HARVESTING STORMWATER

TRADITIONAL ECOLOGICAL KNOWLEDGE AND DRYLANDS STORMWATER INFRASTRUCTURE IN TUNIS, TUNISIA

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A thesis
submitted in partial fulfillment

of the requirements for the degree of

Master of Landscape Architecture

University of Washington

2019

Committee:

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Program Authorized to Offer Degree:

Landscape Architecture

University of Washington

Abstract

HARVESTING STORMWATER:

Traditional Ecological Knowledge and Drylands

Stormwater Infrastructure in Tunis, Tunisia

Fatema Maswood

Chair of the Supervisory Committee:

Julie Johnson, Department of Landscape Architecture

In Tunisia, the presence of water wavers between poles of scarcity and catastrophic abundance, its drought-prone climate punctuated by increasingly erratic bursts of precipitation. Flash floods, now frequent in the western parts of the Mediterranean coastal region, are merely one facet of the climate crisis's effects on the region's human settlement and ecosystems. In this thesis I examine Tunisia's capital city, Tunis, as a past and future site of flash flooding, exploring colonial alterations of the urban form during the French colonial era, exacerbated flood risk as a result of development on marshlands, and the possibility of distinctly North African green stormwater infrastructure rooted in traditional ecological knowledge. Pre-colonial water-harvesting methods adapted to the semi-arid climate are analyzed, modelled, and visualized in flood simulations to speculate on their viability as nodes in a decentralized network of small-scale water harvesting systems.

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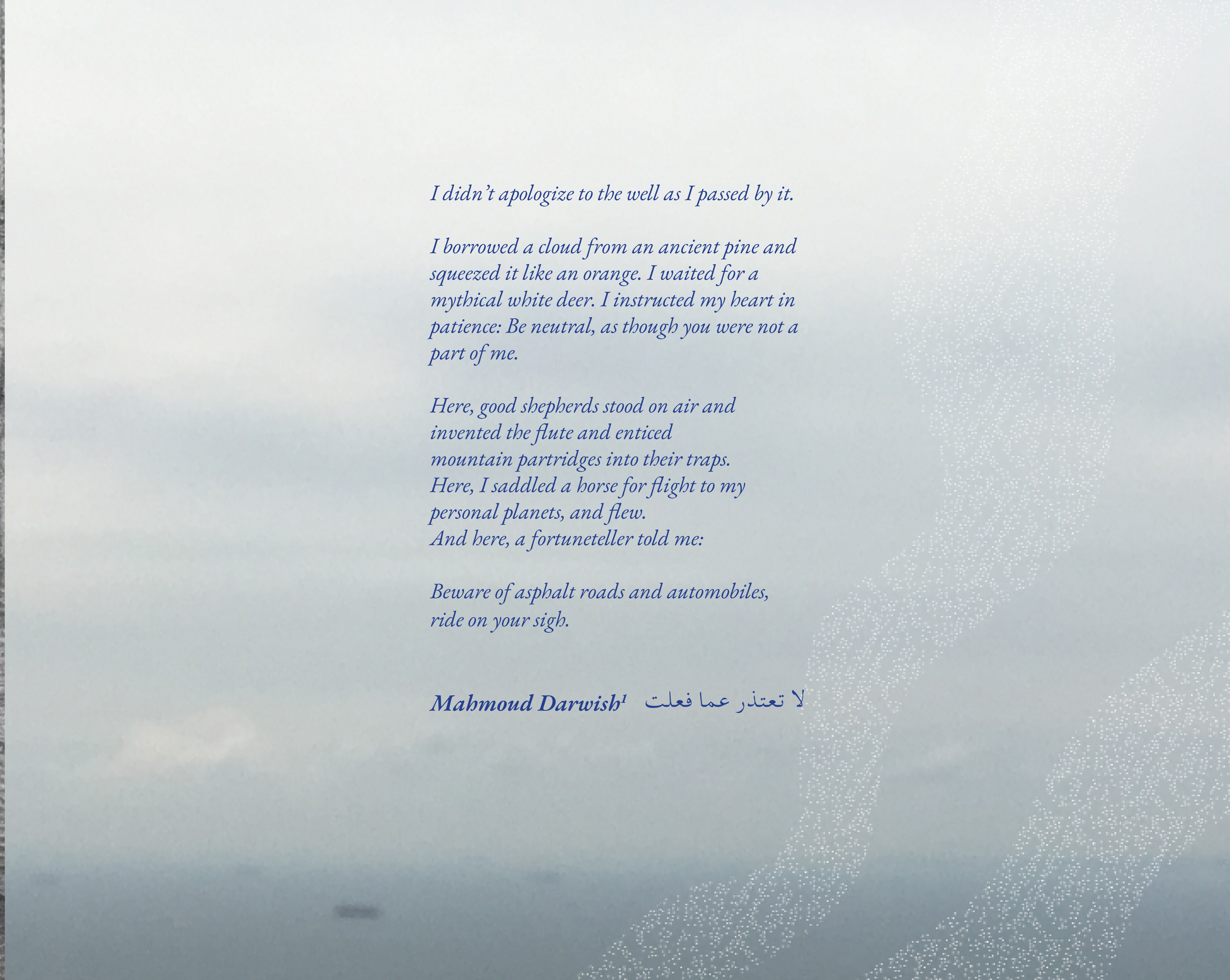
FATEMA MASWOOD



