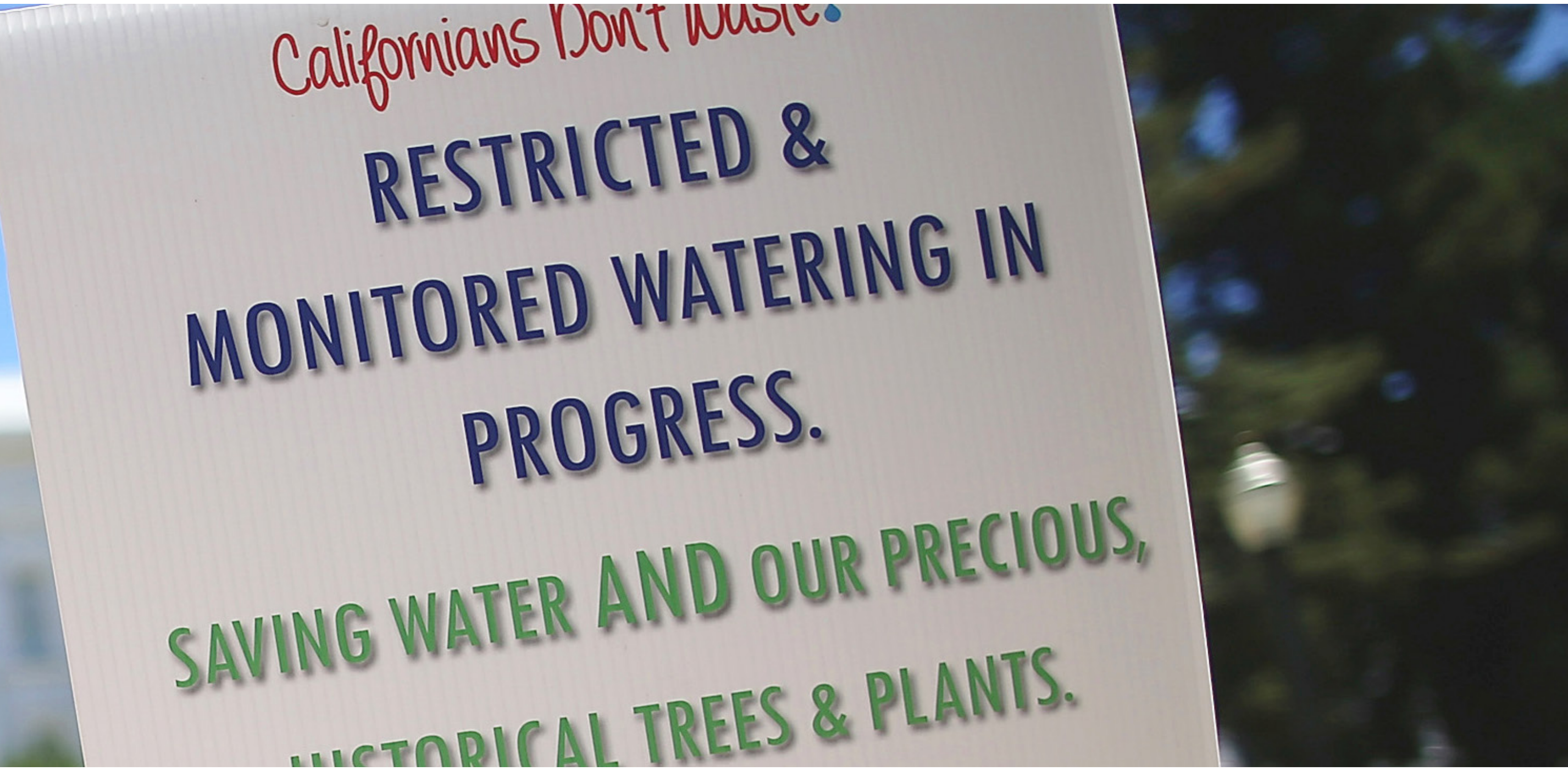


FIG.4.20: Water restriction sign in front of the California State Capitol in Sacramento

Considered as one of America's most progressive States, California has long provided an environment for important social and political changes in American history, and San Francisco is undoubtedly the center for these social-political movements. In the face of climate change, much attention and effort have been brought to environmental issues and a range of NGOs was established in the Bay area to address its impact. As the severe drought prevails, many of these NGOs are actively promoting different policies and programs to help diversify water resources and encourage water conservation. One of these organizations include SPUR (The San Francisco Bay Area Planning and Urban Research Association), a civic planning organization that gathers leaders across the political spectrum to undertake urban issues, such as drought impacts on urban water systems and corresponding green infrastructure developments.[37] Another major NGO based in the Bay Area is the Pacific Institute. This organization is dedicated to researching and developing solutions for global water issues, and in recent years it have been producing some of the most in-depth studies on the California drought phenomenon, making it a leading expert on drought research.[38] Other than the large numbers of NGOs in the Bay Area and San Francisco, the municipal government is also an active driver for multiple sustainable water policies in the city. The stormwater management ordinance and the non-potable water program imposed by the SFPUC are perhaps the most important policies for urban water management during this drought period.[39] The stormwater management ordinance was formed



in 2010 and updated in 2016 to enforce the use of green infrastructure in new and redevelopment projects. Based on the size of the development, these projects are required to achieve different stages of impervious surfaces to assist natural infiltration.[40] As for the non-potable water program, it is a relatively recent program introduced to encourage on-site collection, treatment and use of alternate water resources for non-potable applications.[41] Even though these program would mean that developers have to spend extra money and effort in incorporating sustainable water designs, it is well-received overall and had not caused much conflict between government agencies and developers, mainly due to the constructive relationship maintained between these stakeholders though years of cooperation and open communications.[42] The same concern for the sustainable water management also extends to the public. For example, when water restrictions was first announced at the beginning of the drought, the SFPUC introduced a lawn rebate program to provide funding for residences retrofitting their lawns with drought resistant designs. The program was a huge success and reached its maximum number of applications in matters of weeks.[43] Currently, similar rebate and incentive programs are still being offered to the public. The support for innovation and commitment to the sustainability has always been an integral part of the San Francisco culture and identity. Such culture also makes San Francisco the ideal testing ground for a new direction of water infrastructure and for developing new ways of understanding the relationship between water infrastructure and the urban fabric.

SAN FRANCISCO BAY STAKEHOLDERS

COMMUNITY:

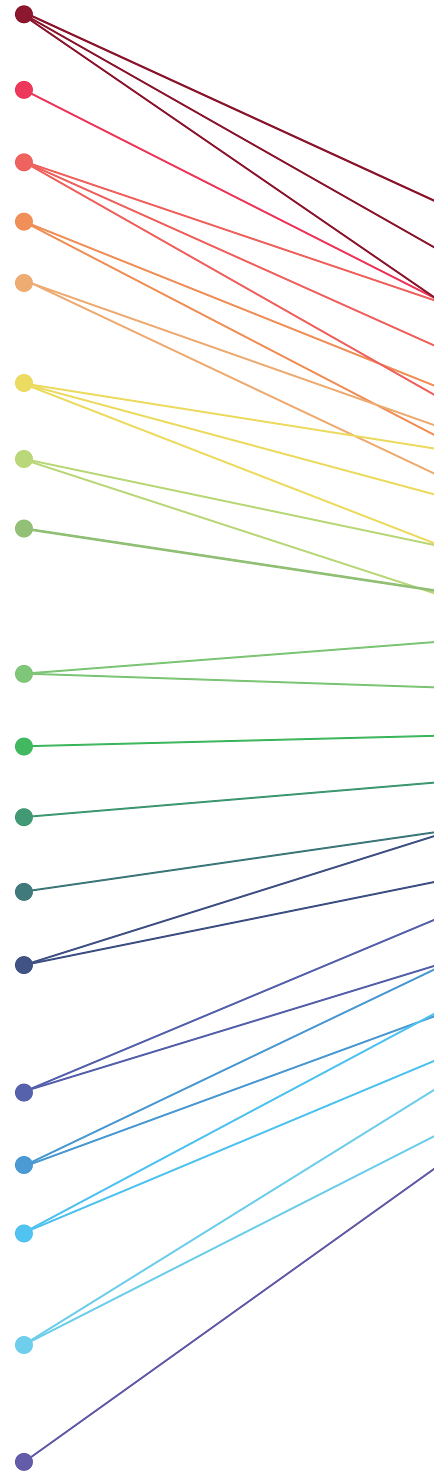
- INSTITUTIONS: MUSEUM, UNIVERSITY, PACIFIC INSTITUTE
- SPUR (PLANNERS AND DESIGNERS)
- URBAN AREA LOCAL RESIDENTS
- RETAILERS
- CONVENTION, EVENT PLANNERS
- SILICON VALLEY: LARGE TECH COMPANIES, START-UP COMPANIES
- SAN FRANCISCO URBAN AGRICULTURE ALLIANCES
- RESTORE HETCH HETCHY

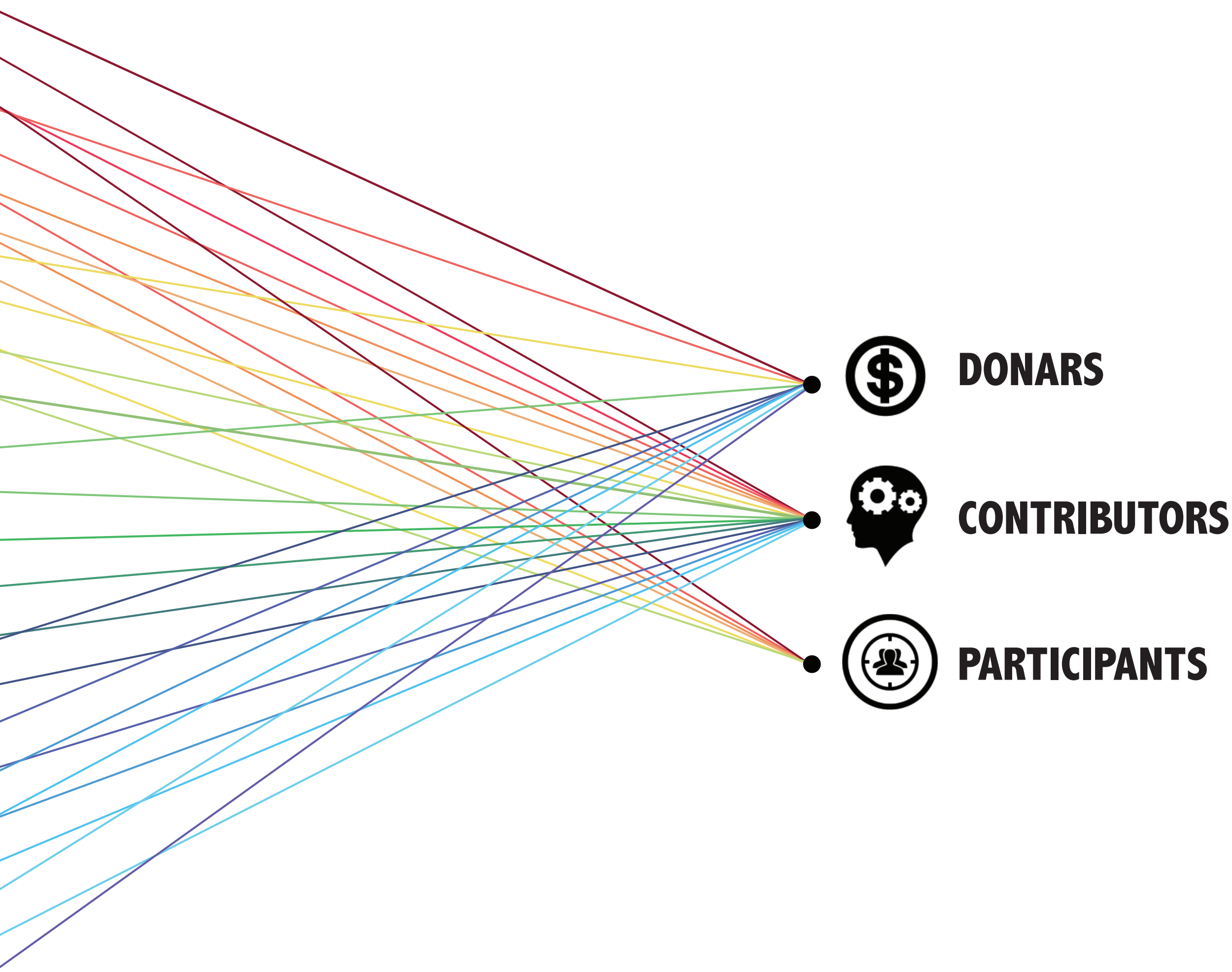
WATER AGENCIES:

- BAY AREA WATER SUPPLY AND CONSERVATION AGENCY
- BAYWORK (WATER/ WASTEWATER WORKFORCE)
- CALIFORNIA URBAN WATER CONSERVATION COUNCIL
- CITY WATER DISTRICTS: WATER SUPPLIERS
- SAN FRANCISCO PUBLIC UTILITIES COMMISSION

GOVERNANCE BODIES:

- GREEN FINANCE SF
- MUNICIPAL GOVERNMENTS
- SAN FRANCISCO BAY REGIONAL WATER QUALITY CONTROL BOARD
- CALIFORNIA DEPARTMENT OF WATER RESOURCES: THE DIVISION OF FIANACIAL ASSISTANCE
- BUREAU OF RECLAMATION (FEDERAL)




DONARS
CONTRIBUTORS
PARTICIPANTS

SAN FRANCISCO BAY STAKEHOLDERS CONT.

FIG.4.21: A range of stakeholders in the city that could participate, contribute or donate/ invest in new water systems. The bubbles further explains their roles in the new water system.

INSTITUTIONS

Combining ideas and knowledge from various fields at an academic level, to design a network that can also act as research ground and education space for students and researchers

RETAILERS AND EVENT PLANNERS

Retailers can set up commercial programs along the system, and convention/ event planners can host temporal events/ festivals at different spaces within the water system.

SILICONE VALLEY

Google
facebook.

These companies form one of the biggest industry in the region, and often involves and endorse innovations and emerging technologies. They may be able to provide funding and resources for the project if the water system can provide them with commercial benefits.

CALIFORNIA URBAN WATER CONSERVATION COUNCIL

California Urban Water Conservation Council

A membership organization dedicated to maximizing urban water conservation by supporting and integrating innovative technologies and practices; encouraging public policies; research, training, public education and partnerships.[46]
A sustainable water system would align with their vision.

CITIES PUBLIC UTILITIES COMMISSIONS

San Francisco Water Power Sewer

Services of the San Francisco Public Utilities Commission

Part of local government, they are responsible for drinking water, wastewater and power services. Their services are supported by the Business Services, Infrastructure and External Affairs bureaus[47]
They would be an important source of financial and technical support.

SPUR

SPUR is a leading civic planning organization that brings people together from across the political spectrum to develop solutions to the urban issues. Their experience, knowledge and support would be important to the realization of the proposed water system.[44]

LOCAL RESIDENTS

Engaging the local residences in the design process to cater to the needs of the communities and better respond to social condition of each district. Communities may also be able to provide funding for the project.

URBAN AGRICULTURAL ALLIANCES

Green infrastructure within the water system provides spaces for small-scale agriculture for urban farmers and communities.

BAY AREA WATER SUPPLY AND CONSERVATION AGENCY

BAWSCA
Bay Area Water Supply & Conservation Agency

Represents the interests of 24 cities and water districts, and two private utilities, that purchase water wholesale from the San Francisco regional water system.[45] Their support would be imperative to the implementation process.

SAN FRANCISCO BAY REGIONAL WATER QUALITY CONTROL BOARD

California Water Boards
State Water Resources Control Board
Regional Water Quality Control Boards

Part of the California Environmental Protection Agency, these boards have the power to preserve and enhance all beneficial uses of the state's immensely complex waterscape and fund projects that helps protect water quality in the Bay area.[48]

CALIFORNIA DEPARTMENT OF WATER RESOURCES

Department of Water Resources
State of California

Part of the California Natural Resources Agency , The Department of Water Resources is responsible for the state of California's management and regulation of water usage.[49]

EXISITNG WATER SYSTEM

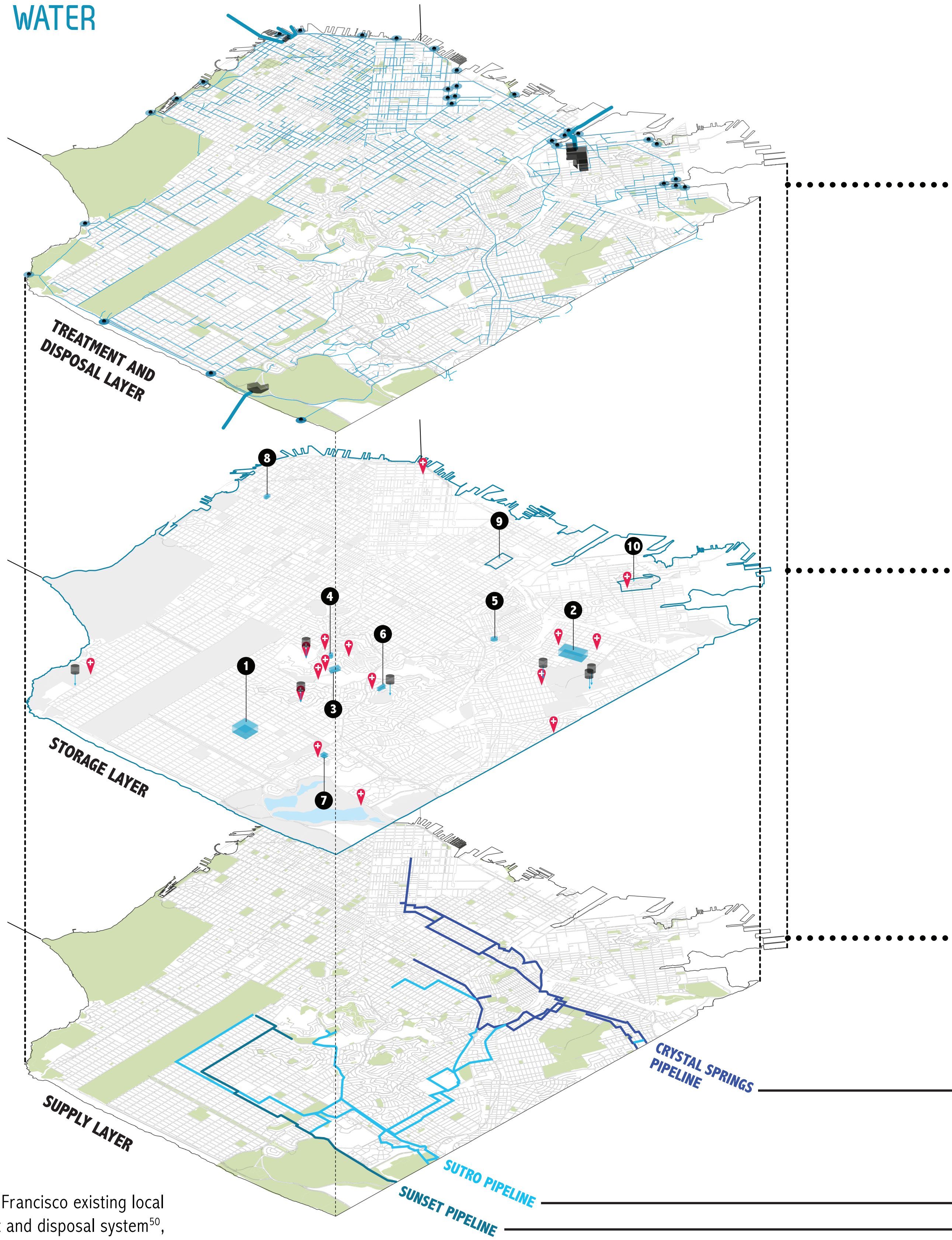


FIG.4.22: San Francisco existing local water treatment and disposal system[50], water storage system[51] and water supply system[52]

FIG.4.23: Combined sewers

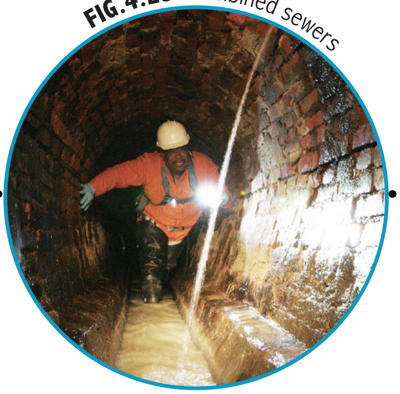


FIG.4.24: Storm drains

COMBINED SEWERS AND DISCHARGE

- MAJOR COMBINED SEWAGE PIPES
- DEEP WATER DISCHARGE
- DISCHARGE POINTS
- WASTEWATER PLANT

FIG.4.25: Sutro Reservoir

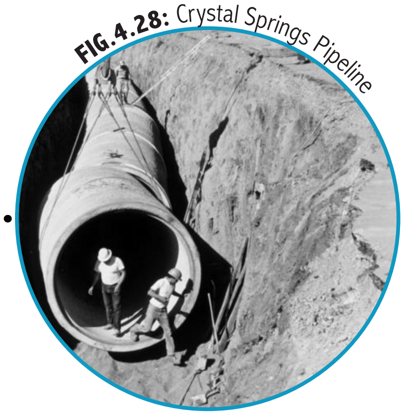
FIG.4.26: University Mound Reservoir

RESERVOIRS PUMP STATIONS

- PUMP STATIONS
- EXISTING SURFACE WATER TANKS
1. SUNSET RESERVOIR 666611 m3
2. UNIVERSITY MOUND RESERVOIR 533364 m3
3. SUTRO RESERVOIR 118861 m3
4. SUMMIT RESERVOIR 52995 m3
5. COLLEGE HILL RESERVOIR 51103 m3
6. STANFORD HEIGHTS RESERVOIR 48831 m3
7. MERCED MANOR RESERVOIR 35961 m3
8. LOMBARD RESERVOIR 10220 m3
9. POTRERO RESERVOIR 3785 m3
10. HUNTERS POINT RESERVOIR 4163 m3

FIG.4.27: Hetch Hetchy transfer pipeline

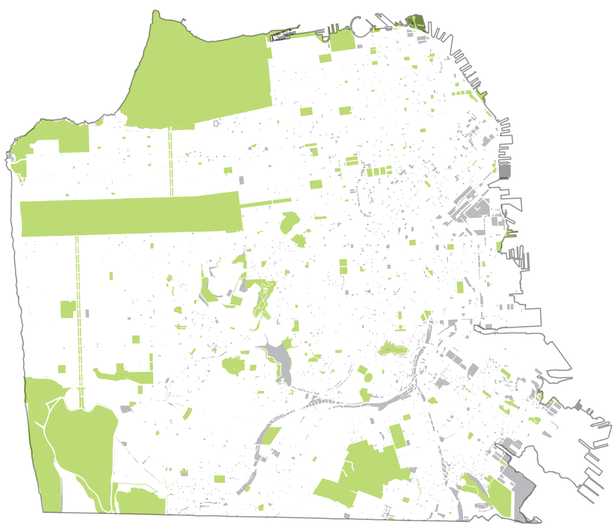
FIG.4.28: Crystal Springs Pipeline



FROM HETCH HETCHY SYSTEM

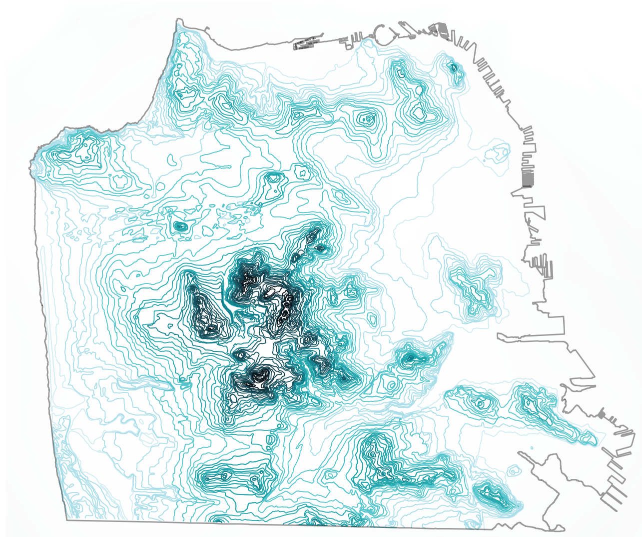
SAN FRNACISCO LOCAL CONTEXTS

FIG.4.29: VACANT & GREEN SPACE [53]



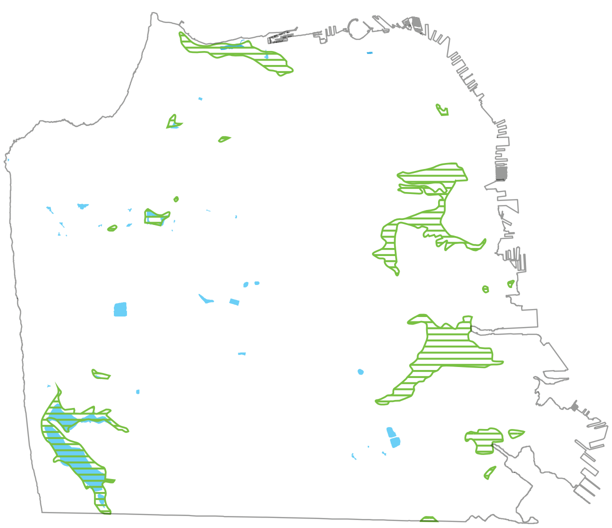
Green Space
Vacant Space

FIG.4.30: TOPOGRAPHY [54]



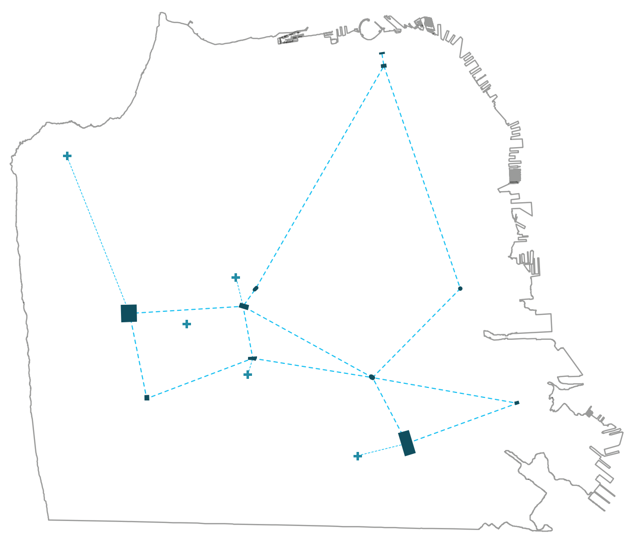
0m 283m Elevations

FIG.4.33: HISTORIC WETLANDS/ WATER BODIES [57]



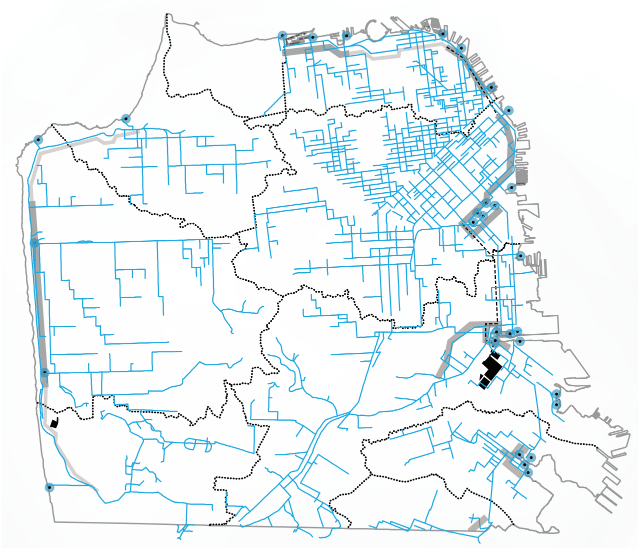
Historic Wetlands
Inland Water bodies

FIG.4.34: EXISITNG LOCAL STORAGE [58]



Water Tanks
Exisitng Reservoirs

FIG.4.31: WASTEWATER NETWORK [55]

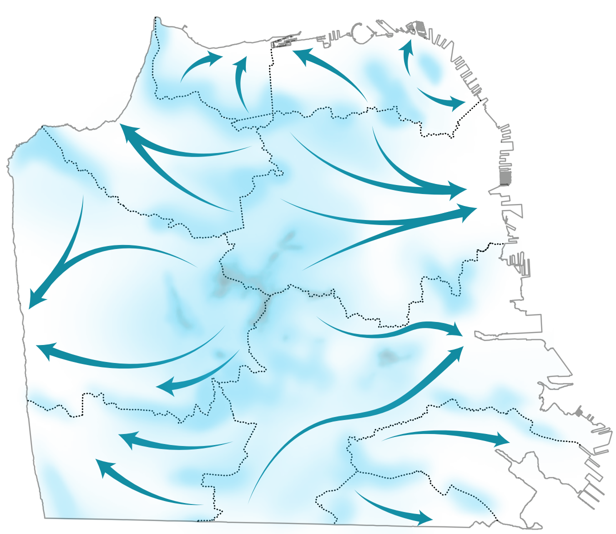


Transfer/ Storage Tunnel
Combined Sewers
Wastewater Plant
Discharge Points

FIG.4.32: SAND DUNES VS. LANDFILL [56]

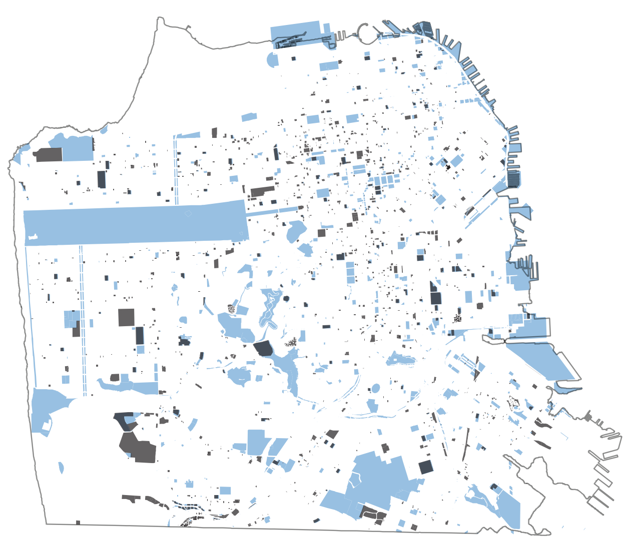
Sand dunes
Landfill

FIG.4.35: WATERSHED AND RUNOFF [59]



Watershed Boundary
Water Direction

FIG.4.36: LAND OWNERSHIP & INSTITUTIONAL SPACE [60]



Publicly Owned Land
Institutional Space

FIG.5.1: Aerial view of San Francisco

60%

SAN FRANCISCO WATER SYSTEM

San Francisco is one of the Golden State's most successful water conservation cities in this 5-year drought. Successful policies and public participation have helped the city achieve and even exceed its initial conservation goals.[1] While the current San Francisco model serves as an example for other California cities, the next steps to continue the progress would require a reinvention of the city's urban water system. In this thesis, three water infrastructure typologies are introduced to capitalize the city's alternative water resources, greywater and stormwater, and 60% represents the proportion of San Francisco water demand that can potentially be replaced with water from this renewed system. Completely separated from the existing Hetch Hetchy network, the new system would depend solely on alternative water resources and the repetition of each typology would form different water-harvesting layers across the city to capture these water resources. While together they work as a full water reuse system, the function of each typology does not depend on each other and can be implemented independently based on changing contexts and timeline. The three typologies are also designed to target different stakeholders in the city to encourage contribution from all levels of society. What distinguish these typologies from typical water infrastructure is their functions beyond water treatment, they are meant to integrate as part of the urban fabric and serve as forms of public space and amenities to provide a series of recreational, commercial, and educational programs to local communities.