I didn't apologize to the well as I passed by it.

I borrowed a cloud from an ancient pine and
squeezed it like an orange. I waited for a
mythical white deer. I instructed my heart in
patience: Be neutral, as though you were not a
part of me.

Here, good shepherds stood on air and
invented the flute and enticed
mountain partridges into their traps.
Here, I saddled a horse for flight to my
personal planets, and flew.
And here, a fortuneteller told me:

Beware of asphalt roads and automobiles,
ride on your sigh.

Mahmoud Darwish[1] لا تعتذر عما فعلت

ACKNOWLEDGEMENTS

I am writing about Tunisia in the context of a natural disaster (flash flooding) embedded in a larger planetary disaster (capitalism). Rather than painting Tunisia and the city of Tunis in a tragic light, I want to preface this by saying that Tunisia is an unbelievably beautiful place. Time spent with family and friends in Tunisia has taught me about true generosity, moving fluidly and confidently between worlds, and fighting when it matters. As a Tunisian-American raised in the United States, I can only write through the lens of diaspora. This work is part of a lifelong process of deepening my relationship with my mother's home, as well as reimagining a world unburdened by colonization. My first acknowledgement is to the land and my family there.

I have so much gratitude for the guidance my committee chair, Julie Johnson, has provided throughout this project and over the past two years. Julie has been a bright light and seemingly endless source of clementines during in my time in graduate school, pushing me to refine my work, and taking time to talk about what transformative work as a designer can look like in between edits. I am also grateful to my committee co-chair, Manish Chalana for reviewing my work. Thank you to Jack Hunter for the hours put into helping me fabricate my models, to Susannah Morey for providing me with access to the Augmented Reality sand box to run flood simulations, and to all of the critics who have offered feedback over the past few months. Thank you to my Dadee and Memety, my two grandmothers who have gifted me with their stubbornness and sense of humor. Thank you to my mother, Ahmed, Nasr, Khalty Thouraya, Sharmin and Navin. Thank you to the Landscape Architecture department for being a home for the past two years. Thank you to my cohort and to everyone in the CBE shop and digital fabrication lab for the solidarity and camaraderie. And thank you to Tycho for poems and design advice, for steering the craft, for building worlds together.

Finally, I offer my gratitude to the Coast Salish people, whose land I have lived on during the process of writing and researching this work, and to all water protectors everywhere.

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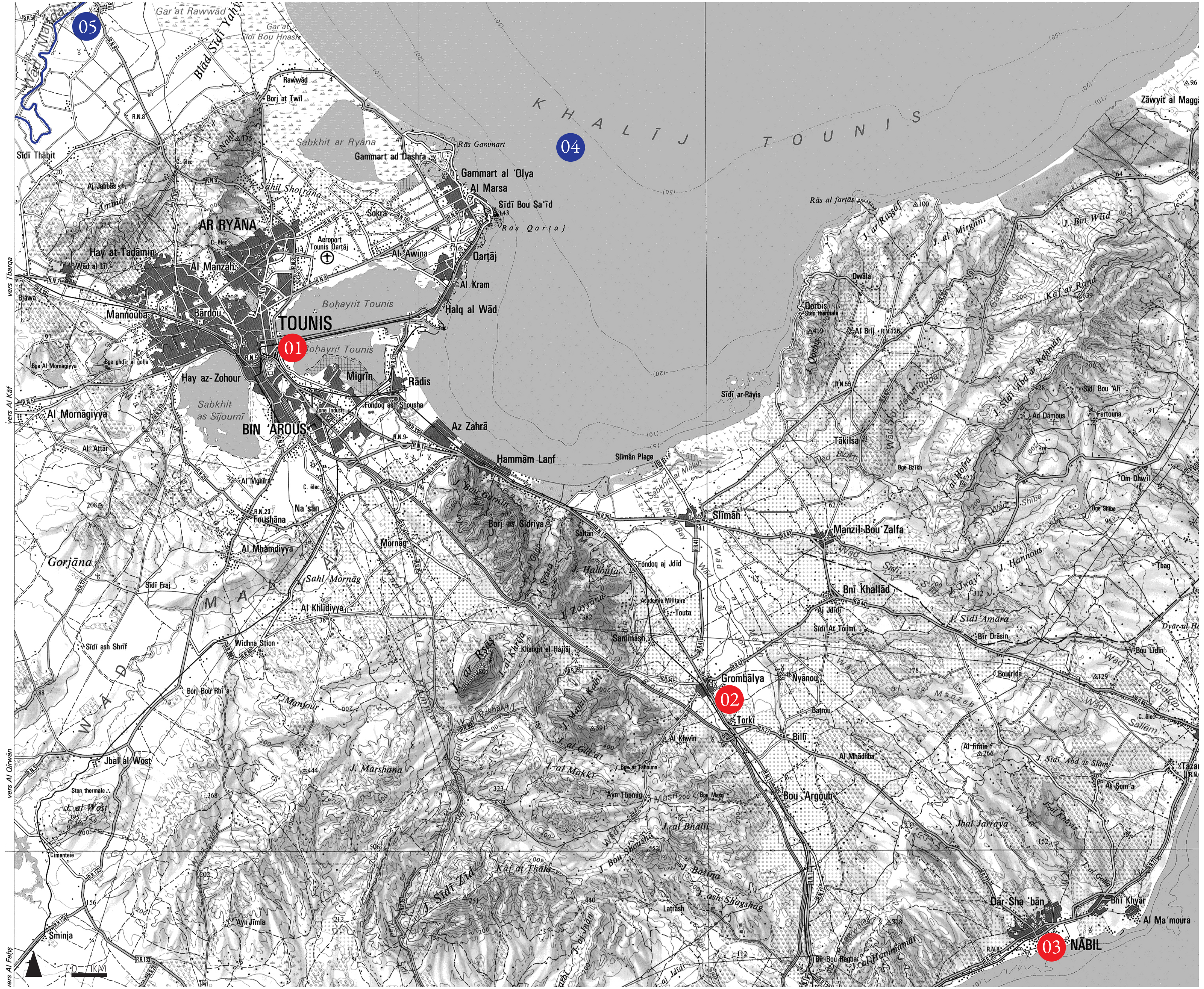
Source:Creative Commons



01 Tunis, TN
Capitol city of Tunisia, received 150-250 mm of rain in October 2018 storm

02 Grombalia, TN
Received 100-200 mm of rain in October 2018 storm.

03 Nabeul, TN
Received 150-250mm of rain in October 2018 storm.

04 Gulf of Tunis, Mediterranean Sea

05 Medjerdah River, the country's largest river and only perennially flowing major watercourse

PREVIOUS:
Figure 1.2 Topographic map of Northeastern Tunisia. Major cities and dense settlement, including the capitol city of Tunis, are located along the Mediterranean coastline, rendering them vulnerable to sea level rise. Mountainous regions hem the country's coastline, surrounding the capitol city and most densely populated regions.

Source: Sabria.org, modified by author.

FRAMING CLIMATE DISASTER

"The supposed 'naturalness' of disasters becomes an ideological camouflage for the social (and therefore preventable) dimensions of such disasters."

– Neil Smith[2]

"Wail if it rains, wail if it doesn't rain."