The first typology in the proposed system is

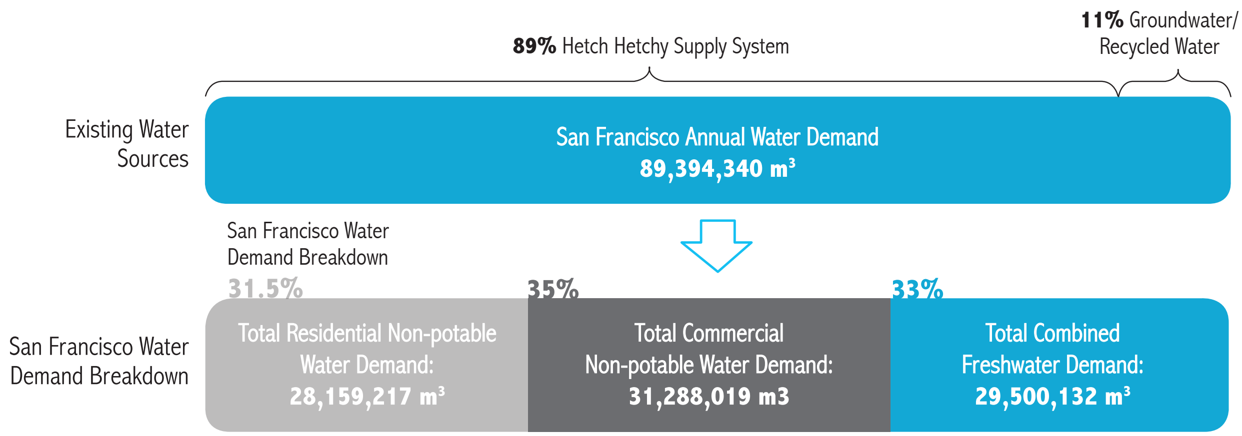


FIG.5.2: Chart comparing San Francisco water demands with exisitng water sources[2]

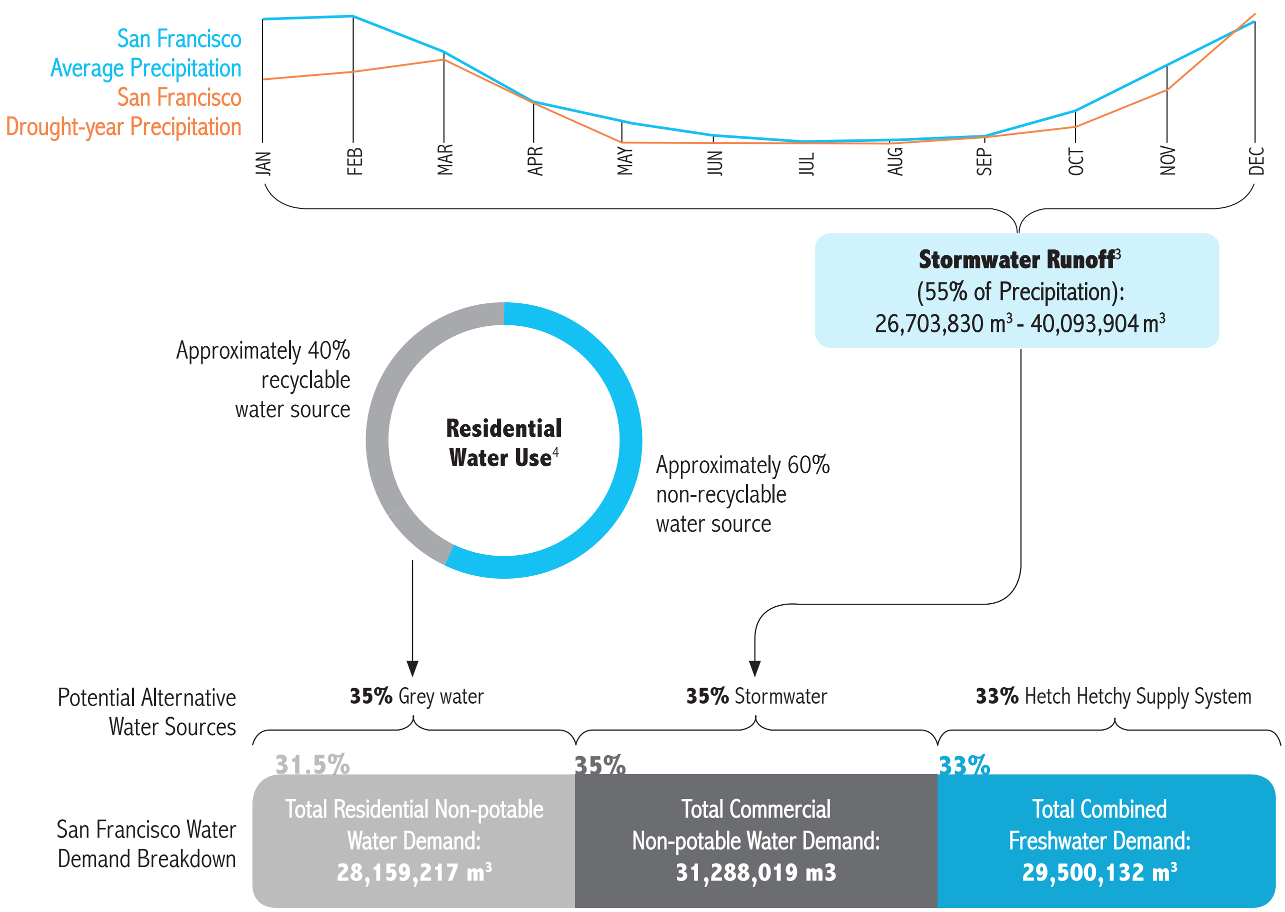


FIG.5.3: Chart comparing San Francisco water demands with proposed alternative water sources

the water block, a system composed of household greywater bio-filtration module designed for typical San Francisco backyards. The water block however refers to the courtyard strip formed within a residential block, when fences are removed between residences and multiple household bio-filtration modules are connected. Essentially, the typology creates a local greywater recycling system within every residential block that also double as a shared, recreational open space for its residents. The other two typologies then focus on the capture of stormwater in the city, the runoff that is currently disposed into the combined sewers. The retention basins are depressed zones with a small water storage tank below its surface. This typology is applied to smaller institutional open spaces, such as schoolyards, existing sports courts, parking close to civic buildings. etc. The basins are used to collect and store non-potable water to supply to adjacent institutional buildings. The last typology, the constructed wetlands, employs a similar layered catchment and storage strategy to capture surrounding stormwater runoff, but different from the retention basins, the typology also includes a filtration process. The water cleansing is achieved through bio-filtration processes supported by the wetland plants and physical infiltrations. The treated water would eventually enter a large underground water tank before redistributed for commercial non-potable uses and irrigation. The retention basins and constructed wetlands along with the deep storage tanks would play a significant role in the urban fabric, acting as programmed public spaces and parks for local communities. The changing water levels transforms the atmosphere and programs in these typologies, allowing citizens to engage and utilizes the spaces in various ways. This merge of water infrastructure with urban public space would bring citizens face to face with the generally hidden water systems and help redefine the concept of water resources. The proposed design will help enhance the city's physical water systems and catalyze a change in the water consumption culture.

PROPOSED WATER SYSTEM URBAN PLAN

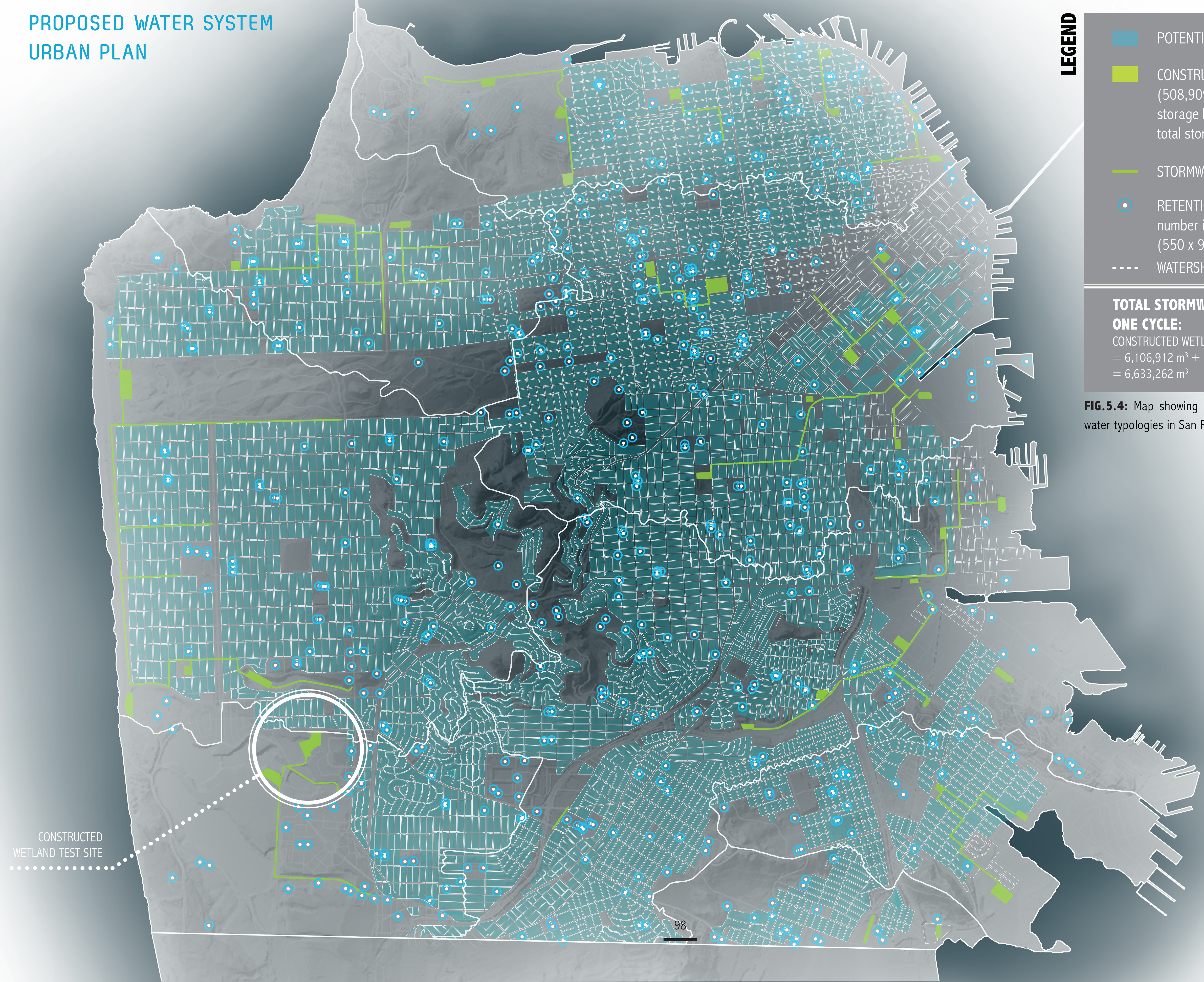
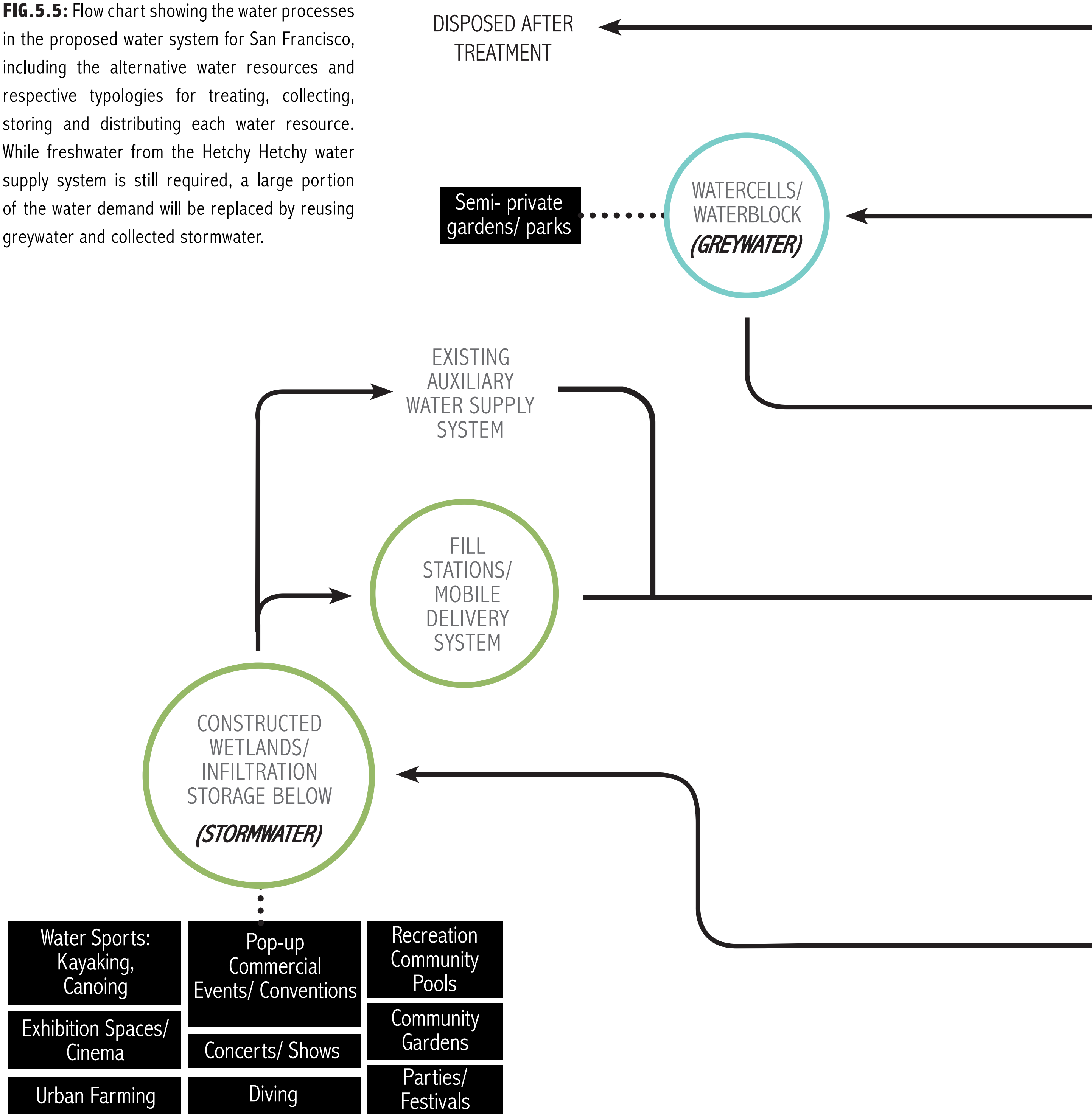
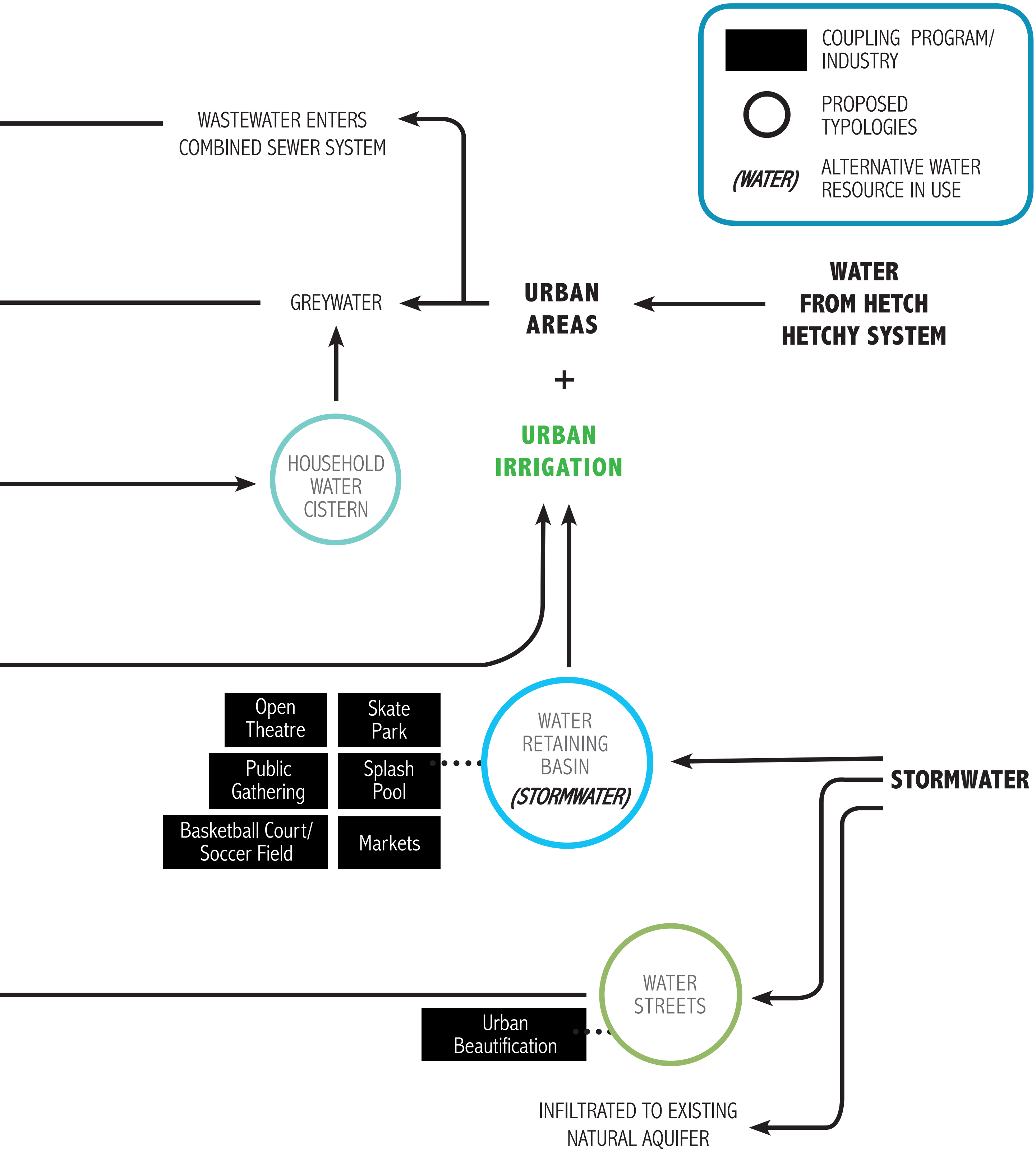


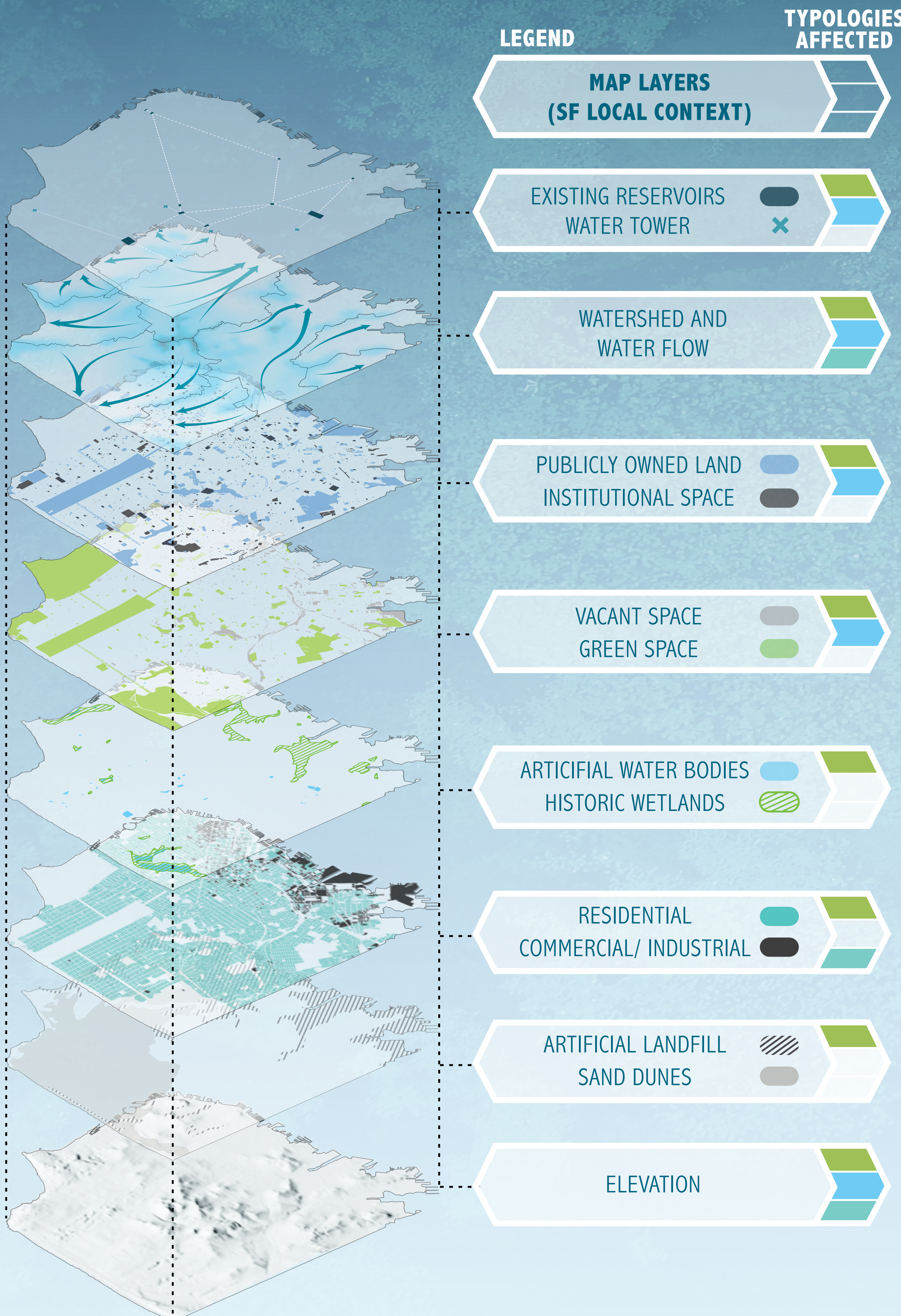
FIG.5.4: Map showing locations of different proposed water typologies in San Francisco. (1:50000)

SAN FRANCISCO WATER SYSTEM FLOW CHART

FIG.5.5: Flow chart showing the water processes in the proposed water system for San Francisco, including the alternative water resources and respective typologies for treating, collecting, storing and distributing each water resource. While freshwater from the Hetchy Hetchy water supply system is still required, a large portion of the water demand will be replaced by reusing greywater and collected stormwater.