– Tunisian proverb [3]

On September 22, 2018, flash floods inundated coastal cities and towns of the Cap Bon in the Nabeul Governate, a peninsula in Northeastern Tunisia jutting out into the Mediterranean Sea. In cell phone videos of the event, murky waters sweep cars and building debris down flooded roads; people are pulled out of rising waters with rope[4].The floods resulted in five deaths.[5] Just weeks later, on October 18 and 19, another series of flash floods struck the cities of Tunis, Sidi Bouzid, Kef, Kasserine and Siliana, resulting in four more deaths, as well as school closures, road blocks, and infrastructural damage.[6] The National Institute of Meteorology recorded up to 225 mm (8.8 inches) of rain in 24 hours in the center of the peninsula, nearly half of the average annual rainfall in the region and the most precipitation recorded in a single event since the organization began recording data in 1995.[7]

In Tunisia, the presence of water wavers between poles of scarcity and catastrophic abundance, its drought-prone climate punctuated by ever more erratic bursts of precipitation. Flash floods, increasingly frequent in the western parts of the Mediterranean coastal region[8], are merely one facet of the climate crisis's effects on the region's human settlement and ecosystems. Rising sea levels threaten the Mediterranean coastline that is much of the country's northern and eastern border.[9] The Sahara Desert, which covers the majority of the country's Southern landmass, expands as desertification[10] continues a decades-long creep north.[11]

Figure 1.3. Flooded streets in the city of Nabeul following September 2018 flooding. Source: France 24.

Critical geographer Neil Smith writes that "**at all phases, up to and including reconstruction, disasters don't simply flatten landscapes, washing them smooth. Rather they deepen and erode the ruts of social difference they encounter.**" [12] In landscapes that are politically tenuous or tumultuous, natural disaster magnifies the conditions of ongoing social and political crises. There is no shortage of trying political context in Tunisia. The country still nurses a 'post-colonial hangover'[13] that lingers in political and economic structures in the aftermath of French colonization of the Maghreb (North Africa). Tunisia's resources have long been valuable to foreign interests. Mining, primarily for phosphate, has occurred in southern Tunisia since Roman times and became a driving force in the French colonial economy at the turn of the 20th century, prompting the construction of rail lines from phosphate-rich regions to chemical processing plants on the coast.[14] The country's historic reputation as the "granary" or "breadbasket" of the Roman Empire[15] lives on in Tunisia's agricultural sector, which now accounts for 11% of GDP and employs one quarter of the country's labor force.[16] High quality olive oil, cereals, and organic produce are exported, while cheaper edible oils and grains are imported and subsidized.[17] The construction of dams and large-scale irrigation throughout the country's agricultural regions are linked to the short-term yields demanded by an export-dominated economy.[18]

The coexistence of a robust global economy and a healthy ecosystem are near impossible to reconcile, and Tunisia, with an "annual GDP growth rate exceeding 5% since 1995" and considered "among North African countries with the strongest growth potential"[19] relies upon agriculture, oil, and phosphate as its primary exports.[20] A commendable GDP has not translated to quality of life and health for working-class and rural Tunisians, nor has it translated to effective environmental stewardship practices.

Tunisia does not suffer from the denial of climate crisis endemic here in the United States. There is widespread recognition not only of a changing climate but also of the social and political implications of environmental stress. In 2014, Tunisia joined only two other nations in the world to integrate climate protection and recognition of climate change into its constitution.[21] Today, Tunisia is one of only eleven nations in the world that references climate change at the highest level of legal frameworks.[22] Despite progressive legal language, creeping neoliberal policies and unchecked urban development continue to shape cities, leaving a wake of altered hydrology and magnified disaster risk.

In the midst of these concerns, we return to the question of flooding. Infrastructure designed to control the movement of water has justified human expansion into water's terrain, constructing disaster. A flood exists at a confluence of water narratives: its meted-out distribution or wanton extraction, its scarcity or overabundance, its spiritual resonance or market power. In a flood, water is the matter of an existential threat and an essential resource. Where does landscape architecture meet the political ecology of a flood?

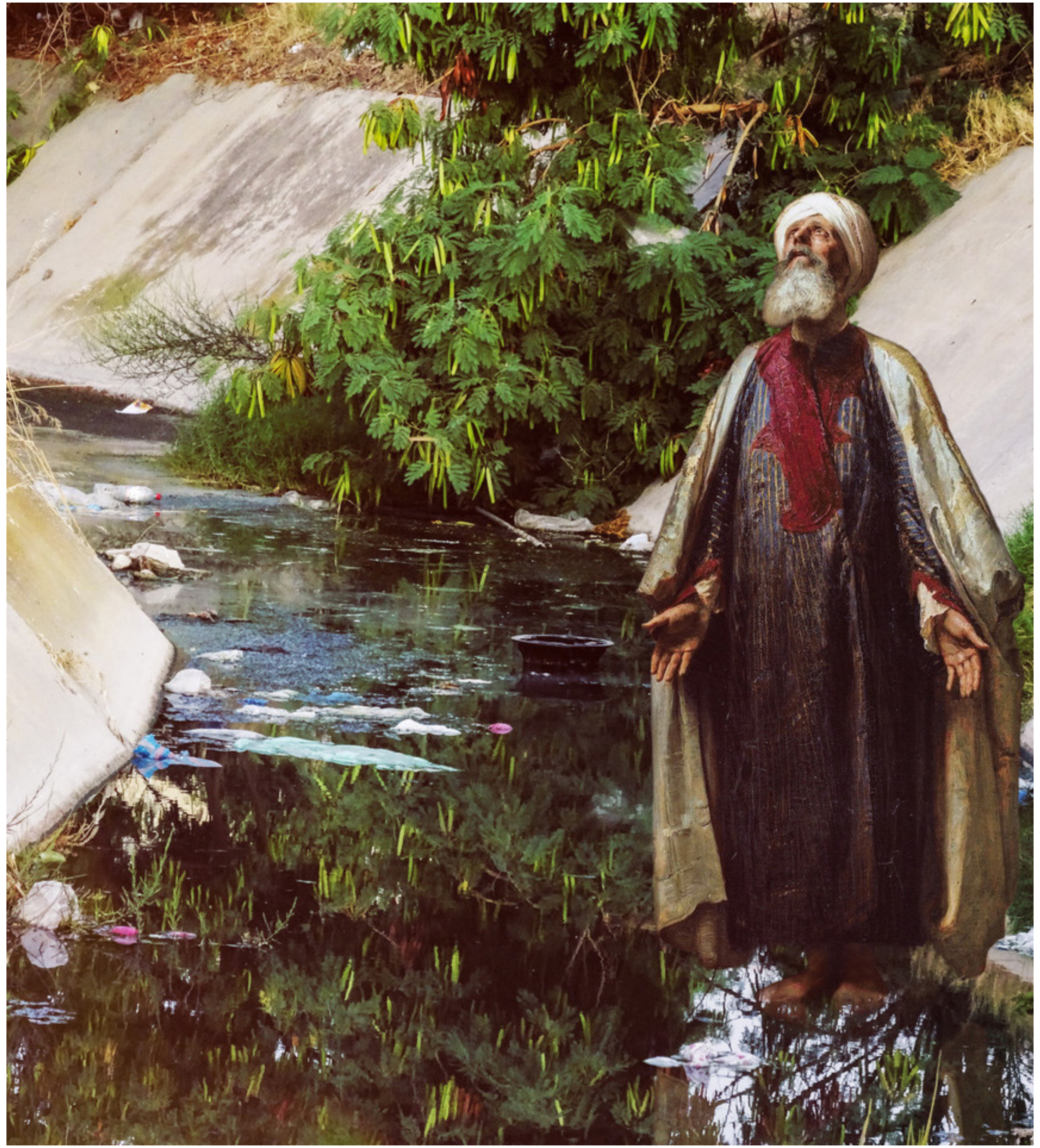


Figure 1.4. Mohammed Oussama Houij's photocollages intermingle colonial paintings of Tunisians with contemporary images of areas strewn with trash. The series, called "Zabaltuna" (which roughly translates to "You Trashed Everything Around Us") is as much a biting critique of the current political administration as it is a condemnation of the country's history of colonization.
Source: https://www.facebook.com/zabaltunaproject/

RESEARCH FRAMEWORK

This thesis examines Tunisia's capital city, Tunis, as a past and future site of flash flooding. The threat of existential disaster – a concern certainly not limited to the Mediterranean coastline – can be a catalyst for transformation. It provides an imperative to hold solutions proposed by market forces or stagnant political regimes up to the light, questioning their efficacy in meaningful change. In assessing a historical record of anthropogenic (human-caused) alteration of ecological systems, current climate projections, and the daily barrage of new and unprecedented disasters, we arrive at a context that 'change,' as in 'climate change,' does not adequately convey. Rather, social and ecological interactions with the political world emphatically underline that climate disaster stems from environmental exploitation. Ongoing climate disaster traces its symptoms to an extractive relationship with the land for purposes of economic yield, a relationship intensified and invisibilized in a global economy.