COUPLING PROGRAM/ INDUSTRY
PROPOSED TYPOLOGIES
(WATER)
ALTERNATIVE WATER RESOURCE IN USE
WASTEWATER ENTERS COMBINED SEWER SYSTEM
GREYWATER
URBAN AREAS
+
URBAN IRRIGATION
WATER FROM HETCH HETCHY SYSTEM
HOUSEHOLD WATER CISTERN
Open Theatre
Skate Park
Public Gathering
Splash Pool
Basketball Court/ Soccer Field
Markets
WATER RETAINING BASIN (STORMWATER)
STORMWATER
WATER STREETS
Urban Beautification
INFILTRATED TO EXISTING NATURAL AQUIFER


LEGEND
TYPOLOGIES AFFECTED
MAP LAYERS (SF LOCAL CONTEXT)
EXISTING RESERVOIRS
WATER TOWER
WATERSHED AND WATER FLOW
PUBLICLY OWNED LAND
INSTITUTIONAL SPACE
VACANT SPACE
GREEN SPACE
ARTIFICIAL WATER BODIES
HISTORIC WETLANDS
RESIDENTIAL
COMMERCIAL/ INDUSTRIAL
ARTIFICIAL LANDFILL
SAND DUNES
ELEVATION

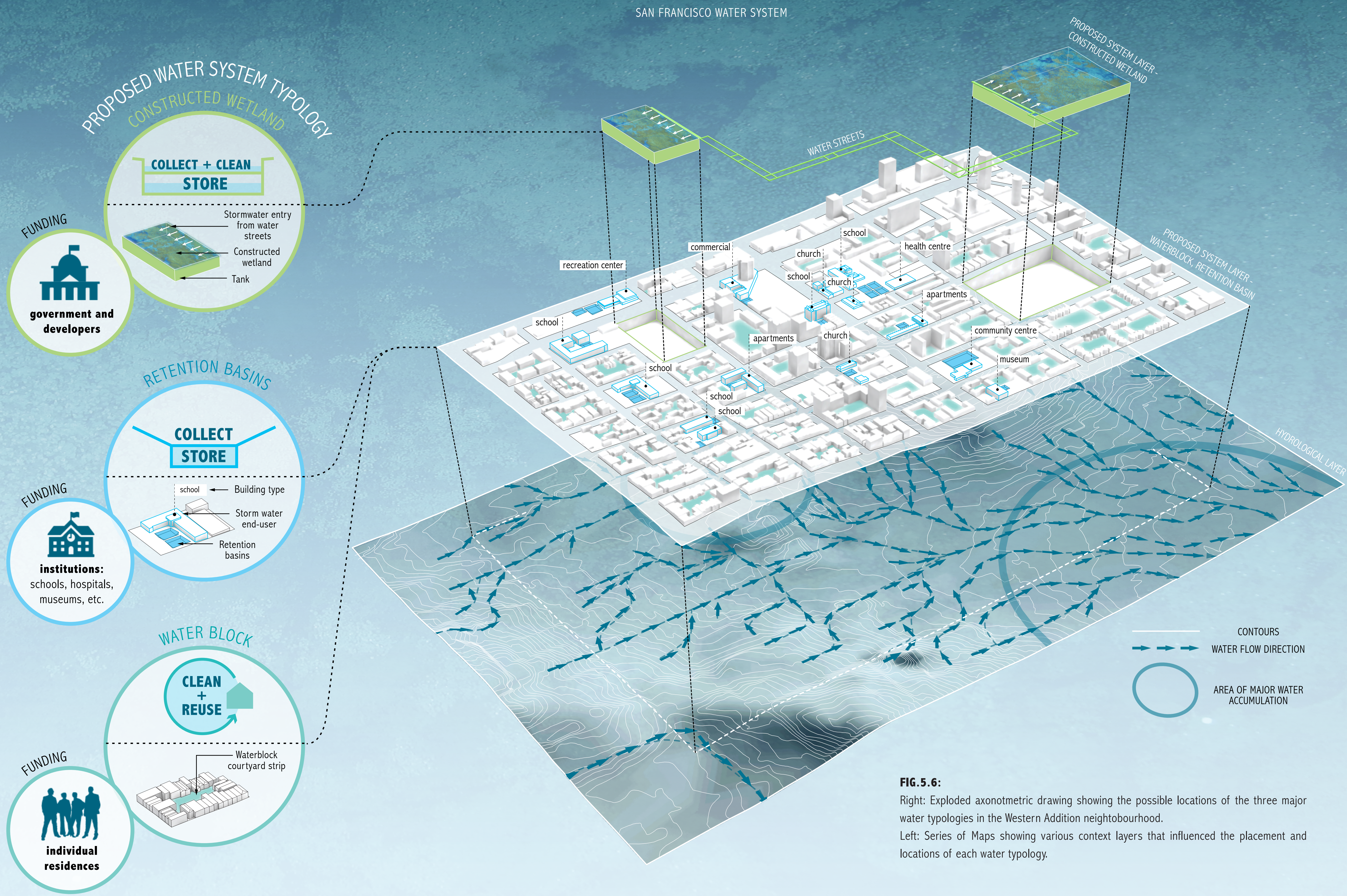
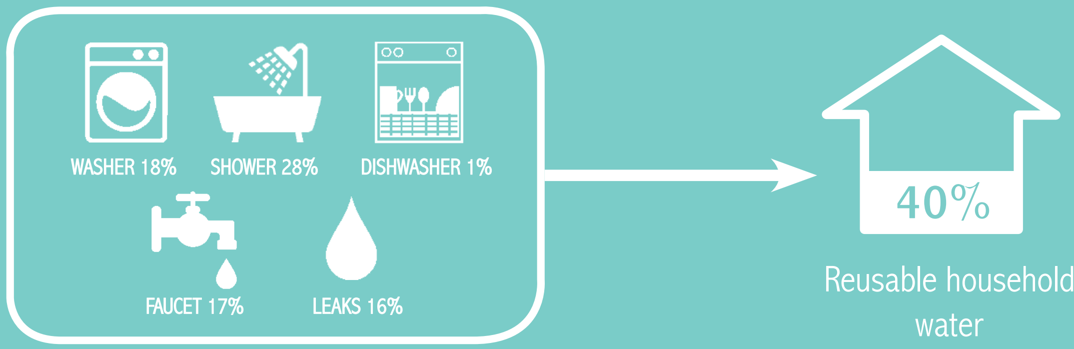


FIG.5.6:

Right: Exploded axonometric drawing showing the possible locations of the three major water typologies in the Western Addition neightobourhood.

Left: Series of Maps showing various context layers that influenced the placement and locations of each water typology.

01_ WATERBLOCK



Total annual volume from waterblocks = San Francisco annual household water use: 56,372,060 m^3 x **40%**

= **22,548,824 m^3**


FIG.5.7: Aerial view of typical San Francisco residential blocks

The first typology in the proposed water system is the waterblock, a typology that functions largely as a field, a repetition of small-scale structures, over the city. This design draws inspiration from the European model of a courtyard residential block where the center open space is shared among multiple residences. Currently, a typical San Francisco residential block is made up of multiple residences, each with its individual backyard that is completely fenced off. The proposed system suggests a shift towards the courtyard model, where fences will be partially removed to form a strip of shared open space within the block. In this shared space, special greywater-recycling modules (see fig.5.14) can be installed to filter and treat household greywater through a series of wetland physical and biological processes. This center green space does not only serve as an effective local water treatment typology to maximize the use of alternative water resources and minimize greywater disposal; it also transforms the block into a secure, semi-private space shared among residents. Although the adaptation of this typology would signify a necessary conversion of private land into public space, the government can encourage public participation through a range of incentive programs, such as tax deduction and elimination of wastewater disposal fees.[5] This bottom-up strategy includes citizens as part of the water system and maximizes its effectiveness through the repetition of small-scale structures across the entire city. The decentralized filtration module also allows for a flexible expansion of the water handling system, so individuals can choose to participate in the program at any time.

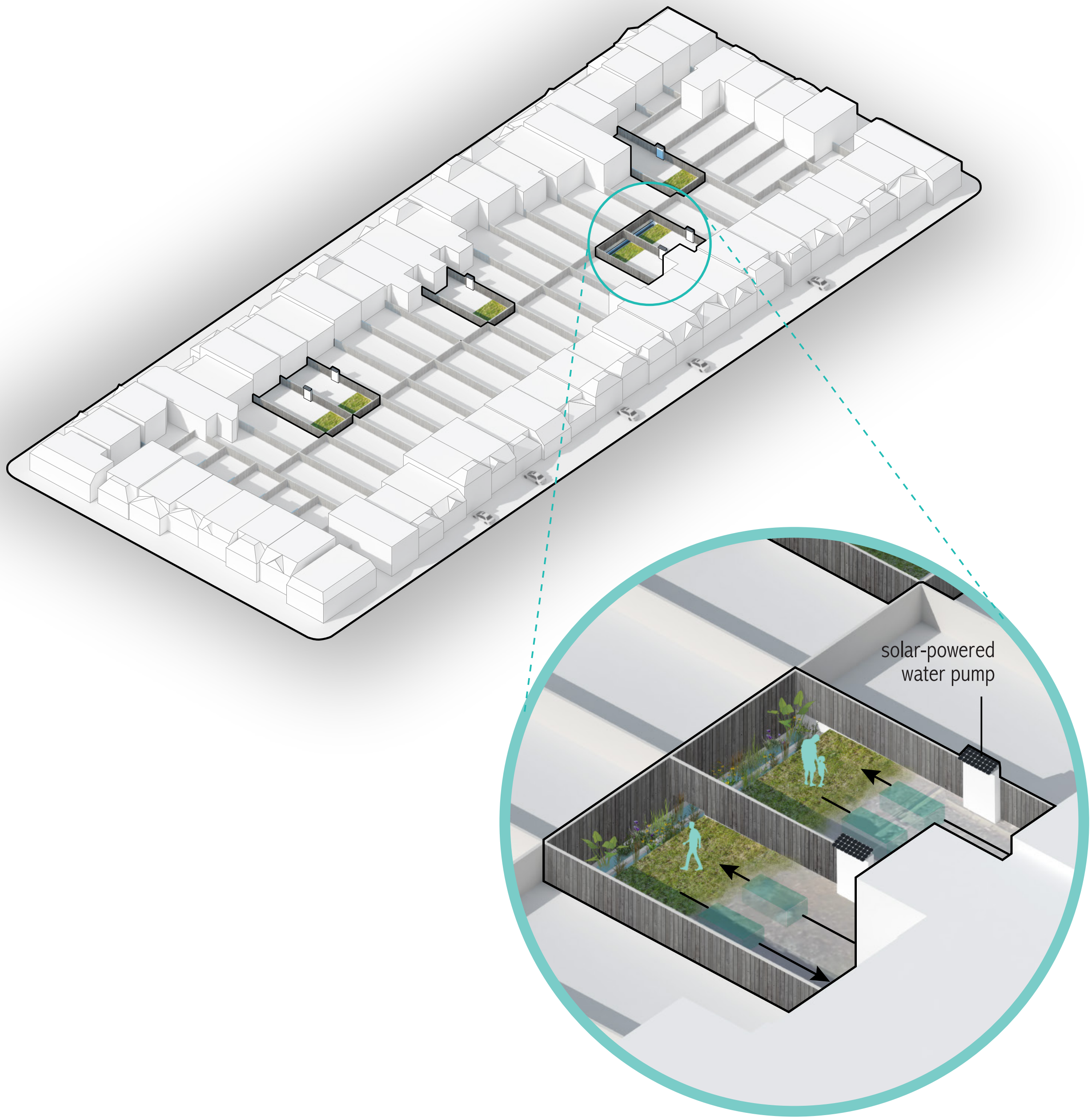


FIG.5.8: CASE 1 INDIVIDUAL PARTICIPATION

Individual filtration module is installed in participating residences. Only participants receive returned greywater. Adjacent participants may connect filtration unit but keep fence between lots. Solar powered water pumps are used to draw water into the residential water cisterns after treatment in the filtration unit.

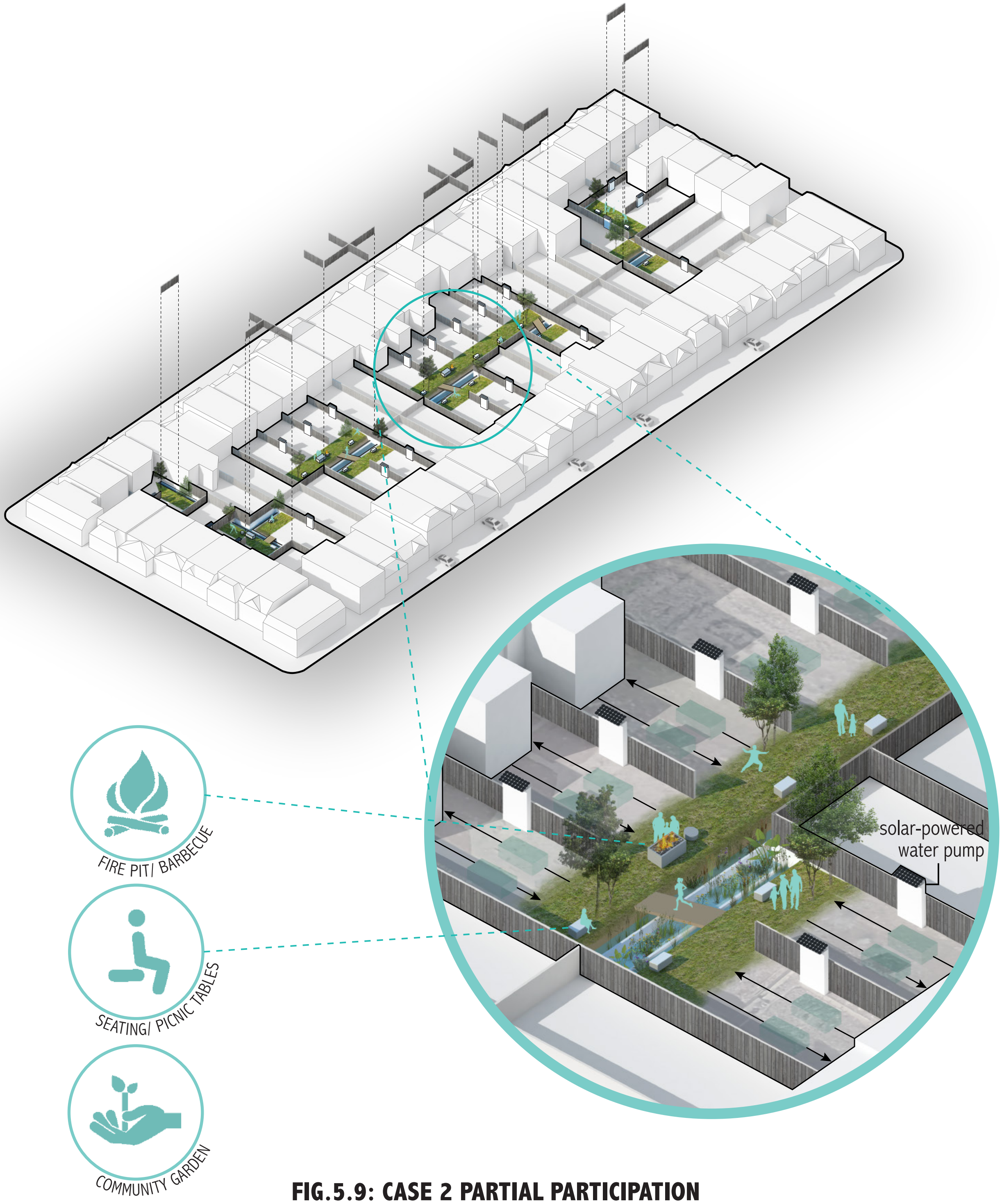
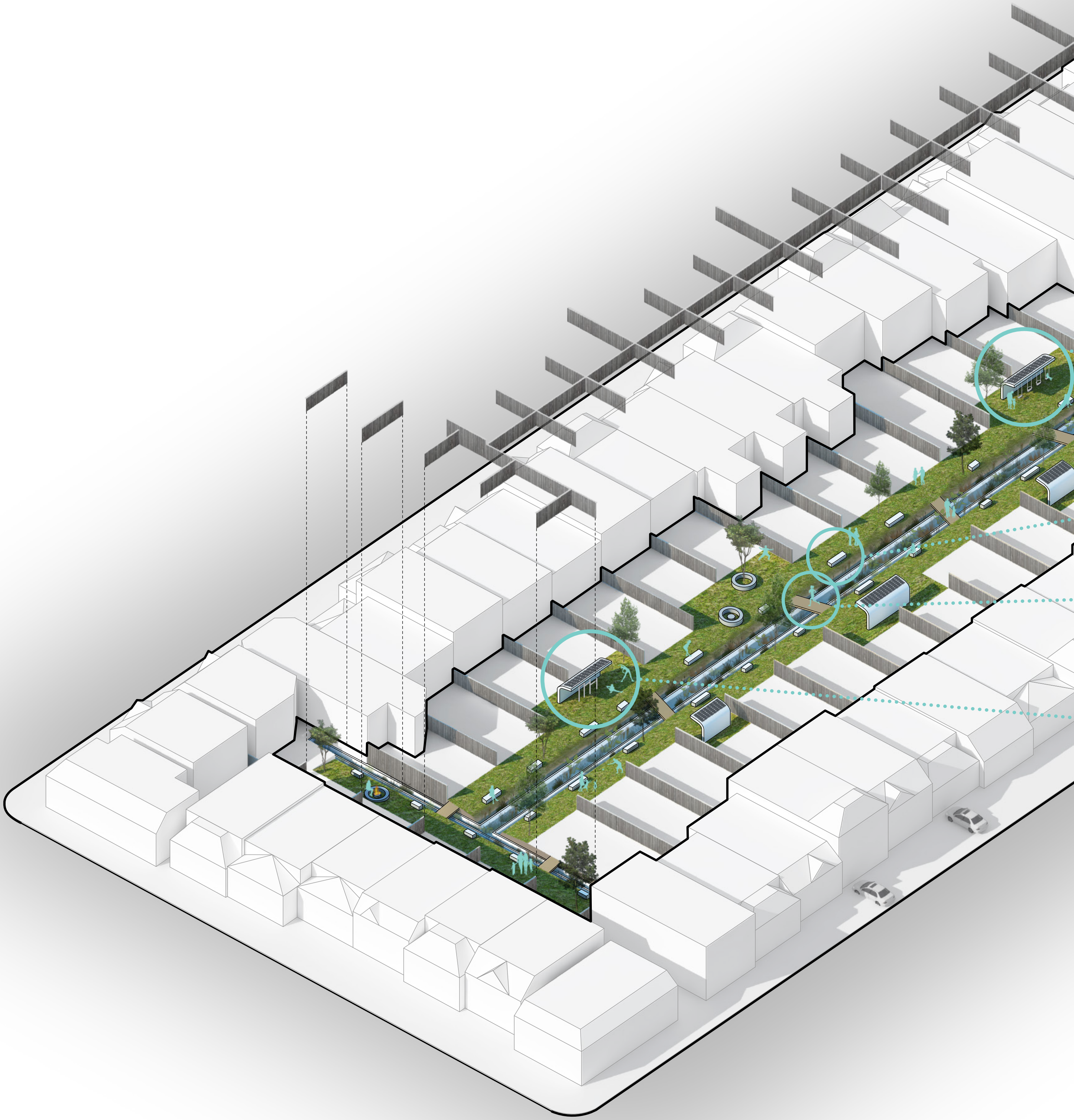


FIG.5.9: CASE 2 PARTIAL PARTICIPATION

Filtration modules installed in participating residences and fences between participant residences will be removed, forming small pockets of common green space between several residences.

60%



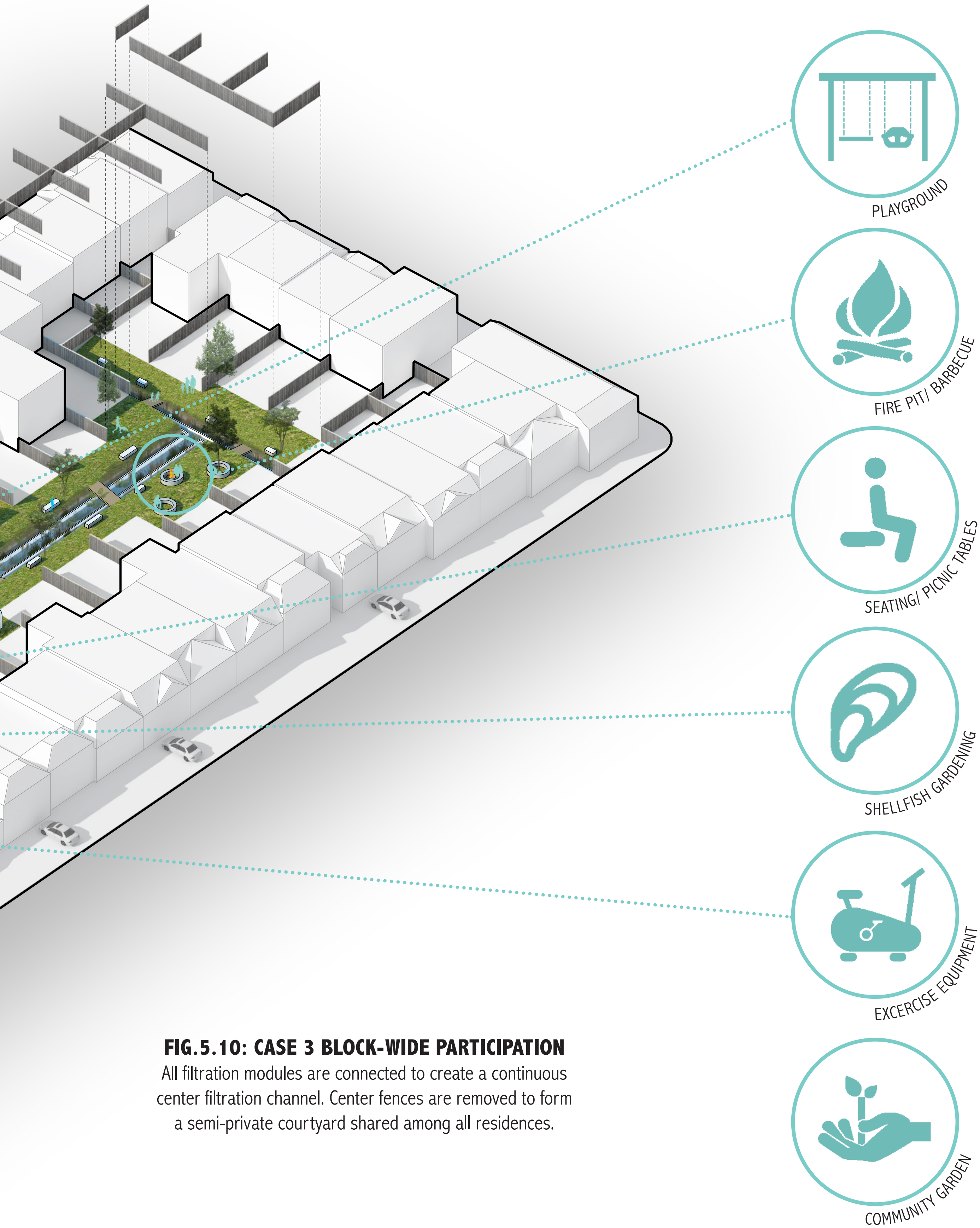


FIG.5.10: CASE 3 BLOCK-WIDE PARTICIPATION
All filtration modules are connected to create a continuous center filtration channel. Center fences are removed to form a semi-private courtyard shared among all residences.

60%

FIG.5.11: EXISITING CONDITION SECTION

Greywater + wastewater all enter into combined sewage system. All water sources are disposed.[6]

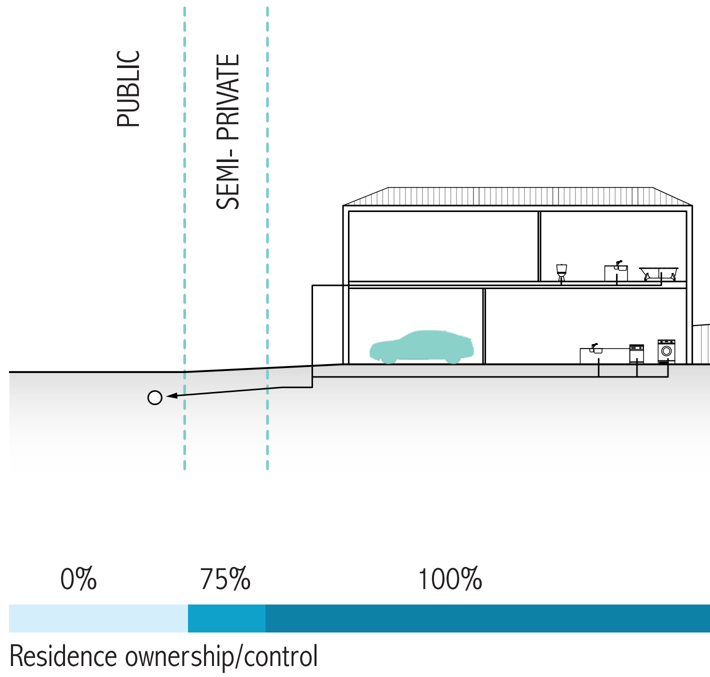


FIG.5.12: PARTIAL PARTICIPATION SECTION

Through government funding and reduced sewage disposal fees, individual residence participates in water block program. Individual filtration module is installed in the backyard to return greywater into residence. Only blackwater is disposed in the new system. Greywater first enters septic tank for primary treatment, then it enters shallow cell for biofiltration with wetland plants. Finally, bio-treated water enters infiltration cell for secondary treatment and is directed to a storage cistern eventually.

Reusable sources include water from: [7]

clothes washing/ showering/ bathing/ dishwashing

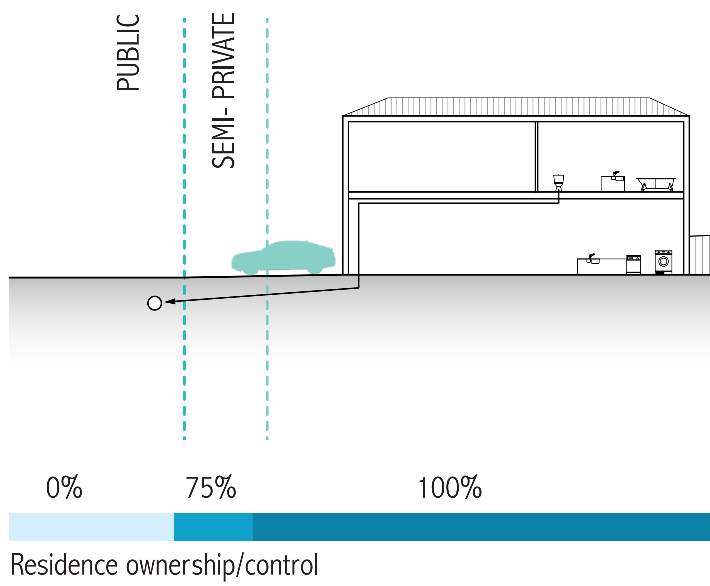
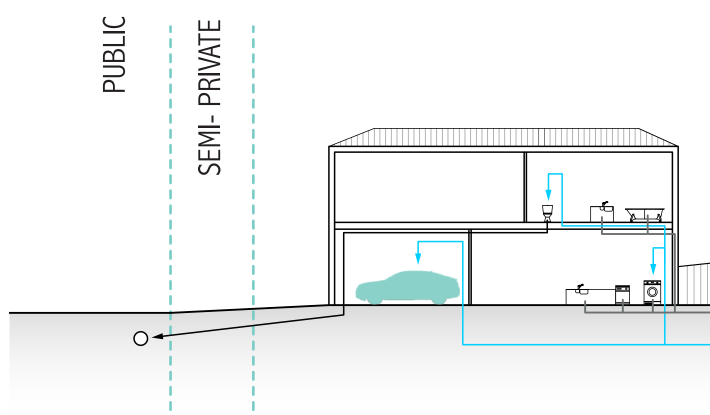
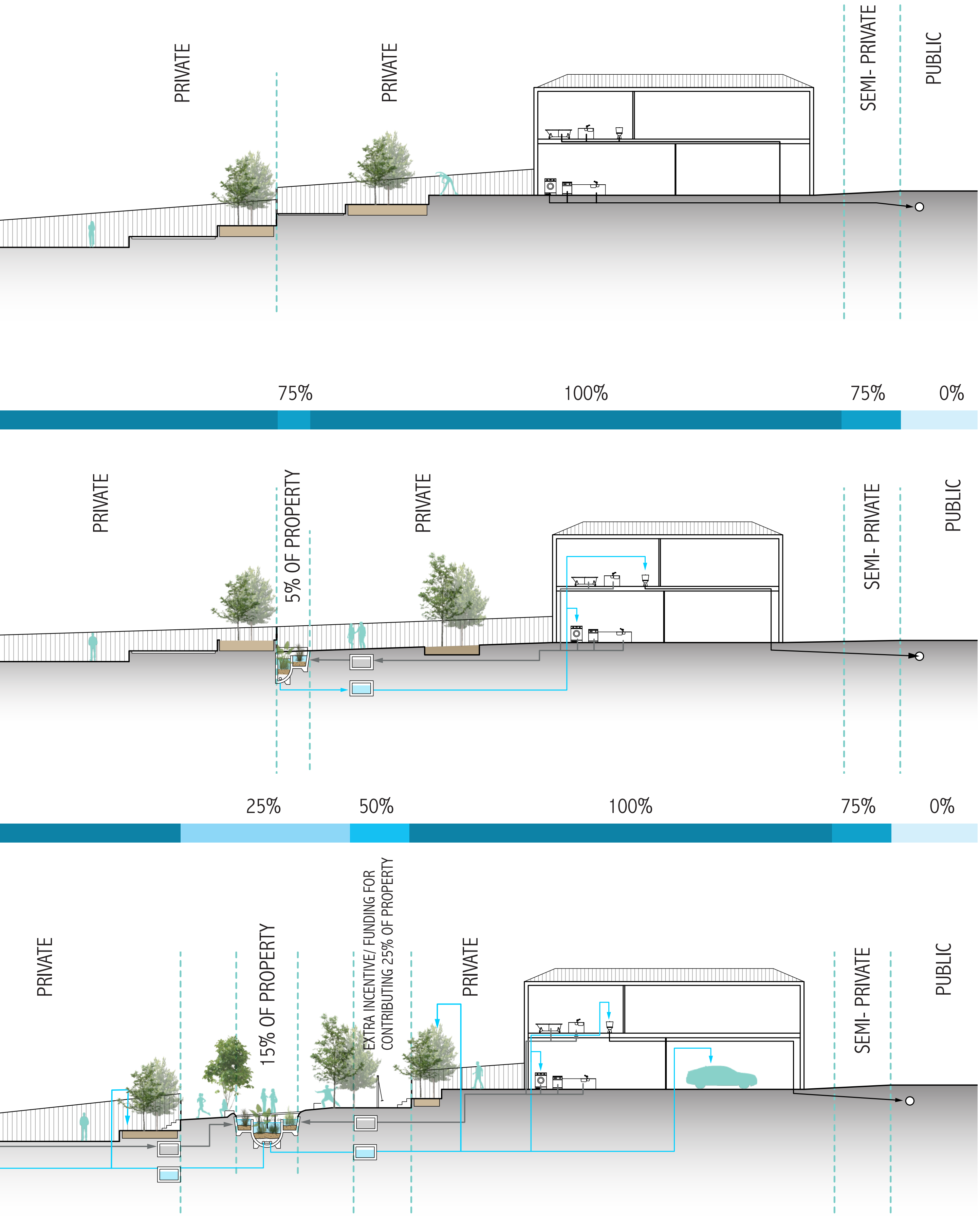


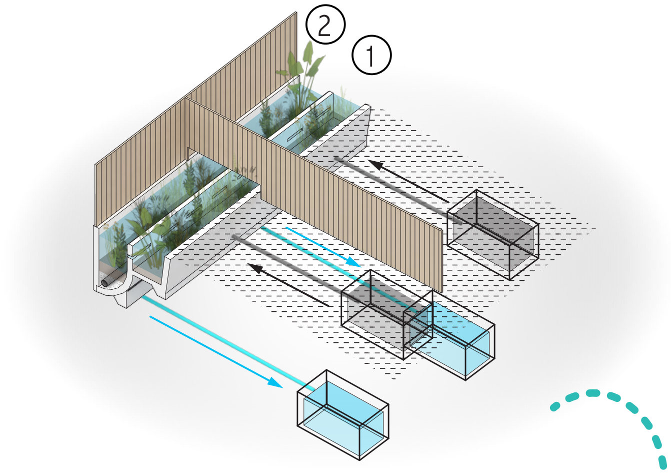
FIG.5.13: FULL PARTICIPATION SECTION

In the full participation scenario, greywater will be collected and treated first in septic tanks at every house. Then the greywater will be guided to the central filtration channel that collects and treat greywater from all households. Greywater will be treated through wetland and infiltration processes. Finally, treated water will be distributed to individual household storage cisterns. Recycled water will be used for:

laundry/ mechanical cooling / car-washing/ toilet/ irrigation[8]



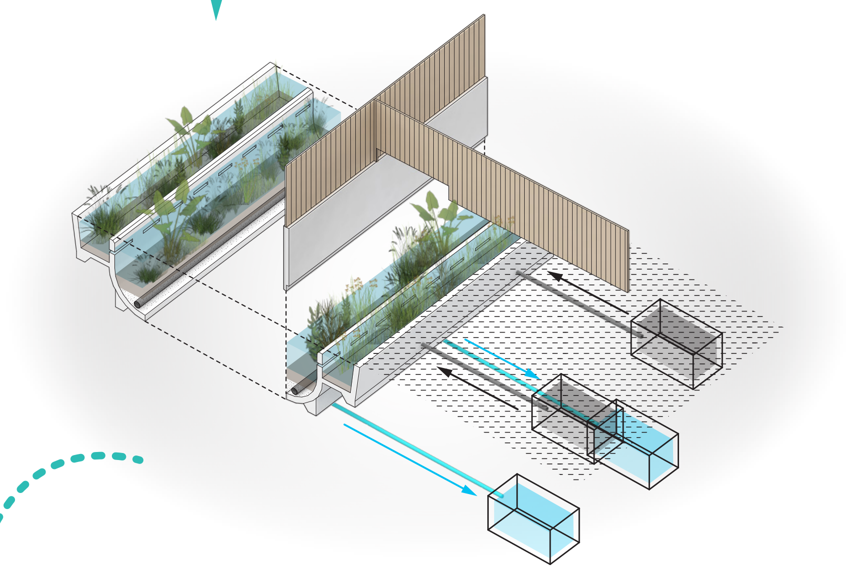

PRIVATE
PRIVATE
SEMI- PRIVATE
PUBLIC
75%
100%
75%
0%
PRIVATE
5% OF PROPERTY
PRIVATE
SEMI- PRIVATE
PUBLIC
25%
50%
100%
75%
0%
PRIVATE
15% OF PROPERTY
EXTRA INCENTIVE/ FUNDING FOR CONTRIBUTING 25% OF PROPERTY
PRIVATE
SEMI- PRIVATE
PUBLIC



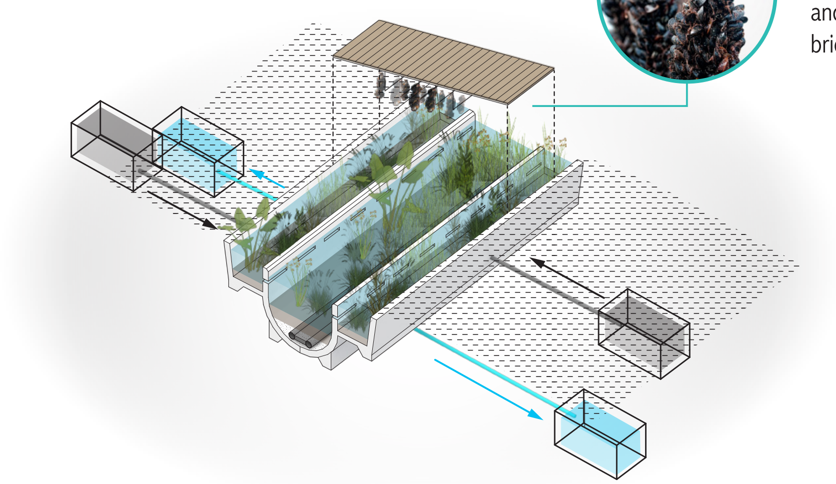
Single filtration unit:

Installed in individual participant backyard. Greywater first enters into a septic tank for primary treatment. Then water is guided to the filtration unit, which is divided into two parts: (1) shallower cell treats greywater by wetland plants (2) then the water spills into deeper cell for the infiltration process. Filtered greywater is returned to underground storage cisterns for future applications.

When more lots participant in the water block program, individual filtration units can be jointed by removing partition wall and fence. This allows for flexible expansion of the system.



Shellfish growth can help remove impurities and metals from water. Ropes and cages are added underneath all bridges to facilitate shellfish gardening.



Center filtration channel formed by combining multiple filtration units. Small bridges are added over the channel to allow pedestrian circulation in the courtyard.

FIG.5.14: Waterblock water recycling processes

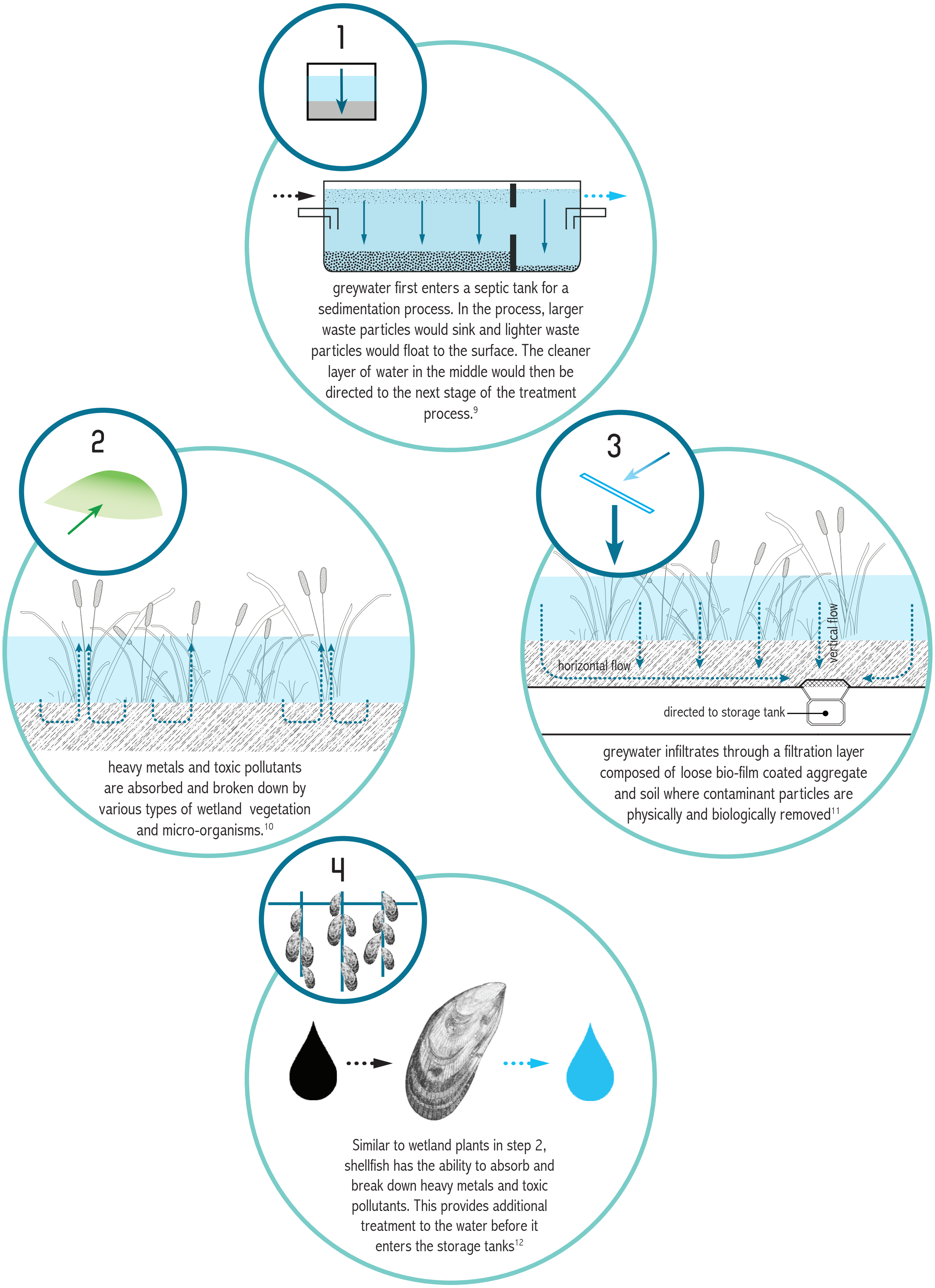


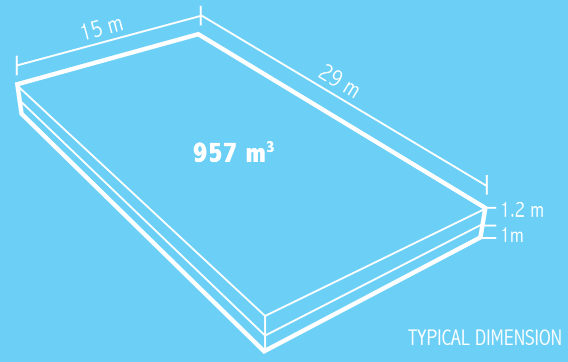
FIG.5.15: Greywater cleansing processes applied

FIG.5.16: View of the shared courtyard in a waterblock

02_
RETENTION BASINS

550 BASINS ACROSS SF

X



Total volume in 1 cycle (before water is extracted from system)

$957\ m^3 \times 550$

$= \mathbf{526{,}350\ m^3}$

FIG.5.17: Schoolyard in San Francisco, potential site for the retention basin typology

The retention basin typology mainly targets public open spaces or vacant lots in the city, especially areas adjacent to any institutional buildings, such as schools, hospitals, churches, museums, community centers and civic buildings. A retention basins is essentially a sunken space designed to collect and store stormwater. Since the top of the basin is at grade with city roads and neighbouring storm drains would be covered, nearby stormwater would enter the retention basin instead of the combined sewer system. Below every retention basin is a 0.8m- 2m deep tank for the storage of stormwater. The collected water is then returned to adjacent buildings for non-potable uses. Beyond its water handling functions, the stormwater basin also double as a public open space for the surrounding community. Different programs and activities are activated in the space depending on water levels and weather conditions. In dry conditions, the space can be used as basketball court, playground, rock climbing facility, markets and so on. In wet conditions, the space is converted into city pools for water sports like kayaking, paddle boarding and so on. This typology can be an effective and multi-objective response for developers and investors to comply to the SFPUC's stormwater management ordinance and non-potable water program.[13]

60%

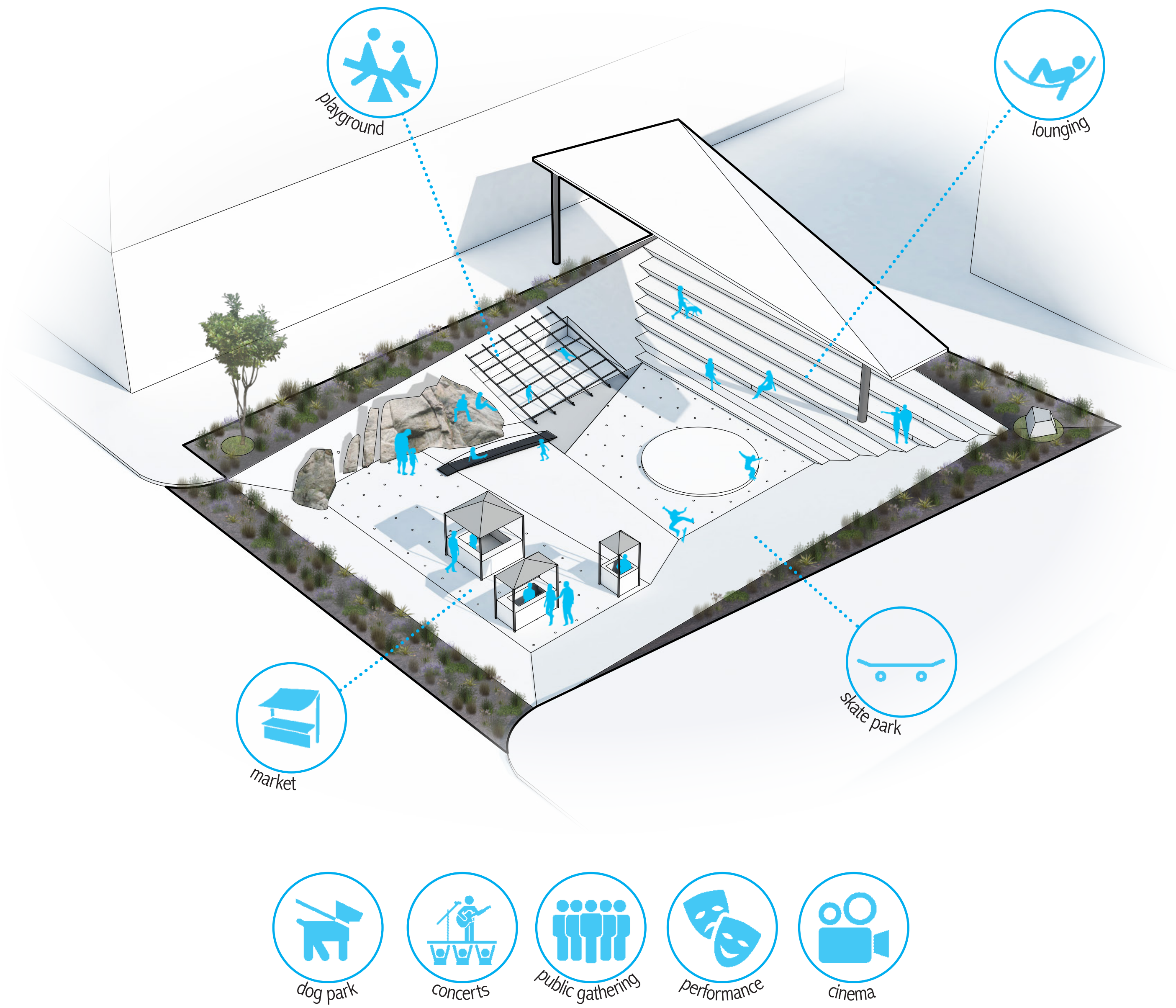


FIG.5.18: Type 1 Retention Basin, located at open spaces close to institutional buildings. Bubbles show the types of programs available in the basin during **dry condition.**

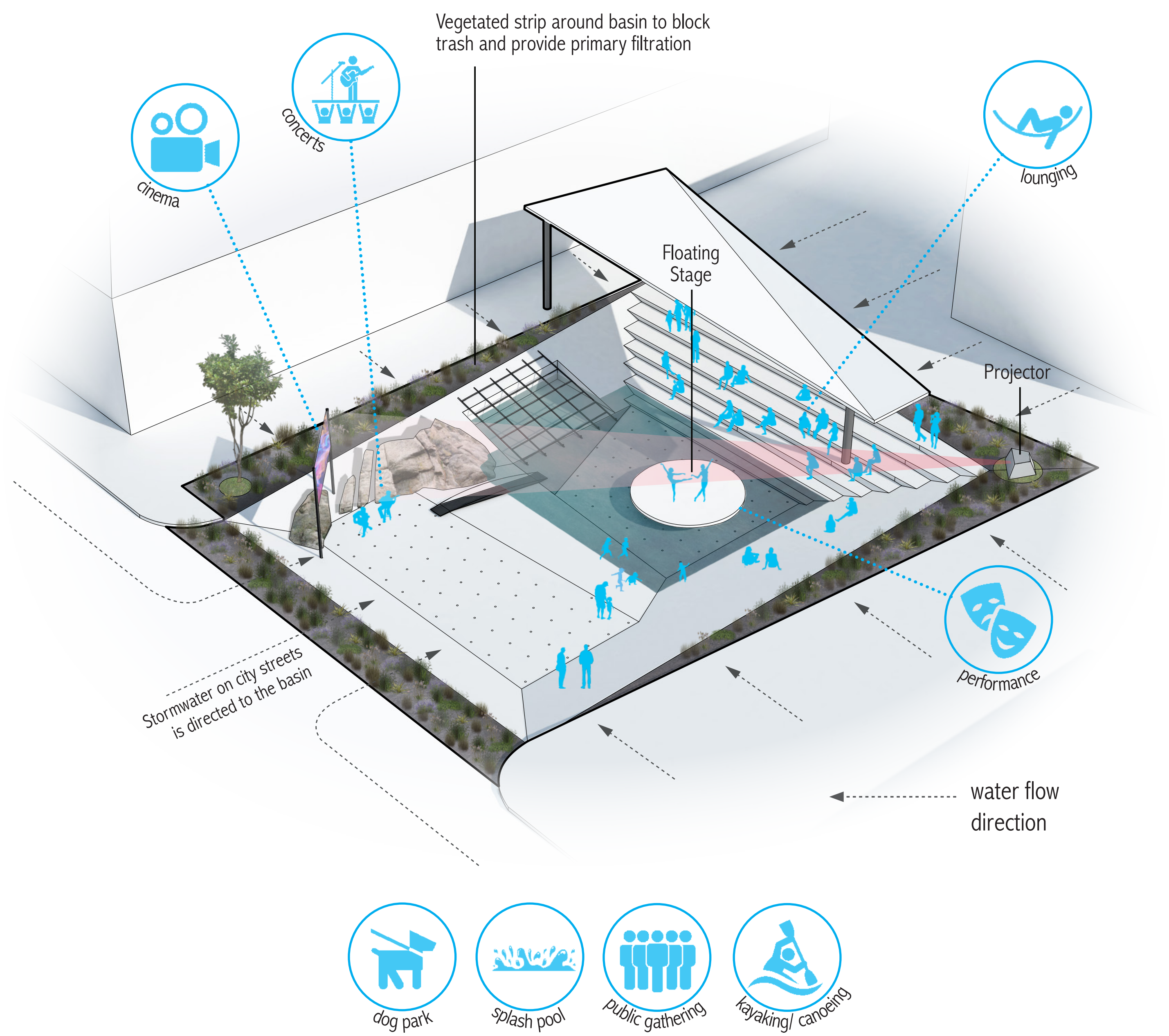


FIG.5.19: Type 1 Retention Basin, located at open spaces close to institutional buildings. Bubbles show the types of programs available in the basin during **wet condition.**

FIG.5.20: Type 2 Retention Basin, located in open spaces close to institutional buildings and replacing existing sports ground, such as basketball courts and tennis courts. Bubbles show the types of programs available in the basin during **dry condition.**

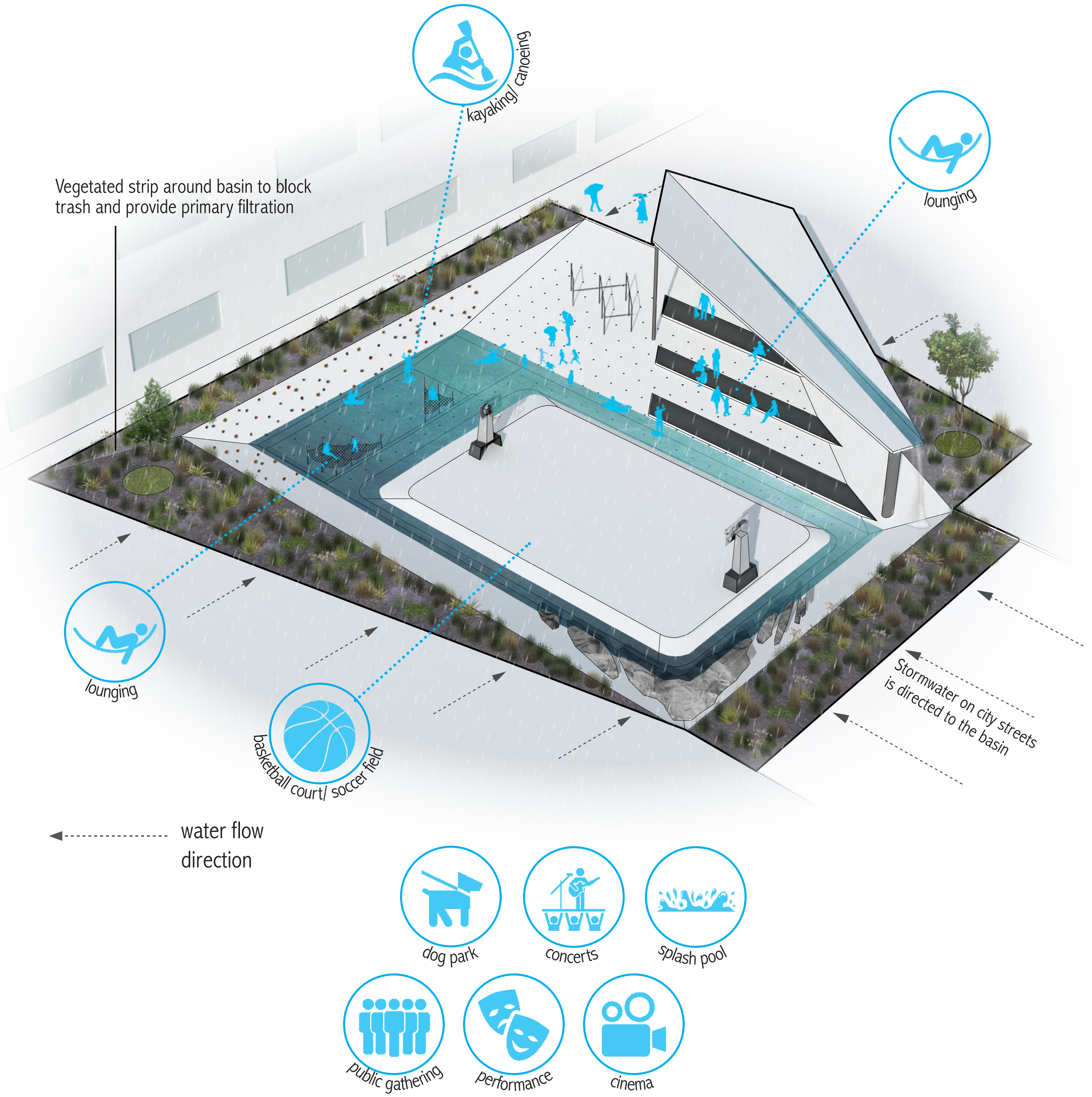


FIG.5.21: Type 2 Retention Basin, located in open spaces close to institutional buildings and replacing existing sports ground, such as basketball courts and tennis courts. Bubbles show the types of programs available in the basin during **wet condition.**