Potowatami scholar-activist Dr. Kyle Powys Whyte argues that:

> *Anthropogenic climate change is an intensification of environmental change imposed on Indigenous peoples by colonialism...colonialism and capitalism laid key parts of the groundwork for industrialization and militarization—or carbon-intensive economies—which produce the drivers of anthropogenic climate change, from massive deforestation for commodity agriculture to petrochemical technologies that burn fossil fuels for energy.*[23]

Whyte's definition calls our attention to the connection between economics and resource extraction, coterminous with histories of racialized violence. These are narratives that rarely find their way to mainstream environmental rhetoric. Using Whyte's definitions as a broad overview of harm on the landscape creates a frame for further analysis. Climate resilience requires a recognition of the linkages between colonization and altered ecologies, and consideration of what practices precede extraction for economic yield.

If climate change is a result of colonization, what responses are pre-colonized and de-colonized? Are they effective in a contemporary setting? While the latter question requires site-specific analysis, the former can find resolution in countless examples of anthropogenic relationship to the environment that do not preclude the care and keeping of ecological systems.

Decolonization is a multivalent and complex process, and one far beyond the scope of this thesis to address adequately. However, I address one seed of decolonizing work by exploring the reassertion of traditional water management technologies in a North African urban context. Enlivening practices that have been in place long before colonization and continue to the present offer opportunities for a more holistic assessment and relationship with environment. Traditional water management technologies constitute a traditional ecological knowledge base that plays a role in disaster mitigation. These pre-colonial and indigenous approaches to water management serve as a foundation for urban infrastructure futurism that is distinctly North African.

SYSTEMS THEORY

Systems theory provides a mode of understanding where a series of floods in 2018 meet a history of resource extraction, and how reading a temporally expanded landscape can lead to a more resilient future. It posits that interdependent entities and processes interact to form complex and dynamic sites, and this holds true for examining the political ecologies of water resilience.[24] Utilizing a systems-based design approach requires entering a hybrid terrain, exploring 'innovation' that does not end with fixed solutions, but rather integrates a level of dynamism and adaptation that can be more valuable than static approaches or concrete solutions. Landscape architecture theorists Michael Murphy and Per Hedfors make a case for the implementation of systems theory as an approach for reckoning with ongoing crisis:

> *There is compelling reason to believe that the looming crisis of the environment calls for change that is both profound and immediate. But, unless our perceptual abilities allow it, we will remain unable to comprehend reality in a new and more integrated way. We continue to think of problems as energy problems or environmental problems or health problems or problems of cultural heritage, and on the basis of that thinking, seek individual rather than systemic solutions, based on a pathogenetic view rather than a salutogenetic view of reality.*[25]