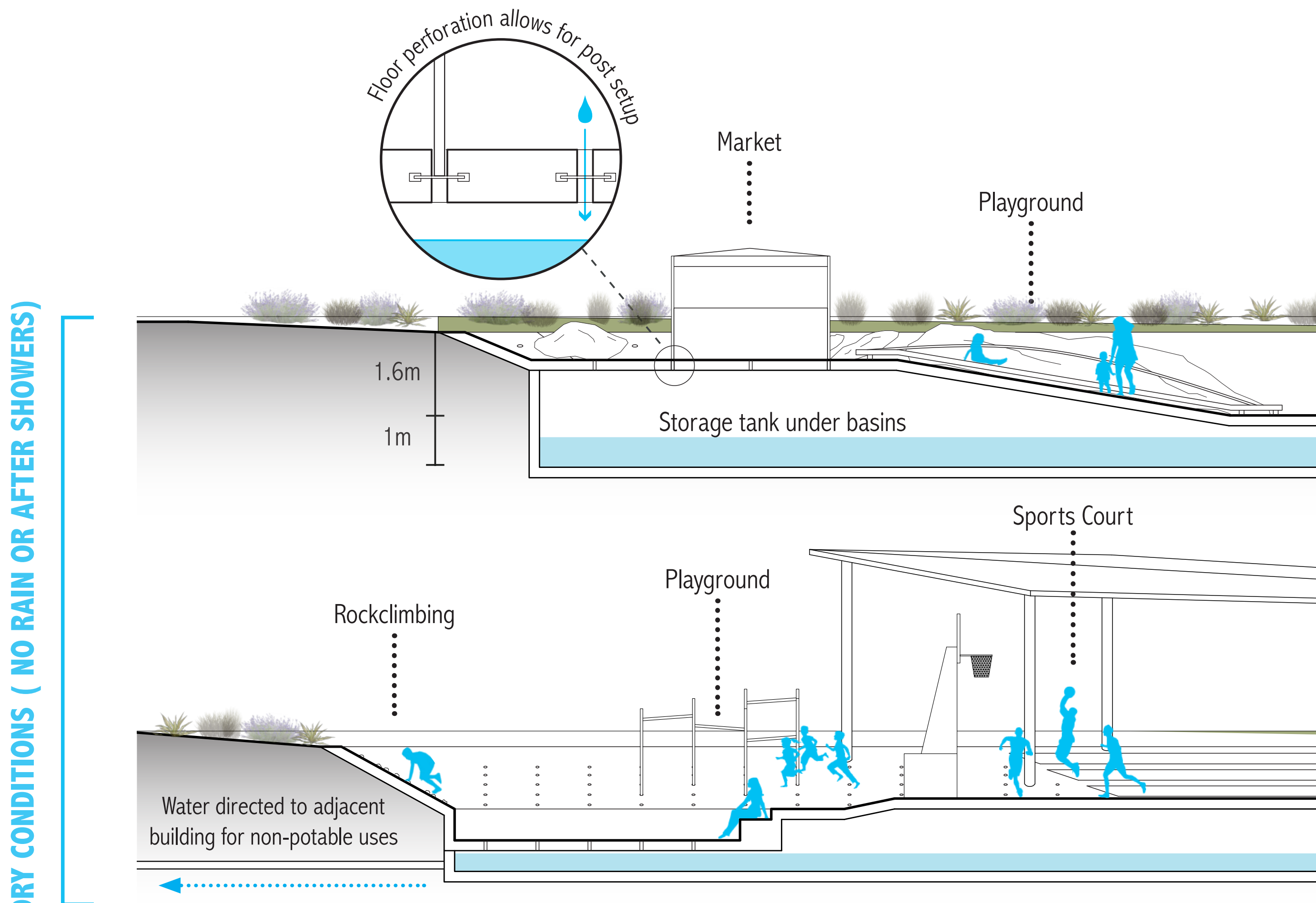


FIG.5.22: Section of retention basins in dry conidtions (1:150)

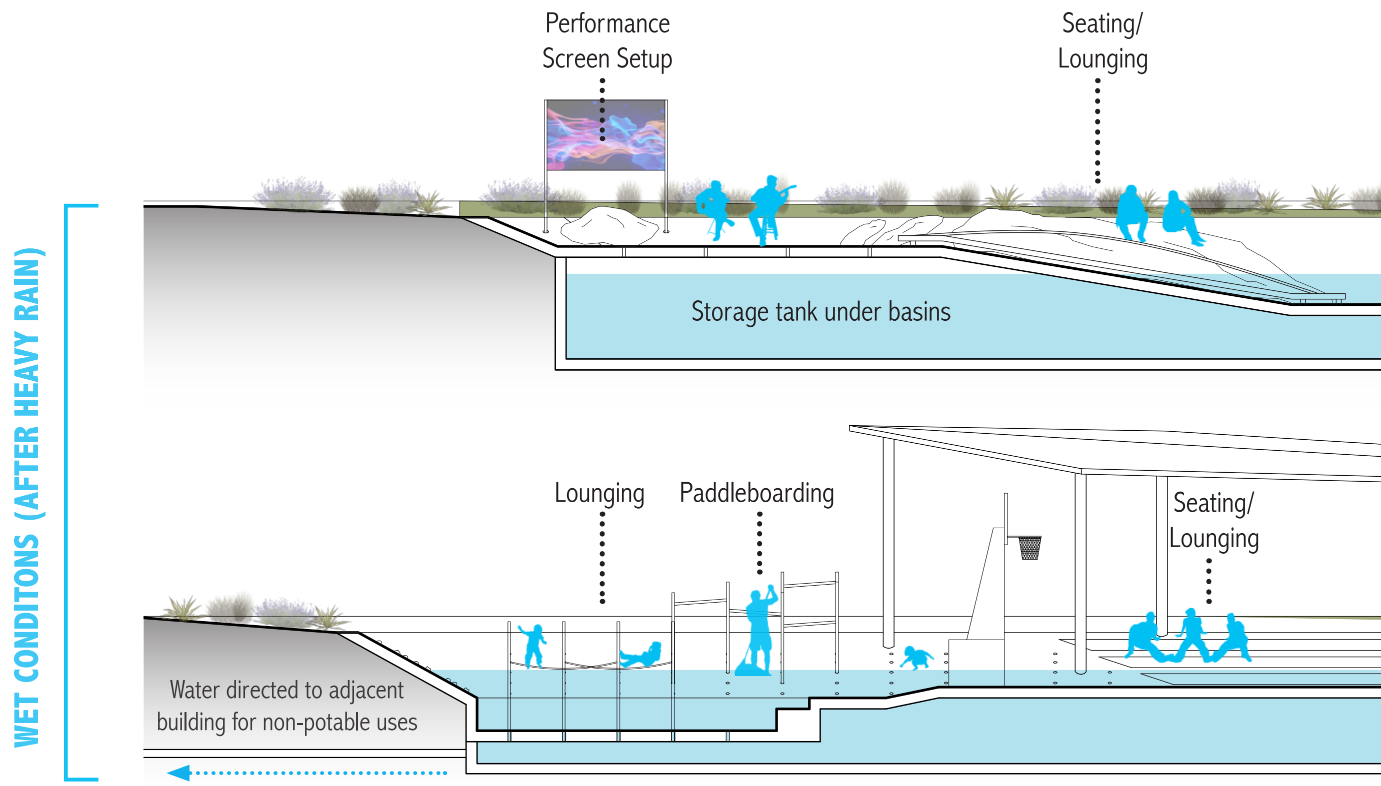
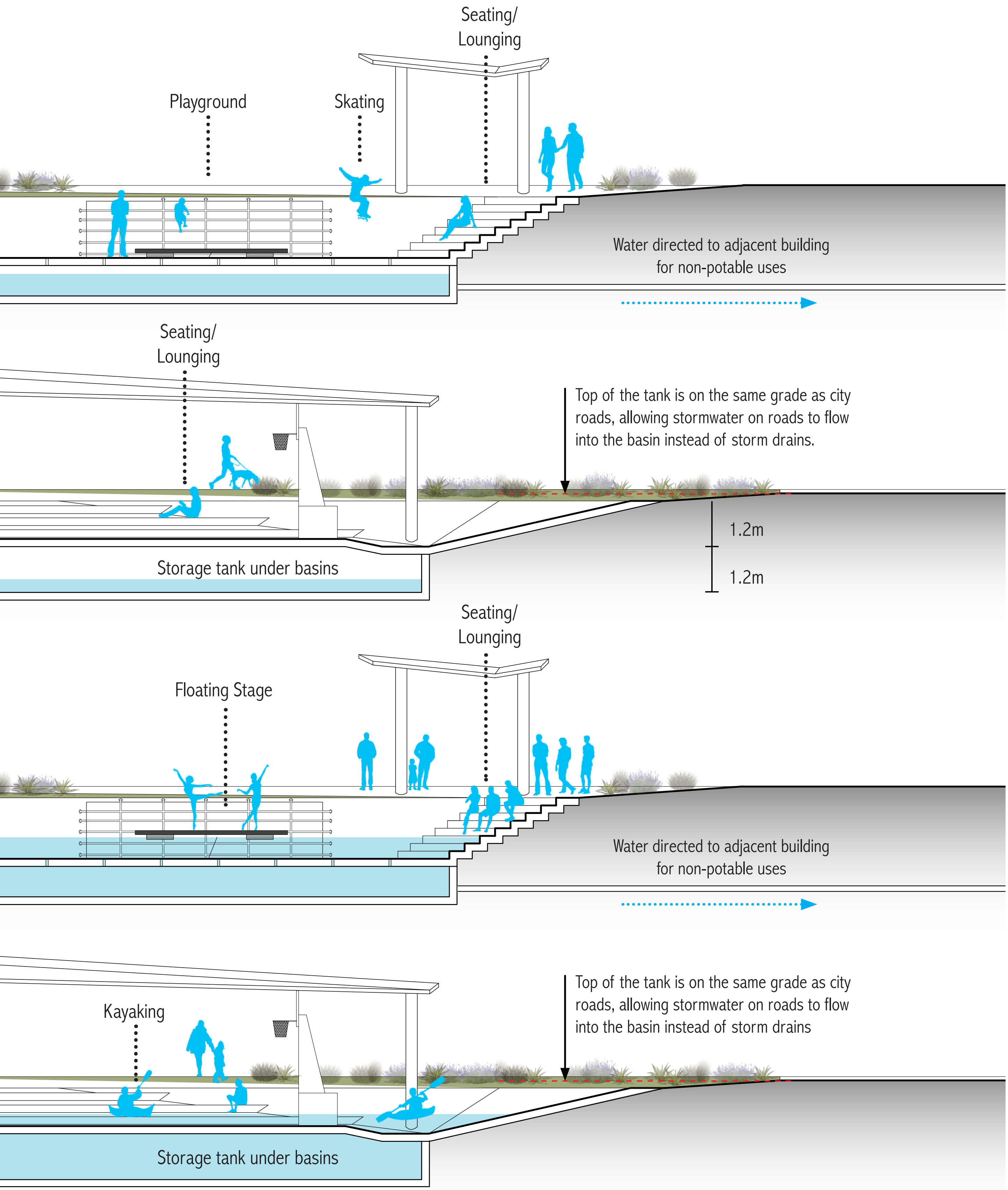
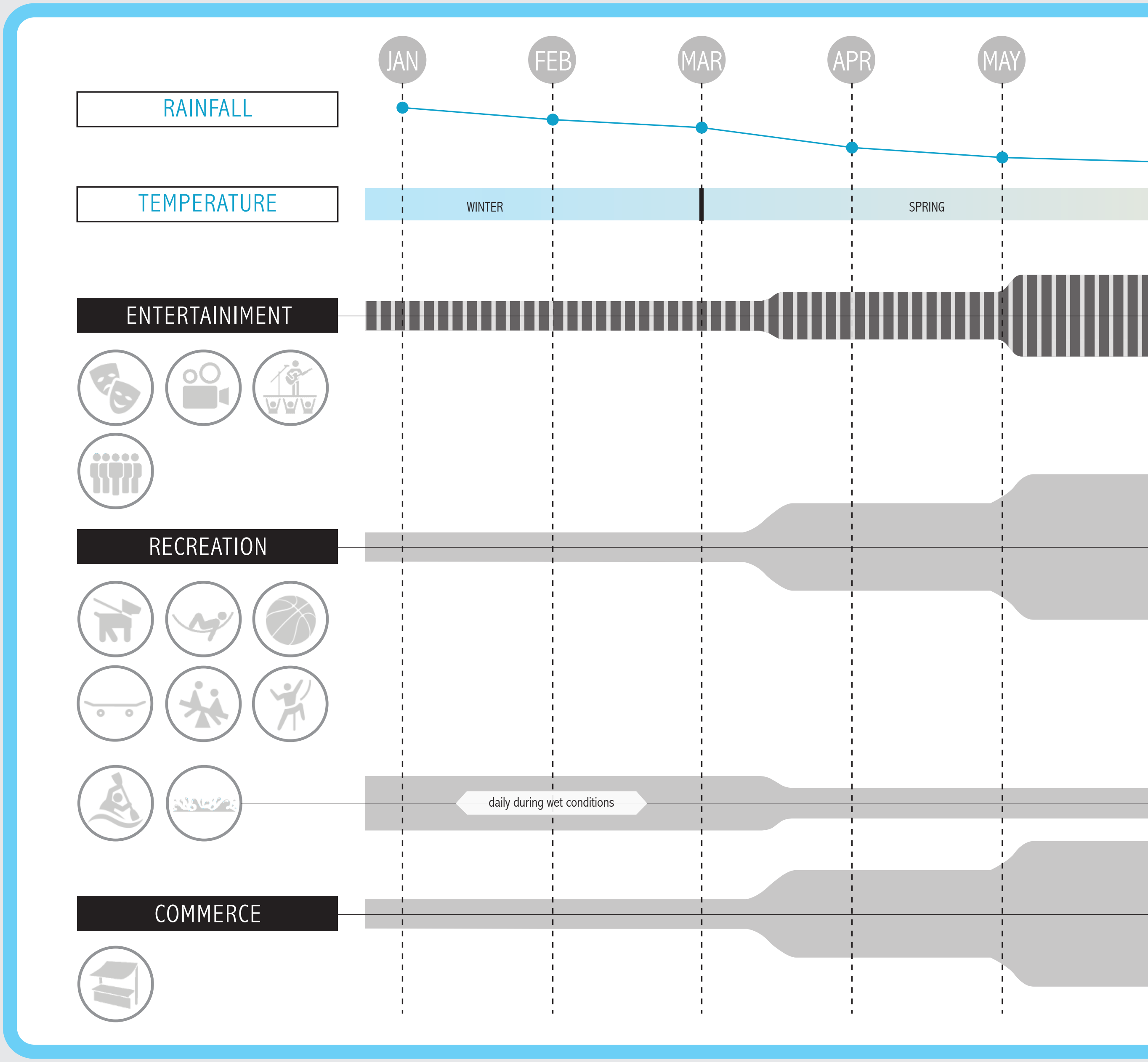


FIG.5.23: Section of retention basins in wet conditions (1:150)


Seating/
Lounging
Playground
Skating
Water directed to adjacent building
for non-potable uses
Seating/
Lounging
Top of the tank is on the same grade as city
roads, allowing stormwater on roads to flow
into the basin instead of storm drains.
1.2m
1.2m
Storage tank under basins
Seating/
Lounging
Floating Stage
Water directed to adjacent building
for non-potable uses
Top of the tank is on the same grade as city
roads, allowing stormwater on roads to flow
into the basin instead of storm drains
Kayaking
Storage tank under basins

RETENTION BASINS PROGRAM TIMELINE

FIG.5.24: Timeline depicting the programs activated in the retention basins based on San Francisco seasonal precipitation and temperature. Increased thickness of the grey bar represents an increased occurrence of an activity.



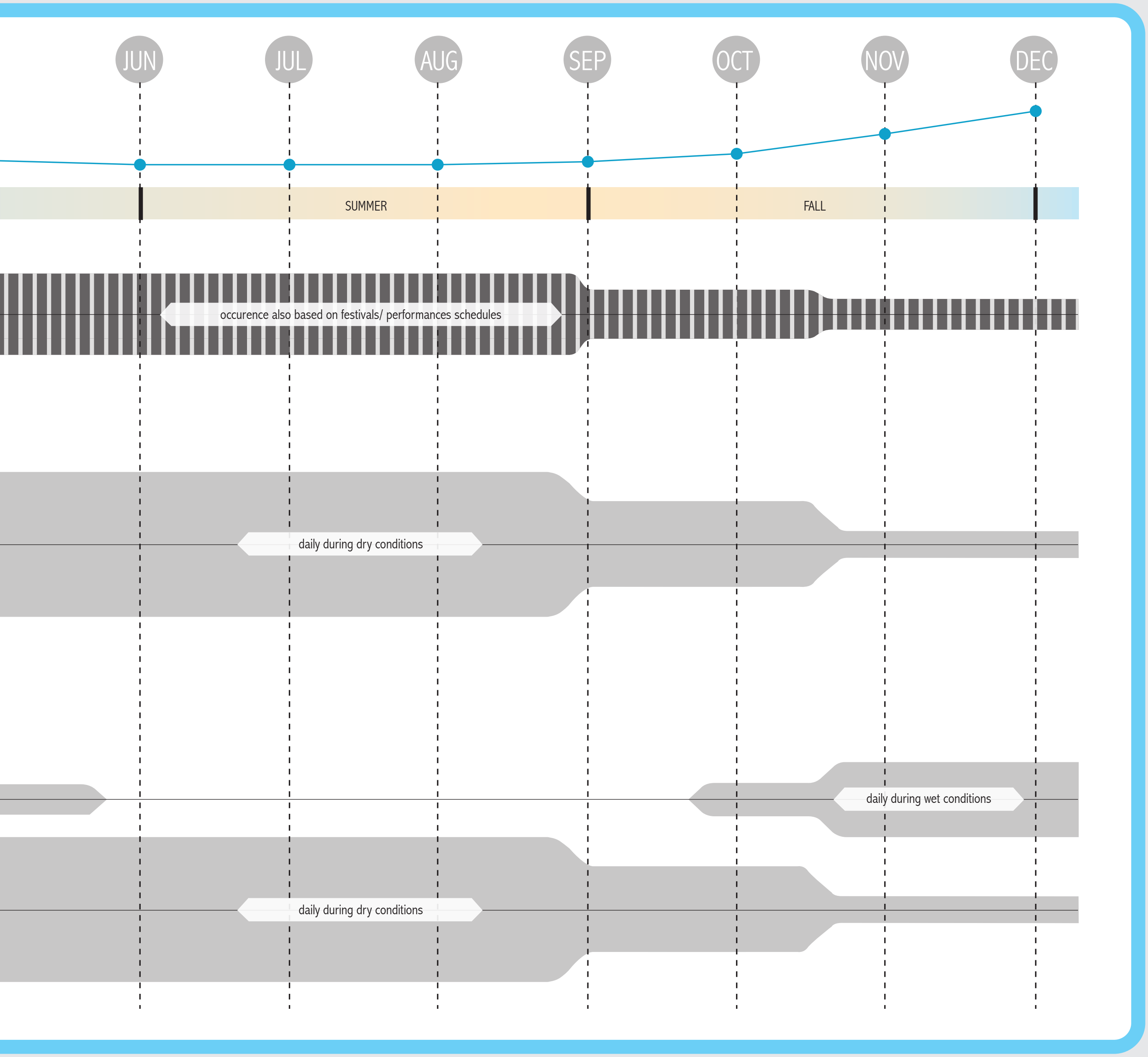
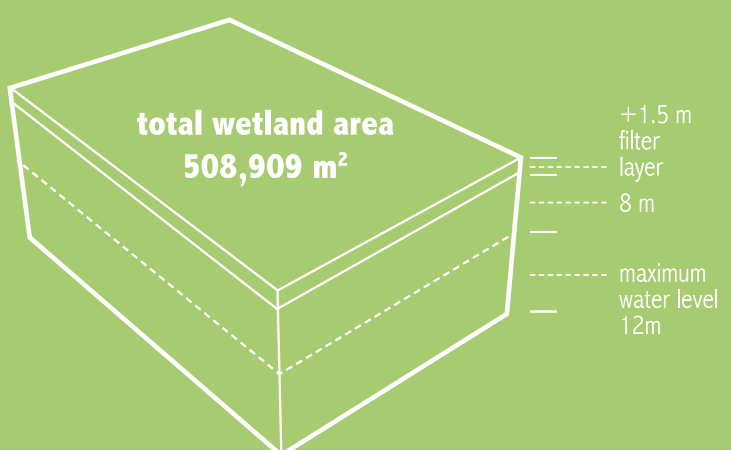

JUN
JUL
AUG
SEP
OCT
NOV
DEC
SUMMER
FALL
occurence also based on festivals/ performances schedules
daily during dry conditions
daily during wet conditions
daily during dry conditions

FIG.5.25: View of the type 2 retnetion basin during wet conditions

03_ CONSTRUCTED WETLAND



Total volume in 1 cycle
(before water is extracted
from system)

$508,909\ m^2 \times 12m$

$=$ **6,106,912m³**

FIG.5.26: Interior of Existing San Francisco Sunset Reservoir, precedent for the underground storage tanks

Constructed wetlands are the largest scale typology in the proposed water system, similar to the sizes of existing in-city reservoirs.[14] Each constructed wetland functions as a layered system individually to collect, treat and store a large quantity of stormwater runoff. On the top layer, water is collected and treated through a series of wetland processes. The water then goes through an aggregate layer where pollutants are removed from the water through subsurface flows. Finally, water enters the underground storage tank below through slit openings on the wetland floor. Water stored in the tanks are either distributed with the existing Auxiliary Water system to buildings in downtown San Francisco for non-potable uses, or delivered with mobile water trucks to city parks for irrigation. These constructed wetlands are located at publicly owned vacant areas, or existing city parks of lower altitude to take advantage of nature water accumulation. The tanks extend underground close to the bedrock layers, so structural reinforcements can be embedded into the bedrock to provide seismic protection. This typology significantly increases local water storage capacity, minimizes runoff into the ocean, and reintroduces the regional wetland landscape into the city. Moreover, these constructed wetlands could serve as major parks in every neighbourhood, providing opportunities for various activities, such as water sports, biking, urban farming, community gardens, café, bird watching etc. People can also enter the storage tanks, especially during dry seasons and use the space for concerts, exhibitions, commercial events and so on. These tanks would form a network of exciting underground urban spaces for people to experience the urban infrastructure and the city in a different way.

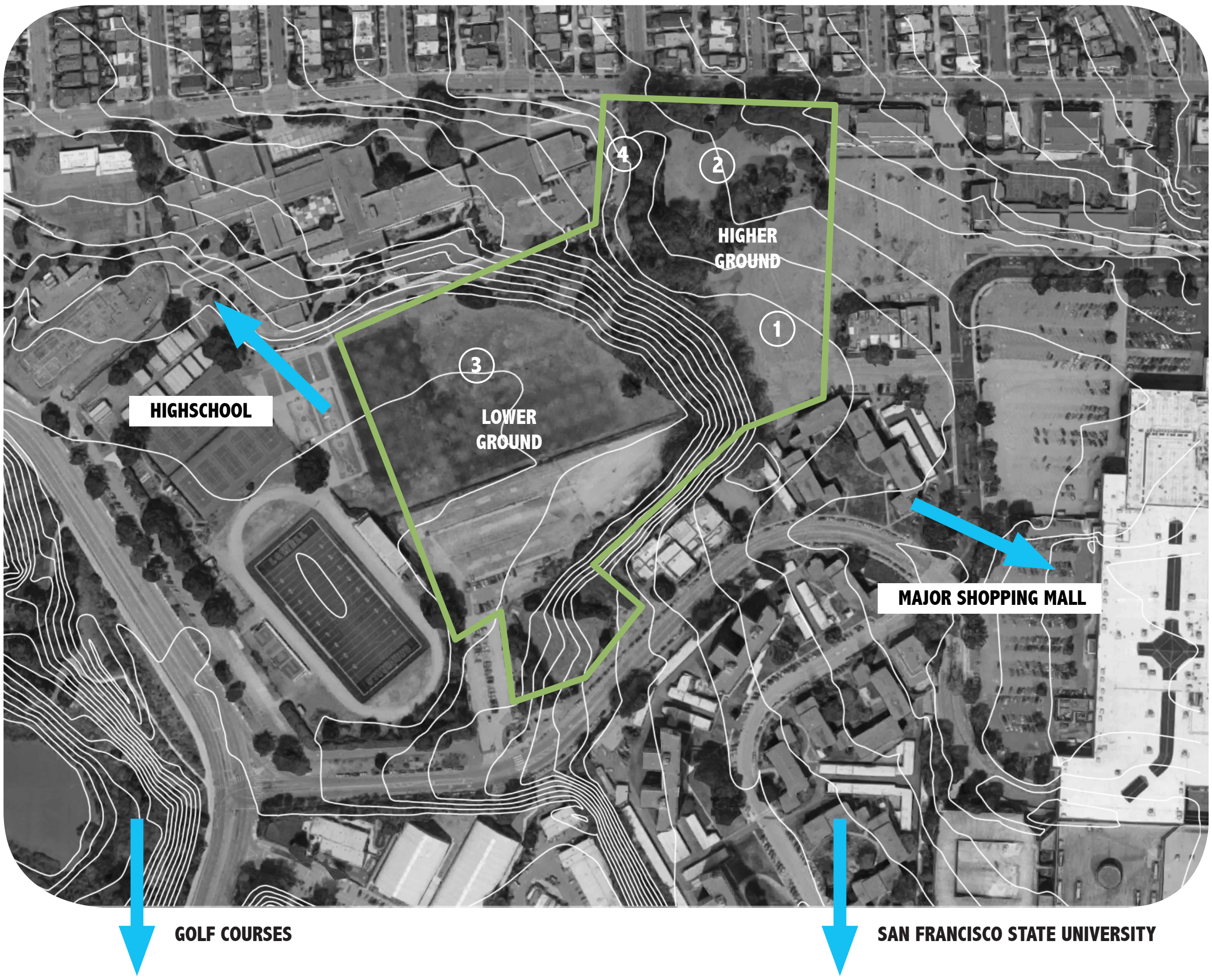


FIG.5.27: SELECTED STUDY SITE FOR CONSTRUCTED WETLAND DESIGN (1:5000)

A site in the Lakeshore District is selected for the purpose of contextualizing the constructed wetland design. The site includes a large sports field, which is part of Lowell High School property and the park and parking lot close to the Stonetown Galleria shopping mall. The site is currently left unused on most days even though it is closed to multiple major public facilities. The introduction of the constructed wetland could transform the site into a major park and create a neighbourhood open space that brings together community stakeholders.

FIG.5.28: 1 _CINEMA PARKING

FIG.5.29: 2 _NEIGHBOURING PARK - ROLPH NICOL PARK

FIG.5.30: 3 _LOWELL HIGH SCHOOL FIELD

FIG.5.31: 4 _DRIVEWAY

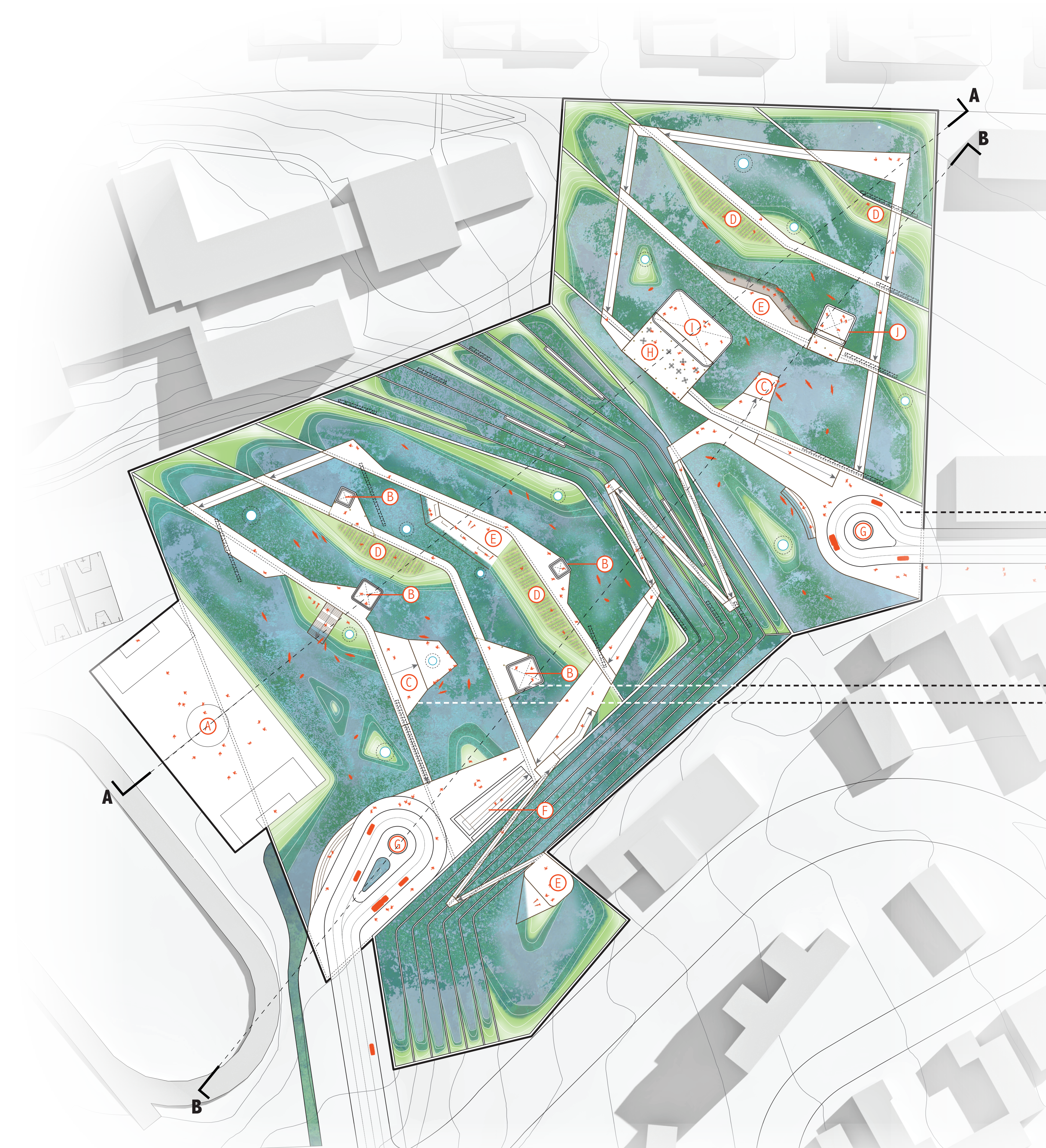
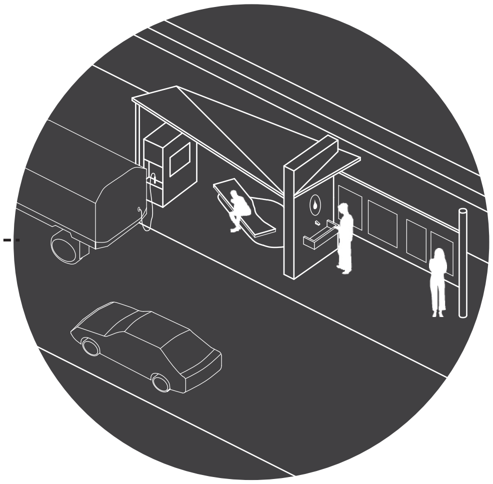
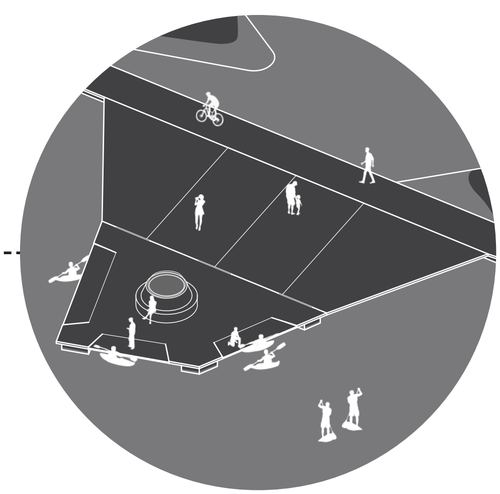


FIG.5.32: Constructed Wetland Ground Plan (1:2000)


Recycled water fill station + Information board


Floating viewing towers + Resting pavillion as entry


Floating deck + Boat launch deck

Water inlet to tank below
Skylight
A. Soccer/ Sports field
B. Floating viewing towers
C. Floating deck/ Boat launch deck
D. Community farming plots
E. Lounging deck
F. Entry ramp to tank below
G. Recycled water filli station
H. Rest pavillion + Cafe
I. Submerged multi-purpose space
J. Submerged control room

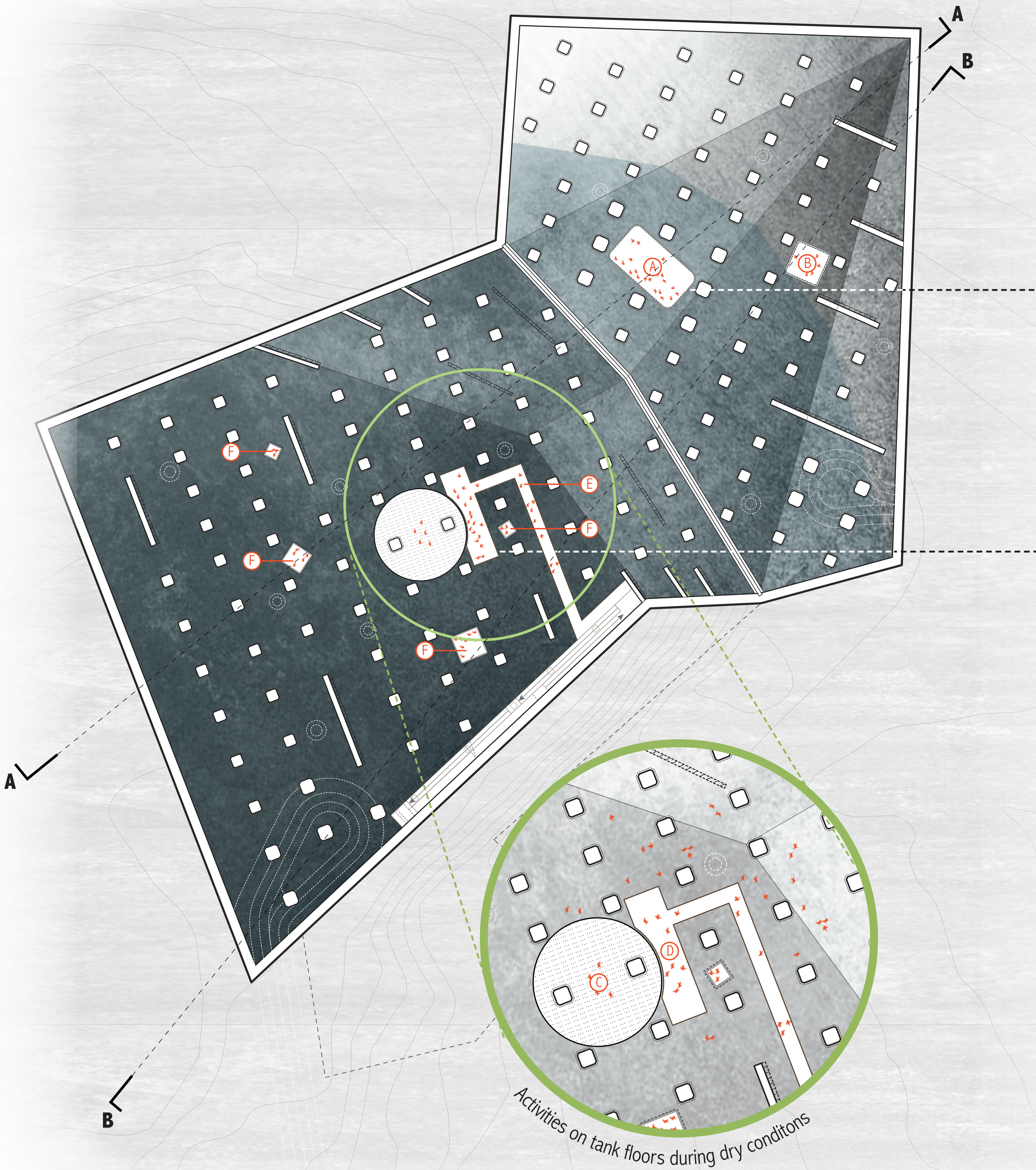
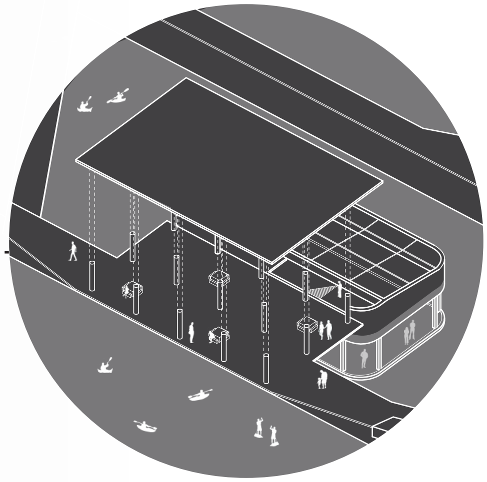


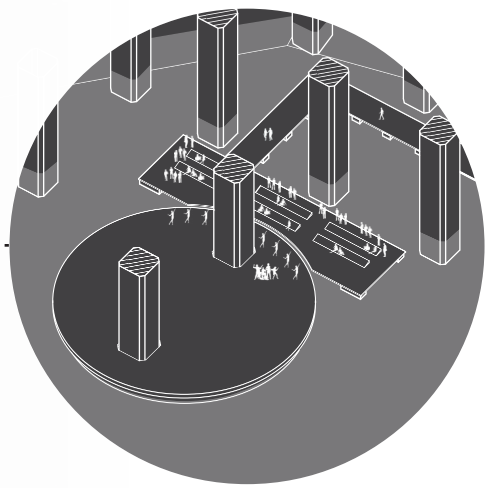
FIG.5.33: Constructed Wetland Underground Tank Interior Plan (1:2000)

WET AND DRY CONDITION WETLAND ACTIVITIES:

WET CONDITION WETLAND ACTIVITIES:



Submerged multi-purpose space +
Resting pavillion + Cafe



Floating centre stage +
Floating path + Audience stand

Water entry wall
Water inlet to tank below
Skylight above
A. Submerged multi-purpose space
B. Submerged control room
C. Floating centre stage
D. Audience stand
E. Floating path
F. Floating viewing towers

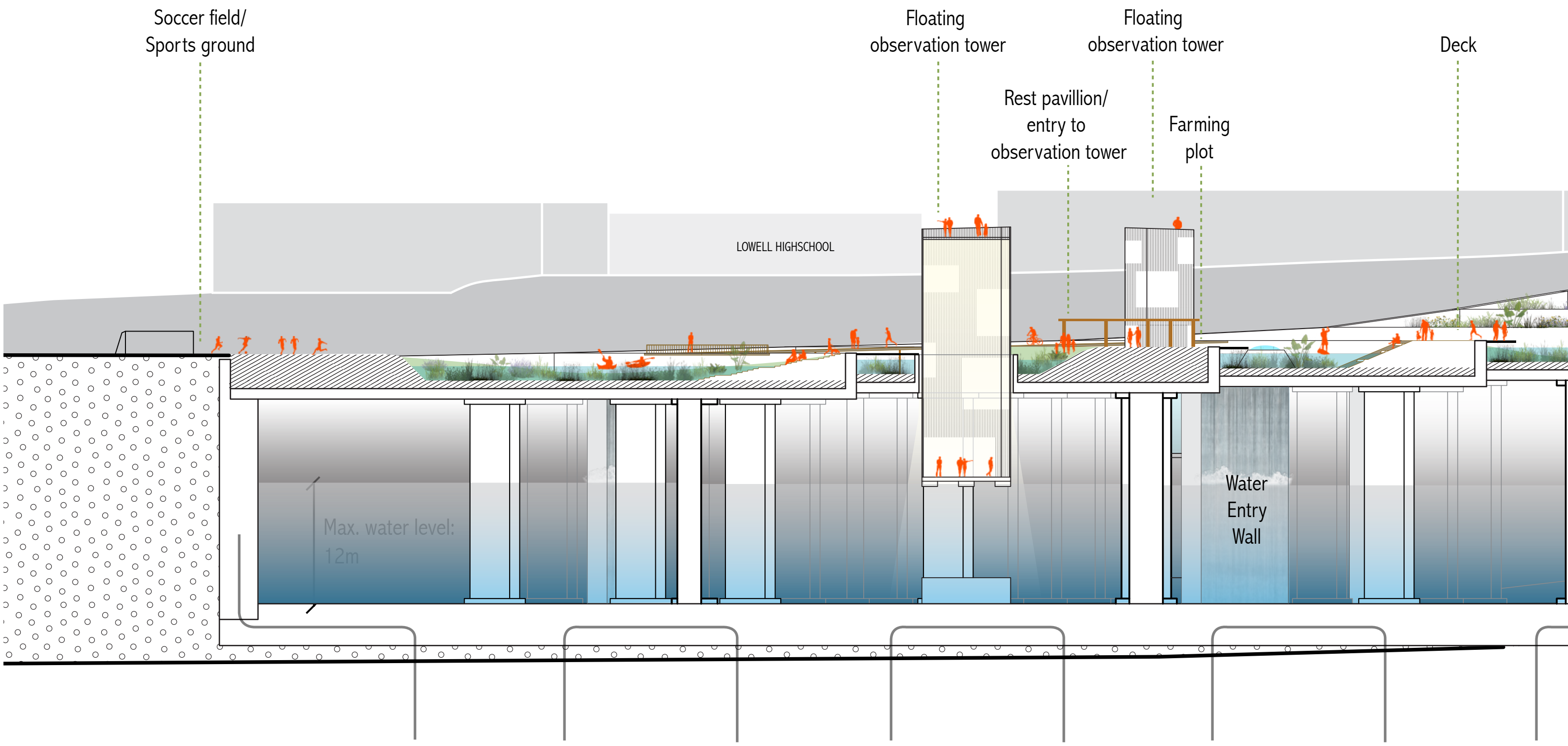


FIG.5.34: Constructed wetland Section A-A (1:700)

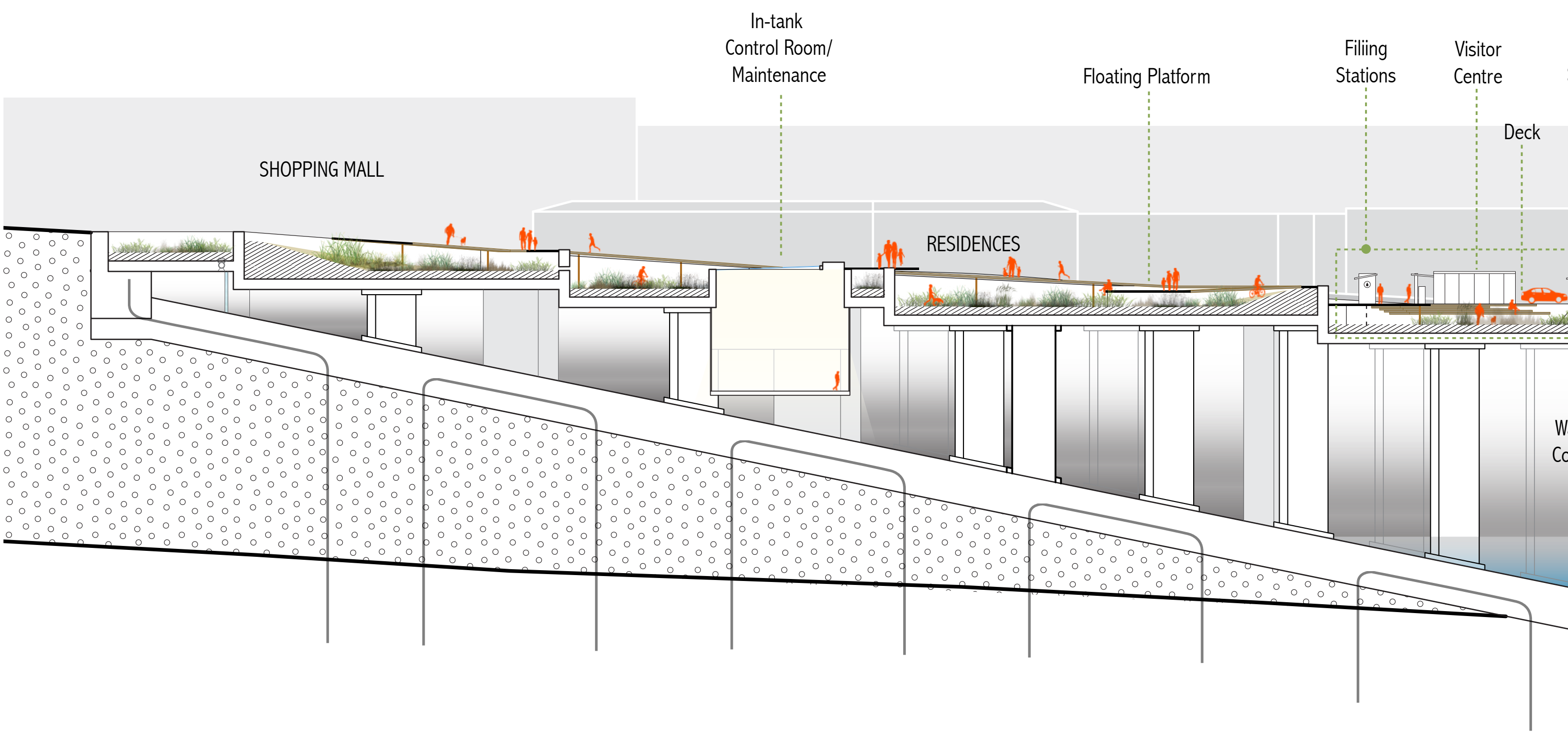
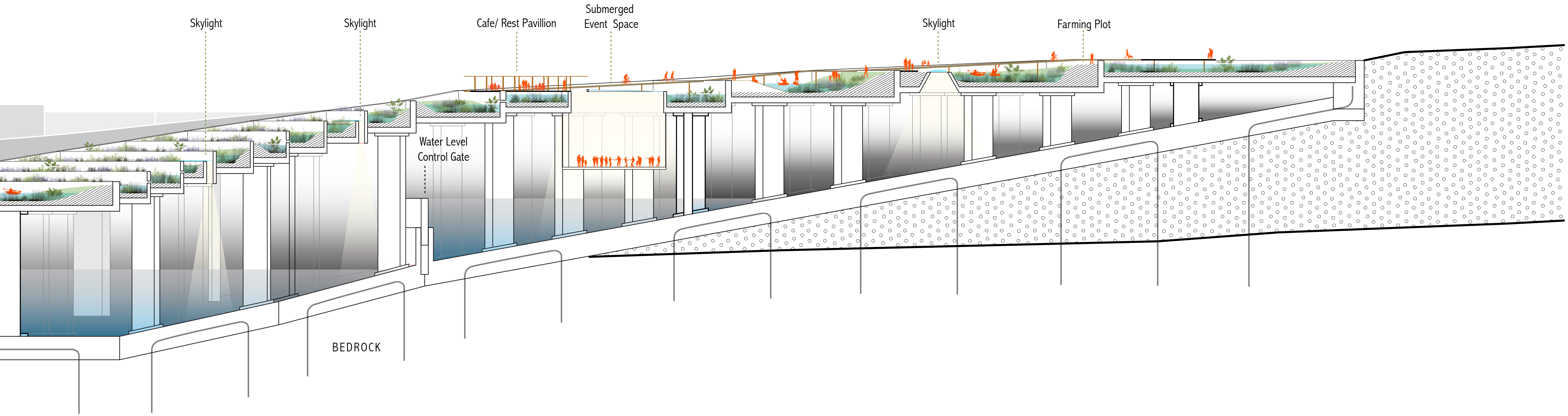


FIG.5.35: Constructed wetland Section B-B (1:700)

AQUACALIFORNIA



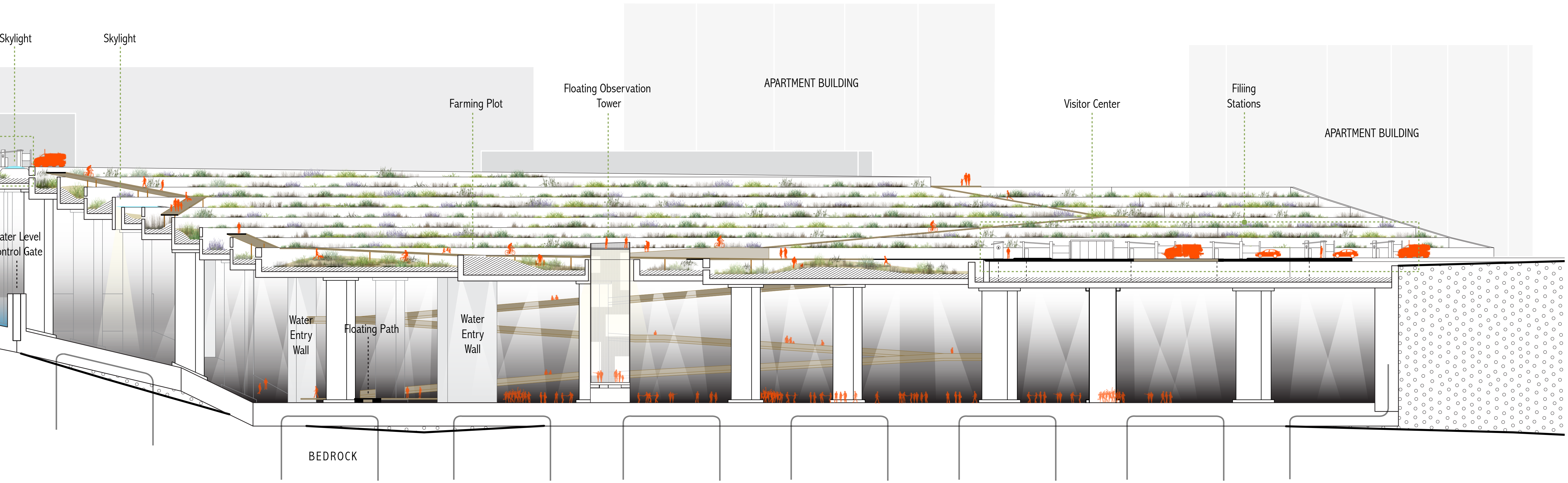
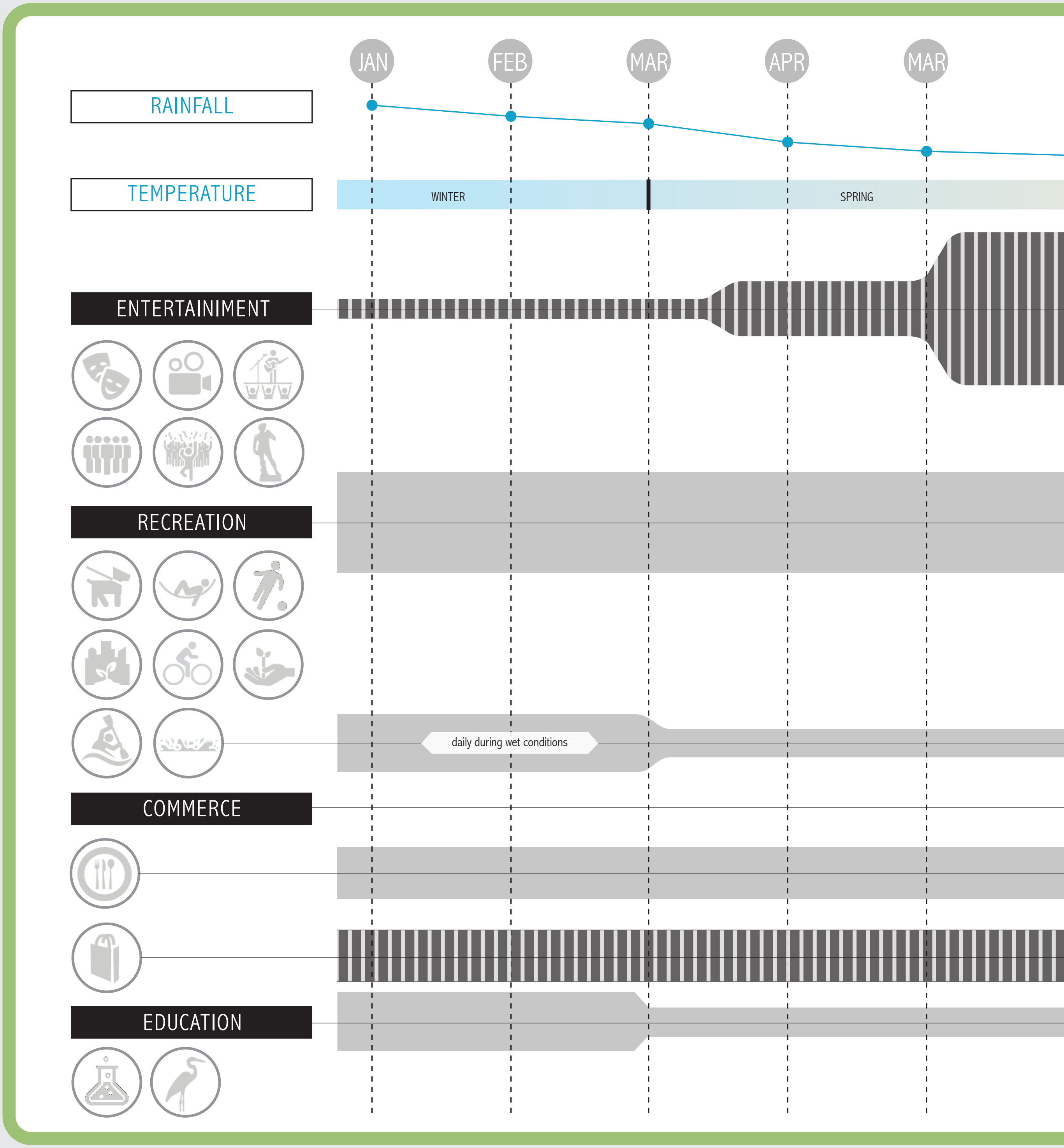
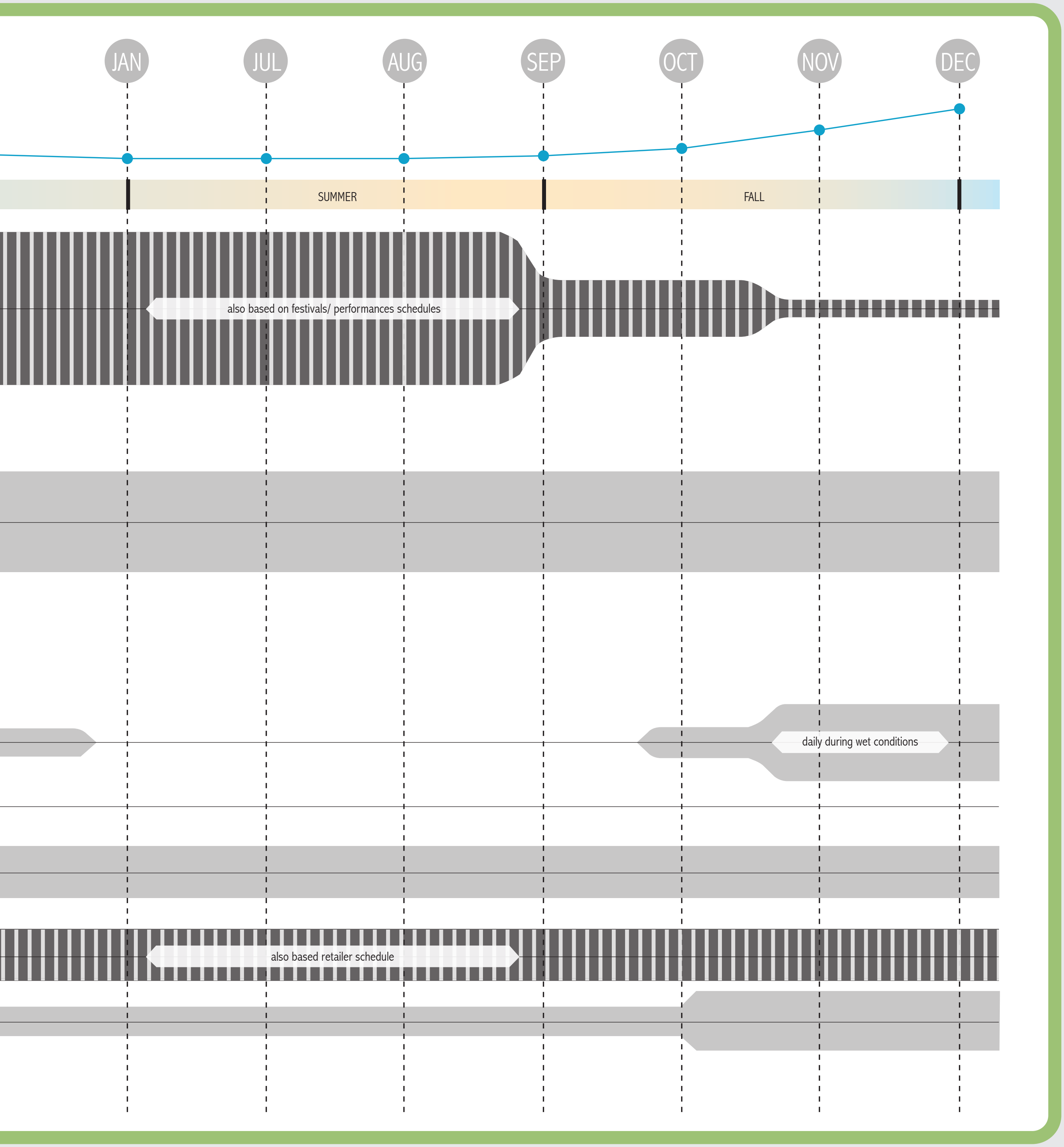


FIG.5.36: View of the constructed wetland during wet conditions

CONSTRUCTED WETLAND PROGRAM TIMELINE

FIG.5.37: Timeline depicting the programs activated in the constructed wetlands based on San Francisco seasonal precipitation and temperature. Increased thickness of the grey bar represents an increased occurrence of an activity.




JAN
JUL
AUG
SEP
OCT
NOV
DEC
SUMMER
FALL
also based on festivals/ performances schedules
daily during wet conditions
also based retailer schedule

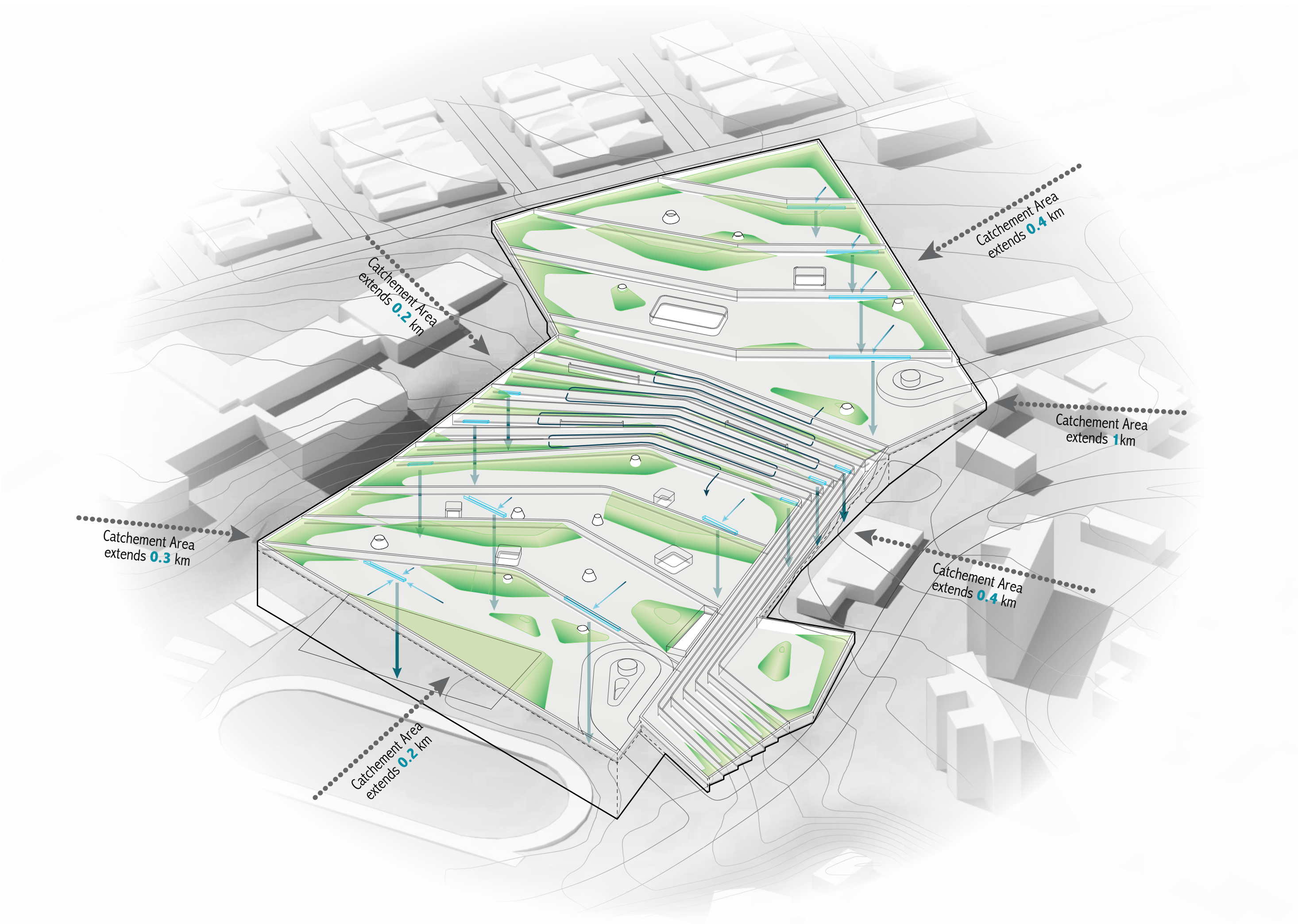


FIG.5.38: Constructed wetland cleansing processes

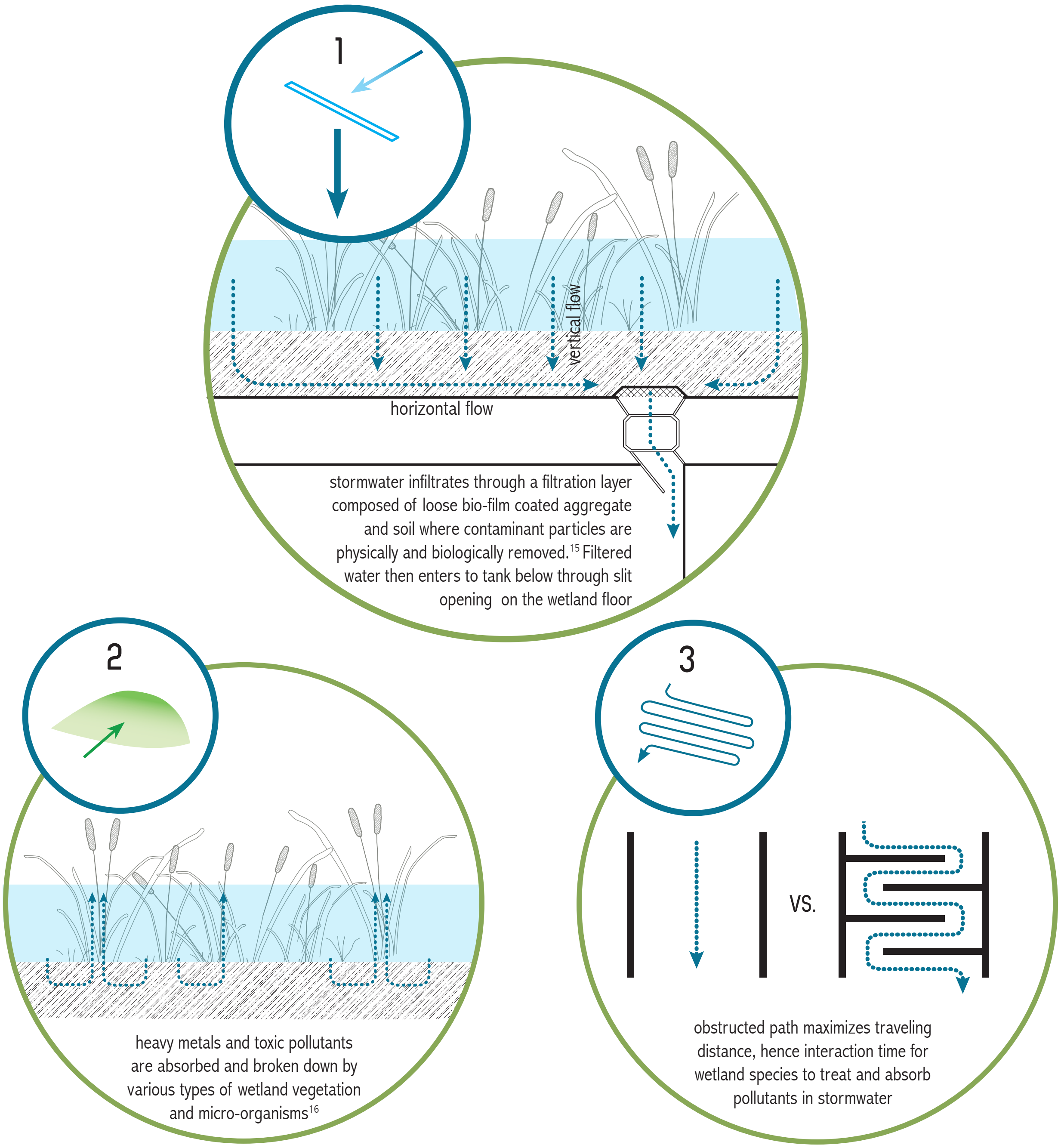


FIG.5.39: Stormwater cleansing processes applied

FIG.5.40: View inside the underground storage tank

COLLECTION AND DISTRIBUTION

Collection: The collection of stormwater and the delivery of filtered water is a crucial part of the larger constructed wetland system. Aside from water flow guided by natural topography, water streets can be formed in areas with high water accumulation to guide stormwater into the wetlands and provide primary filtration. These water streets are essentially typical city streets lined with vegetated bioswales and permeable pavements. These elements are then connected with continuous underground water channels that lead to the wetland. (p.147) Since the construction of water streets would require major alterations to the street surfaces, they would be located only at selected area with high water flow, and would be installed during routine street upgrade projects.

Delivery: The delivery system on the other hand, must be implemented along with the construction of the wetland. There will be two methods of water delivery. The first method utilizes the existing Auxiliary water system which is a high-pressure water system owned and operated by the San Francisco Fire Department.[17] This system is separate from the drinking water supplies and is only used for fire hydrant water supply. The majority of the pipelines in the Auxiliary system are concentrated in the downtown core where most commercial high-rise buildings are located.[18] Through this system, treated water in wetland tanks will be pumped into the pipes and guided to individual building cisterns for non-potable water supply. For districts without the Auxiliary system, water would be delivered with the use of water trucks. Filling stations are located at every constructed wetland. Water trucks can fill up at these stations and the water would be delivered to city parks, golf courses and sports field for irrigation purposes. These filling stations will also be opened to the public so individuals can fill up personal water tanks and receive recycled water for residential uses as well. This method was already introduced and practiced in some California cities, but it is only available in remote wastewater plants.[19] By introducing the idea of local filling station to different neighbourhoods, residents will be more inclined to utilize this recycled resource.

FIG.5.41: Constructed wetland water collection and delivery system map (1:80000)

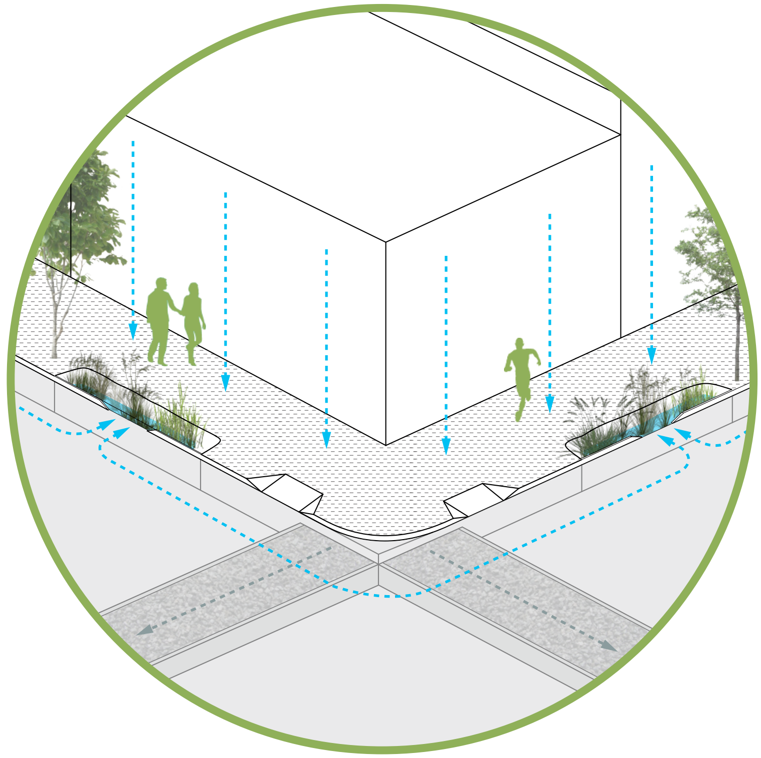


FIG.5.42: Water Collection Streets

Selected streets with high water accumulation are retrofitted with bioswales and permeable pavement. Stormwater will enter into underground water channels directed towards constructed wetlands.

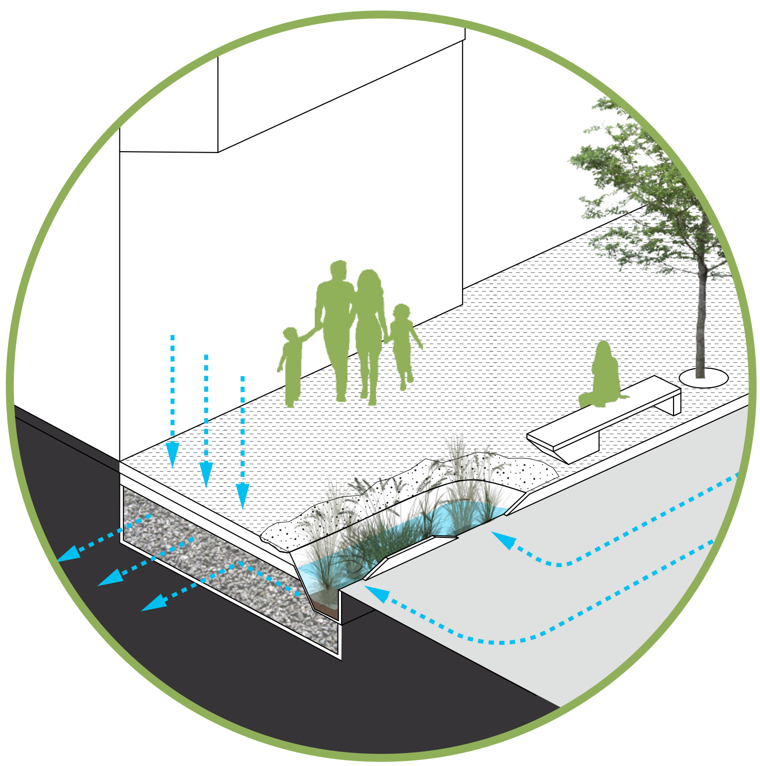


FIG.5.43: Water Street Section

Bioswales connected with permeable pavement and water channel below

FIG.5.44: Auxiliary Water Supply System

The use of existing fire department water delivery system to deliver treated water to individual water cistern adjacent to downtown buildings. Water will be used for non-potable water uses. Method applied to buildings along existing auxiliary system.

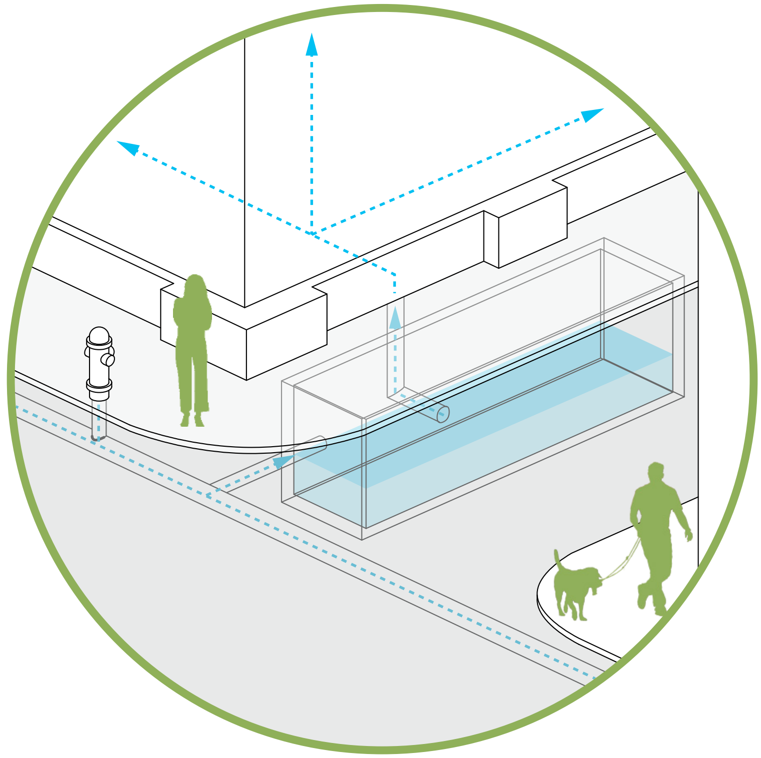
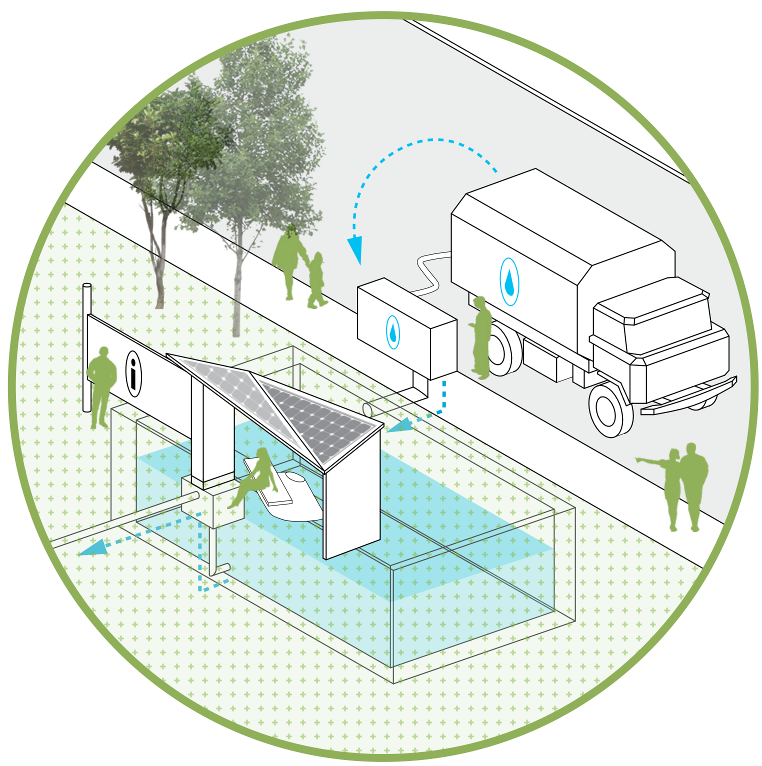


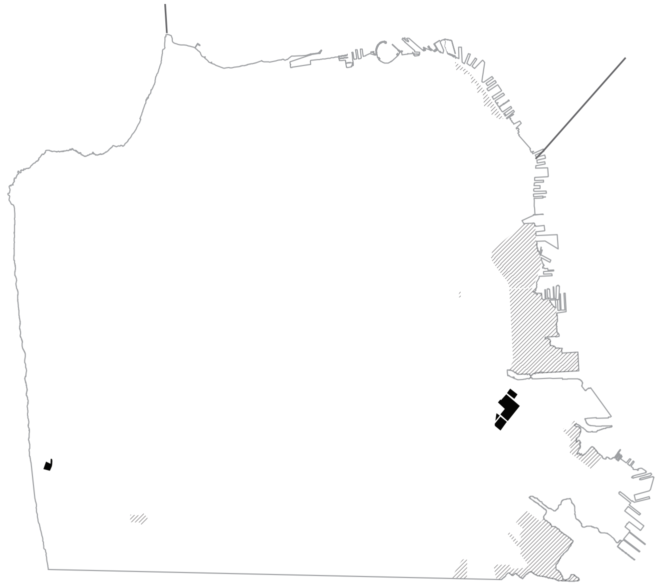
FIG.5.45: Water Truck Delivery

The use of mobile water trucks to deliver treated water to underground cisterns in public parks. Water will be used for irrigation purposes. Method applied to areas not connected to existing auxiliary water supply system.

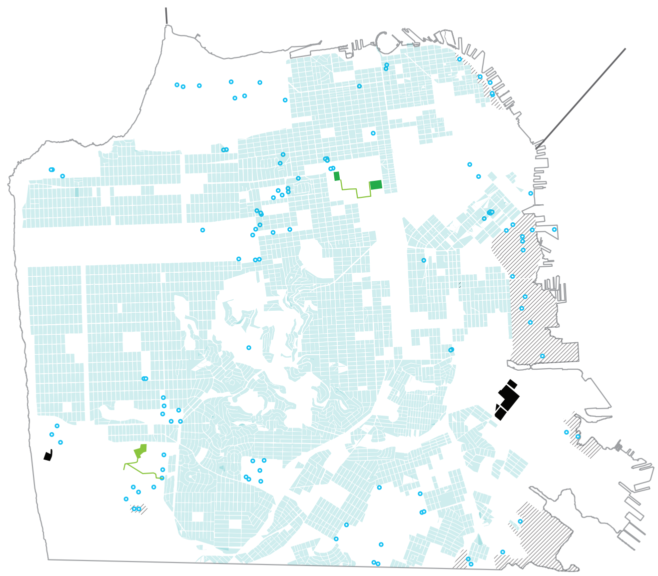


SAN FRANCISCO WATER SYSTEM IMPLEMENTATION TIMELINE

FIG.5.46: Different stages of implementation of the proposed system based on current and projected contexts in San Francisco.

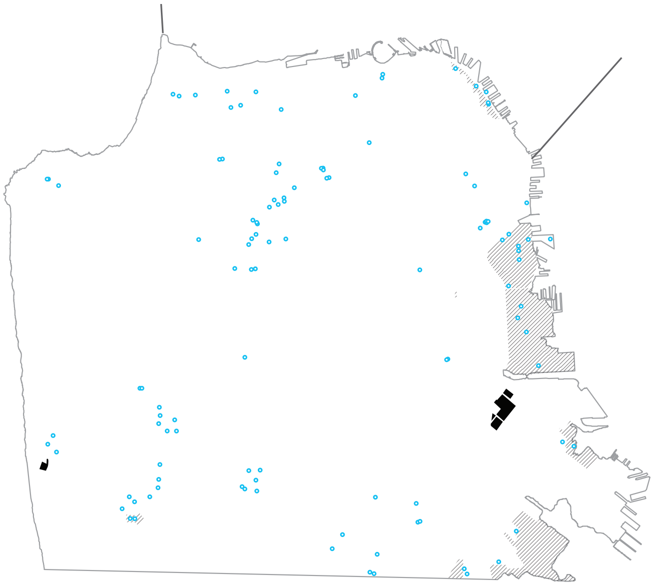


Identify proposed areas of new development. Under the new non-potable water ordinance, all new developments are required to install on-site water return systems. Therefore these area have most potential to adopt the water block program and installation of retention basins.



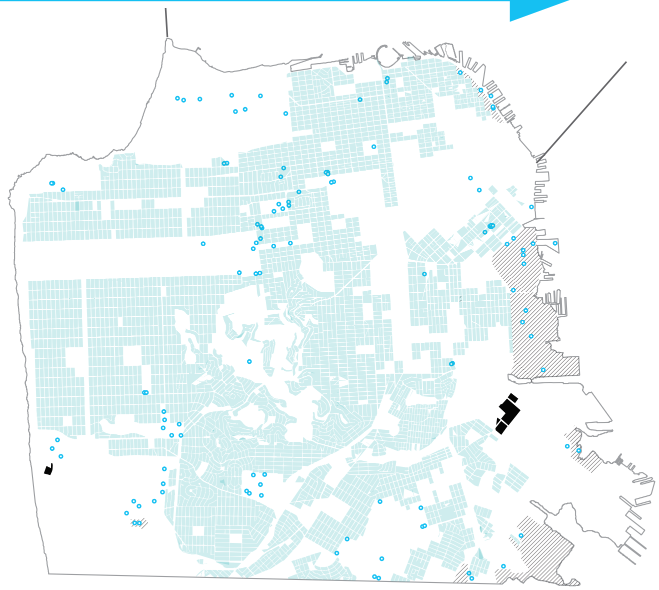
After the smaller scale typologies are established, the first few constructed wetlands and connected water streets would be constructed. They would serve as the first prototypes and trial of the typology. One of the constructed wetlands would be along the existing auxiliary system and one would be off the system to study the effectiveness of both delivery methods.

PHASE 2



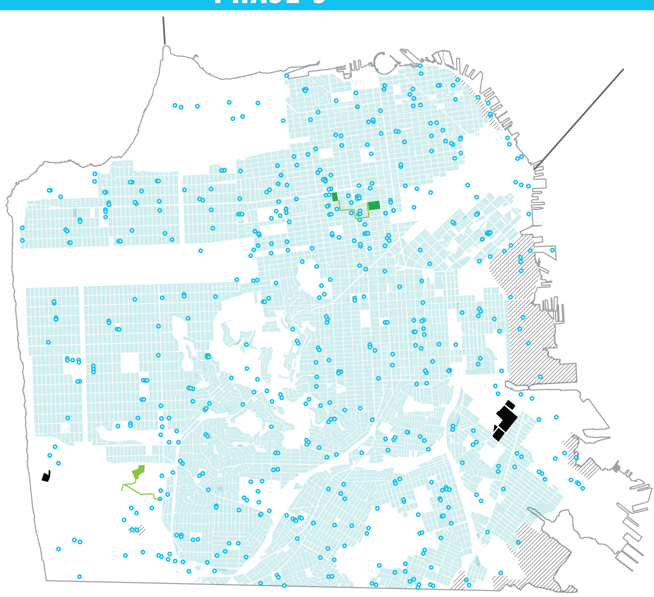
First set of retention basins are installed in the newly developed zones and in open spaces close to major institutional buildings, such as universities, museums, major hospitals and large malls. These institutions have more funding to support and jump start the construction of these basins.

PHASE 3



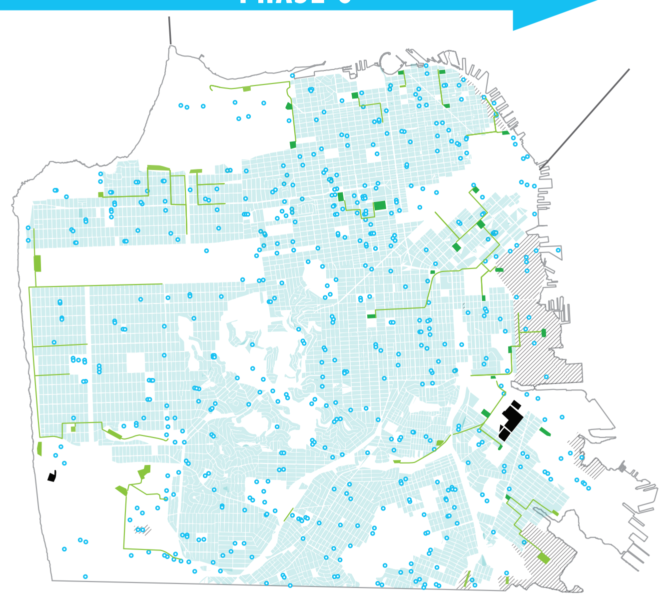
The waterblock program will be introduced first to neighbourhoods and residences of medium to high income. These households would more likely participate and invest in the filtration module, there are also more backyard space in these blocks to contribute to the shared green space.

PHASE 5



The waterblock program would be extended to the other residential block of the city, including those in lower-income neighbourhood. The filtration unit would be already adopted in many parts of the city and would become more affordable.

PHASE 6



In the final phase, all constructed wetlands and water streets would be installed once the first few prototypes are proven effective.

SAN FRANCISCO WATER SAVINGS

The current annual water demand in San Francisco is approximately 89, 394, 340m^3. About one-third of the demand is for commercial uses and the rest is for residential uses. San Francisco would have to continue partial dependence on the Hetch Hetchy system because certain water demands such as drinking water, food preparation etc. must rely on freshwater supplies. However, a large portion of the total water demand is for non-potable uses, so these water demands can be satisfied with water sources from the proposed system. Based on current residential water use pattern, about 40% of residential end-water is greywater and can be reused.[22] Assuming this portion of residential greywater is capitalized through the waterblock typology, this would replace about 25% of the total annual water demand. In terms of stormwater reuse, the constructed wetlands and retention basins are used to supply non-potable water for the commercial sectors. The total combined storage capacity of the two typologies is about 6,633,262m^3 when the systems are full. Nonetheless, since water is constantly withdrawn from the typologies throughout the year. And based on the daily commercial non-potable water demand, these systems would empty every 77 days. This allows the system to continue to be emptied and refilled about 4.7 times in a year since there is enough precipitation in the region to supply runoff for all filling cycles even during drought years. This shows that commercial non-potable water demand can be satisfied entirely with local runoff and this could replaces up to 35% of the total water demand. In conclusion, the proposed water system could potentially replace a combination of 60% of the current water demand in San Francisco. Given that many Bay Area cities have climate, urban development, population and water use patterns similar to San Francisco. The proposed system would likely produce a similar water saving result when applied to these Bay Area cities.

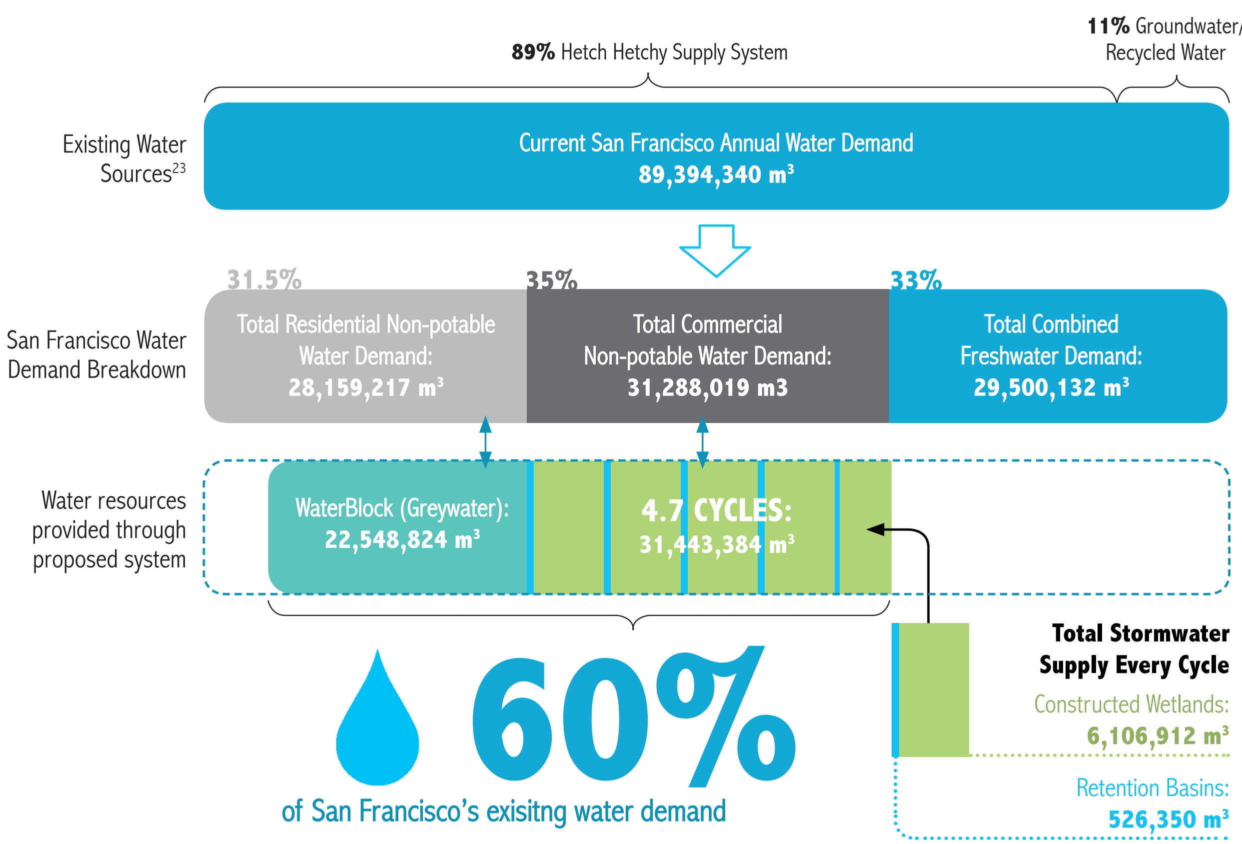


FIG.5.47: Chart showing potential water savings in San Francisco through proposed water system.

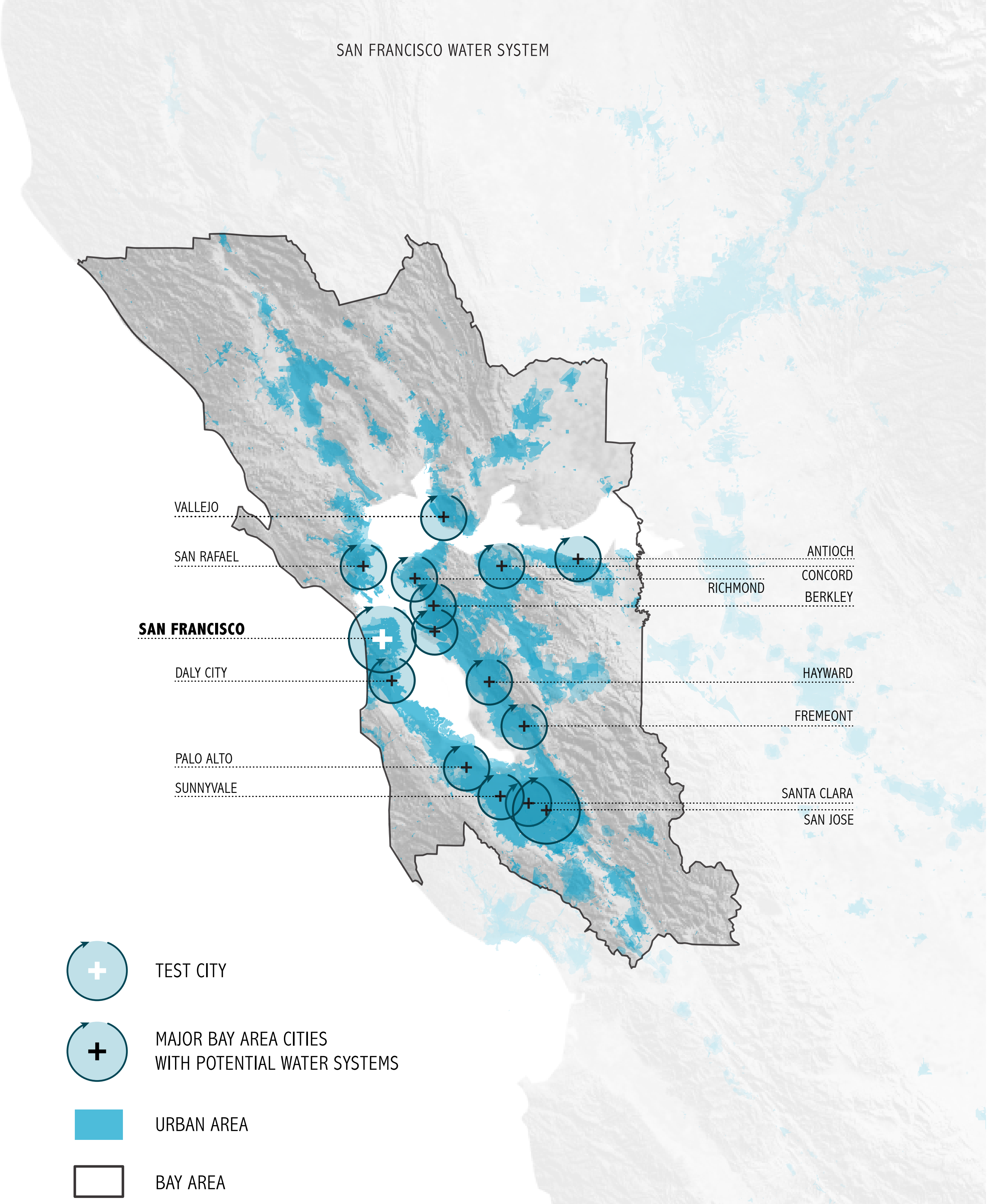


FIG.5.48: Map of potential Bay Area cities that could adopt similar proposed water systems.

04_

BEYOND THE BAY

The proposed water system was designed largely based on the local context of San Francisco and other major Bay Area cities. However with some adjustments, the system and the water infrastructure typologies are also applicable to other urban areas of California, especially in the Central Valley. According to urban growth projections from the state government, slow-growth policies in Northern California and limited developable land supplies in Southern California are squeezing population growth into the San Joaquin Valley.[24] Together with a decline in cultivated land, more farmlands in the region would be converted for urban and real-estate developments in the coming decades, and the conditions of urban centers in Central Valley will likely become more similar to ones in the existing urban zones. The potential new developments in Central Valley represent a unique opportunity for the adaptation and experimentation of sustainable, decentralized water infrastructure.

A main difference between local water issues in Central Valley and Bay Area cities is the water systems' dependency on groundwater.[25] Due to a higher agricultural water demand, groundwater overdraft and land subsidence in Central Valley is more severe than any coastal regions.[26] Currently, water utilities providers in Central Valley are attempting to offset the overdraft by recharging aquifers with recycled wastewater, but the recharge process and amount is still too low in comparison to the withdrawal rate.[27] Therefore, a more intensive aquifer recharge program and a reduction in unnecessary groundwater withdrawal are crucial. The introduction of the waterblock typology is an effective solution in this scenario. As population rises, there will be a corresponding increase in the production of greywater. If this alternative resource can be efficiently reused locally, municipalities can easily cut back on its reliance on groundwater for urban water uses and avoid the expansion of costly wastewater treatment facility.

The other two water typologies focused on stormwater capture, the retention basins and the constructed wetlands, are also applicable to Central Valley urban centers. As mentioned in previous chapters, the recurrent El Nino effect can bring occasional storms to California even during drought periods, causing serious flash floods at times.[28] In many Central Valley cities, such as Fresno, there are already stormwater basins in place to capture stormwater runoff and facilitate groundwater recharge.[29] However, these existing basins are extremely monofunctional, often fenced off from the public and contribute little to the community. To enhance this existing model, some of these stormwater basins can be converted into constructed wetlands to provide extra water treatment and much needed public programs to the city . These constructed wetlands can be installed without the underground storage tank and simply allow treated stormwater to infiltrate into natural aquifers. Similarly, the proposed retention basin typology can also be applied to smaller lots in the city to assist stormwater capture and infiltration by replacing the sealed storage tank with a perforated tank. Undoubtedly, the full application of the proposed typologies in Central Valley must require a careful and in-depth examination of the local context, but the three proposed typologies still serves as effective prototypes for potential water infrastructure development in Central Valley cities.

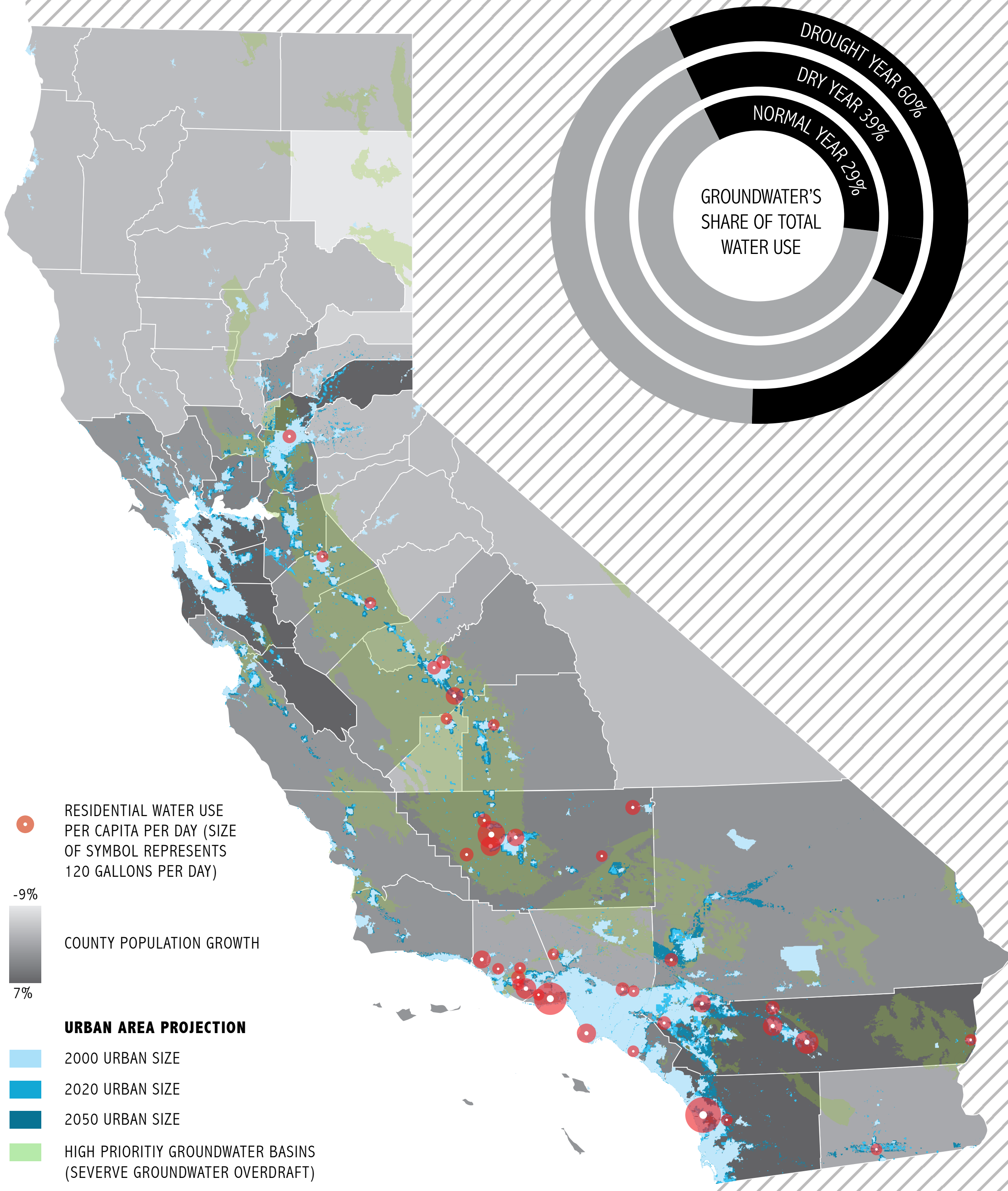
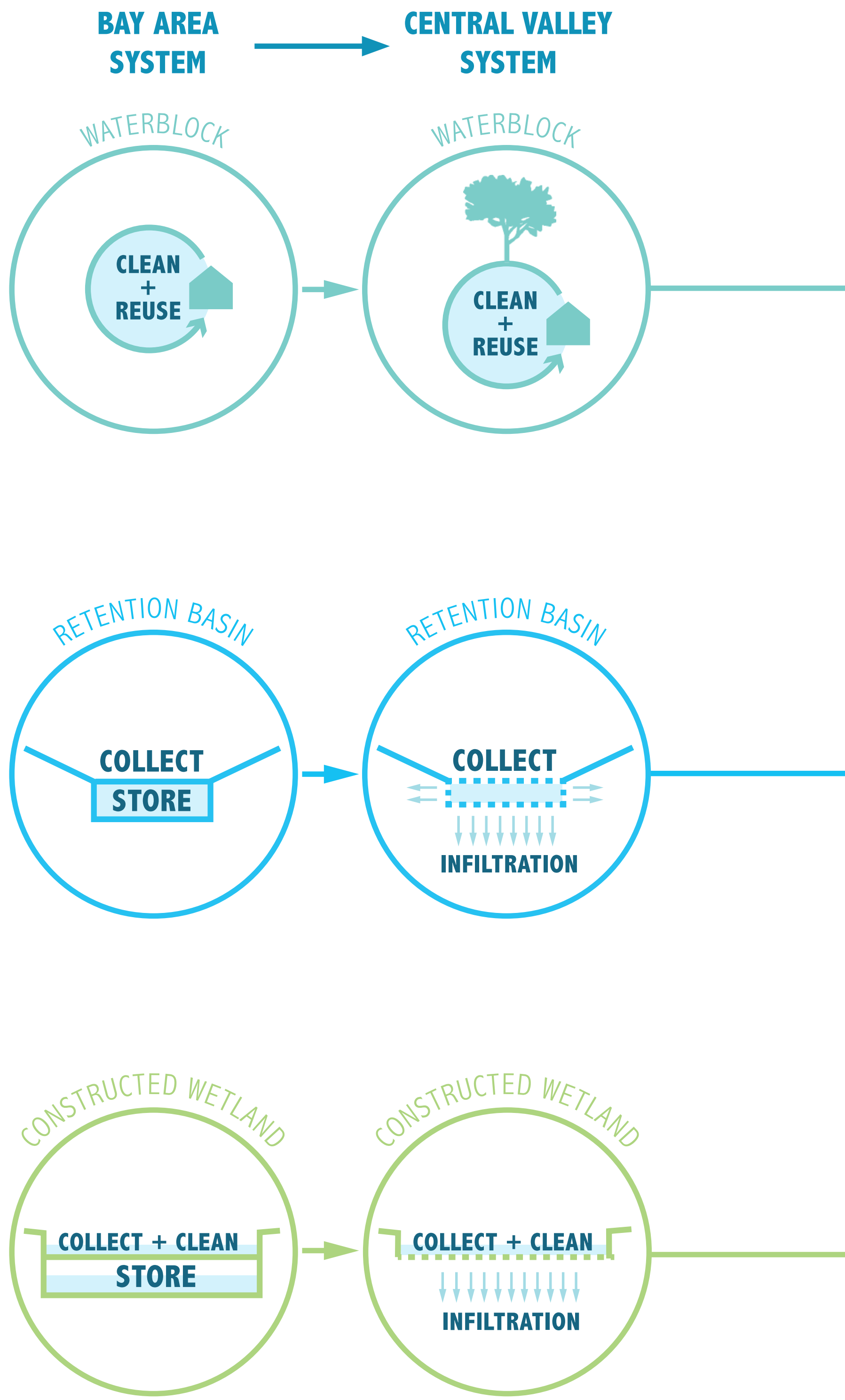


FIG.5.49: Map showing regional per capita residential water use[30], projected urban growth areas[31] and regions affected by severe groundwater overdraft[32]. Many of the biggest residential water users are located in Central Valley and Southern cities that are projected to grow rapidly in the coming decades. These growth areas also overlap with high priority groudwater basins and may add to the groundwater overdraft problem.

CENTRAL VALLEY APPLICATION

FIG.5.50: Figure below explains the adjustments required in proposed typologies to apply the proposed Bay Area water system to Central Valley cities. Photos shows locations in Fresno, a major Central Valley city, where each typology can be applied.



WATERBLOCK

This typology does not require much adjustment as the greywater reuse process is similar in both coastal and Central Valley cities. However, temperature and radiation in Central Valley are relatively higher than coastal regions.[33] Therefore when developing the shared central green space, more trees should be planted along the filtration modules to provide adequate shading and reduce water loss through evaporation.[34]

RETENTION BASINS

The main adjustment in the retention basins is the replacement of the sealed underground storage tank with a perforated tank. Instead of directing the collected water to adjacent institutional buildings for non-potable water uses, the collected water would infiltrate naturally into the ground through the perforated walls.

CONSTRUCTED WETLAND

Existing retention basins in the Central Valley cities will be converted into constructed wetlands. Wetland vegetation and biofiltration aggregates would be added to existing basins to facilitate natural water cleansing processes. Other wetland recreational features such as floating platforms, elevated walkways and decks would also be added to convert the stormwater basins into community parks. However, these wetlands would not be retrofitted with underground tanks in order to allow natural aquifer recharge.

FRESNO POTENTIAL LOCATIONS

FIG.6.1: Millerton Lake Reservoir during drought

CONCLUSION & REFLECTION

FIG.6.2: Sacramento, California, United States

Before the start of this thesis I had the opportunity to travel to Western America during the summer of 2014. As discussed in the previous chapters, that was the hottest year on record in California[1] and much of the state was under an exceptional drought. The trip had certainly raised my interest in the water issues in Western America, but one of the experiences that inspired me most to pursue this topic was a drive from San Francisco to the Yosemite National Park. On that journey, I passed by some of the Central Valley farmlands heavily impacted by the drought, reservoirs depleted of water and countless signs urging for water conservation. With this experience and an assumption that climate change is the sole driver of the problem, I began the thesis as an investigation into the recent drought events. Nonetheless as the thesis progresses, it has become clear that water scarcity in California is a more complicated issue than just climate change; anthropogenic factors play an equally prominent part in these water challenges. In fact, the recent shifts in the hydrological cycle have revealed the deficiencies of our previous unsustainable form of development, highlighting weaknesses such as the heavy reliance on centralized water delivery systems and careless disposal of alternative water resources. These revelations make me understand that in order to ensure long-term water security in California, it would require a paradigm shift in people's perception of water resources and a critical reform of water infrastructure development. Water security and water infrastructure should not remain a topic solely discussed in the scientific community, but one

that involves all expertise and disciplines, including perspectives of urban designers and architects. Although the drought in California may not represent a traditional architectural or urbanistic question, designers and architects should not view it as a barrier. In truth, the political, cultural and social contexts in California provide designers with a unique opportunity to reimagine our approaches towards water management and urbanism. The state is less affected by political and economical instability compared to other global drought-stricken regions. Californians are also more responsive to sustainable innovations and practices, proven by the some of the government and community-based sustainability policies in place. This context provides huge potentials to create real changes in the State and sets an important ground for developing unconventional solutions to water scarcity issues. Ultimately, this is also the goal of the AquaCalifornia thesis; to examine water issues in California through the lens of architecture and urbanism and provide a unique, unconventional solution to these issues. At this stage, AquaCalifornia is purely a speculative proposal based largely on conditions in the Bay Area and the water typologies are developed to focus on capturing only two of the largest alternative water resources, stormwater and greywater. Nonetheless, the project still provides a framework for not just designers, but developers and policy makers to reimagine the potentials of urban water infrastructures. Although the typologies suggested would require much further study and development before its realization, they can still act as prototypes for other drought resistance designs and help launch the discussion

FIG.6.3: Interior of San Francisco Southeast Wastewater Treatment Plant

of water-related issues in the field of planning and architecture.

In terms of the future stages of the project, in order to diversify the water portfolio further and increase its feasibility, it would be necessary to study multiple Californian cities more closely and continue to adjust the typologies to adapt to specific local contexts. Some additional contexts layers that should be considered are the demographic composition of cities, agricultural and irrigation process in different regions and even food accessibility. Since agricultural development is strongly tied to local water processes and it is the second largest water user in the state, more study into agricultural processes may help uncover new opportunities where the proposed design can contribute and help address other forms of water issues. One example of such opportunity is an investigation into how the proposed typologies can be adjusted to accelerate groundwater recharge with filtered stormwater, so urban water resources can be returned to adjacent farmlands for irrigation purposes, connecting the urban and agricultural processes. Looking into the implementation potential of each typology, some of the more challenging sites for the retention basin and constructed wetland typologies would be Southern California inland cities. These areas naturally resemble desert-like landscapes and climate conditions are constantly arid[2], so typologies dependent on local precipitation may not be applicable. However for such regions where locally renewable water resources are rare and limited, it is crucial to question if large-scale urban developments and commercial agriculture is

even appropriate or sustainable. The more effective strategy to counter the water challenges in these regions may depend mostly on policies to control the scale of urban development and limit the rate of agricultural growth. For other California cities outside these desert zones, the implementation of the proposed system is equally dependent on a change in local, state and federal policies. Currently, much of the sustainable policies in place are functioning largely as targets and suggestions, which are not highly effective in enforcing or demanding project investments or realization. Apart from participation from individual citizens or individual organizations, there is a need for more top-down movements from governing bodies to regulate and push forward sustainable, water-cautious projects. Other than offering incentive programs locally, there must be a reform in the laws and regulations, such as water use regulations, water pollutant emission levels control and so on, to ensure water conservation project does not remain as a fictional concept.

Another major step that could benefit the design proposal greatly is the exploration and investigation into other alternative water resources, including wastewater and atmospheric water. Wastewater reuse is already adapted in certain major California cities.[3] However, the wastewater reuse rate remains very low since wastewater requires complicated filtration processes that are often performed in centralized wastewater plants and would require a separate system for its delivery.[4] To enhance the water system proposal, it would be valuable to develop the waterblocks further to incorporate local processes capable of handling wastewater treatment. Another approach is looking into the reduction of the wastewater production by switching to a dry waste system. Similar to existing programs that encourages a switch to a dual flush toilets, this system would help reduce the amount of water needed for waste removal and lower citywide water demand.[5] Combined with the typologies already proposed in AquaCalifornia and maybe other fog harvesting interventions6, future California cities could potentially balance their local water supply and demand patterns with little reliance on the conventional centralized systems.

Approaching the end of 2016, signs of relief from this drought started to emerge. After October 2016, a series of heavy rainstorms triggered by the El Nino Effect have brought precipitation in forms of rain and snow back to the State.[7] This influx of water even caused flash floods in some cities and successfully refilled some reservoirs in the State.[8] This is unquestionably great news for many Californians and some believe the drought is no longer a concern. Nonetheless, these rain events does not signify an end to the water scarcity. According to multiple researches, the local climate trends only indicate higher temperatures and more frequent, severe droughts in the coming years.[9] Groundwater overdraft was also so severe during the drought that a wet year would hardly improve the conditions, especially when the arid pattern returns and the groundwater withdrawal resumes.[10] The flash floods in multiple urban centres[11] also indicate that our urban water systems are out-dated. Stormwater drainage networks are overwhelmed, but the valuable water resource is contaminated and not capitalized. Moreover, citizens began to neglect water conservation needs and resumes their unsustainable water use routine.[12] If California cities and its inhabitants return to their conventional water management approach, water scarcity will likely continue to haunt the state even with temporary relief from the occasional wet years. These fluctuations in the California's weather only further demonstrate the State's urgent need for more localized, close-loop water systems similar to the proposed system in this thesis, in which local water resources can be captured and stored during wet seasons to ensure stable water supplies when arid conditions return.

California is one of the most populated and productive states in the United States and one of the most ecologically diverse landscapes on Earth. The recent shifts in the hydrological cycle have posted immense pressures on this valuable landscape and revealed the danger of our previous unsustainable form of development. The affects of this recent drought have extended far beyond California's local watersheds, proving that water scarcity is not just an issue specific to California or even to the American West, but a global crisis. At this defining moment, the global design community must come together to re-evaluate the relationship between the urban fabric and modern water infrastructure systems. If urbanization once transformed and devastated the natural water landscape, then it also has the ability to reverse some of these unsustainable footprints and contribute positively to the resolution of water scarcity. A new form of urban development that embraces the complexity of hydrological processes will be the key to developing infrastructure models that do not only survive but also evolve with the changes in our natural environment.

FIG.6.4: View of the LA River

ENDNOTES

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Drought year precipitation:
SF average annual precipitation 2011-2015 x 30,000 Acres x 27,154 gallons x 55%
= 15.745 inches x 30,000 Acres x 27,154 gallons x 55%
= 7,054,405,545 gallons
= 26703830 m^3

Historic average precipitation:
Historic SF average precipitation x 30,000 Acres x 27,154 gallons x 55%
= 23.64 inches x 30,000 Acres x 27,154 gallons x 55%
= 10,591,689,240 gallons
= 40093905 m^3

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