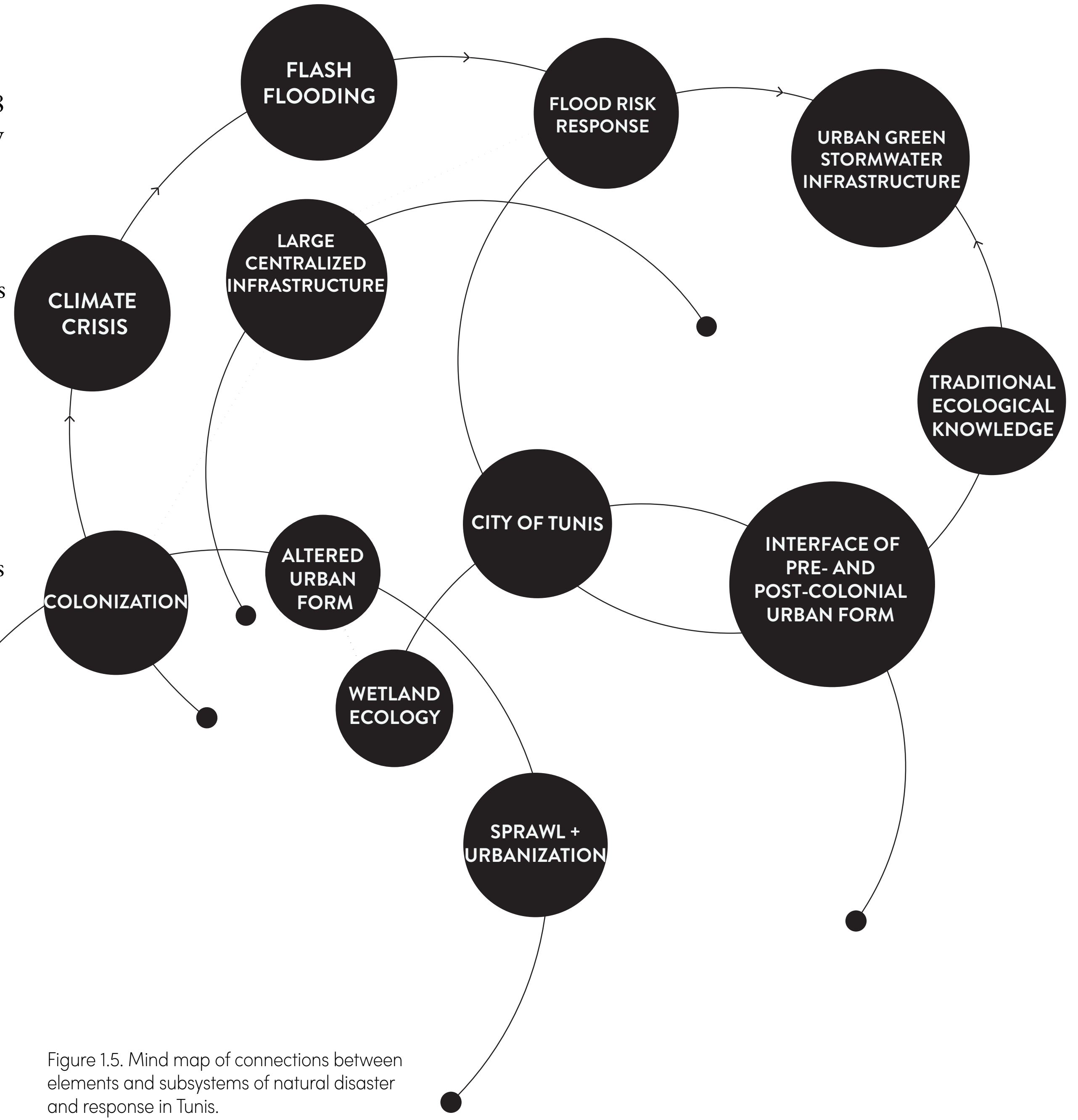


Figure 1.5. Mind map of connections between elements and subsystems of natural disaster and response in Tunis.

Viewing the problem of flash flooding as a question of managing a large amount of water neglects not only the "pathogenetic" investigation that seeks the cause of an ailment, but also the "salutogenetic" approach that probes for those conditions that produce a healthy system. How do we strive for a combination of approaches – tracing causes of contemporary maladies and their lingering symptoms, while also seeking out features of health? Looking forward to future storm events spurred on by climate change is not merely seeking the treatment for symptoms. Preparedness requires assessing the inroads that have created conditions of climatic and social upheaval, interrogating what systems must be unraveled, and determining where to begin knitting back together.

Analyzing problems as systems also serves to interrupt accepted logic, demanding a more nuanced interrogation of possible resolutions. Rather than merely existing in the realm of ecology or urban design, an analysis of water runs tendrils to numerous sub-systems. The presence of salt pans in downtown Tunis, the construction of dams, and the shortcomings of Tunisian institutional politics and public data access are all characters in the story of a flood. Seemingly disparate threads are part of a much larger narrative, shaping a pathway to disaster response that considers each of those elements. Together, they construct an argument suggesting traditional technologies can be legitimate and valuable responses to flooding.

In the first part of this thesis, I trace some of the history of enhanced flood vulnerability in the morphology of the city of Tunis, connecting historic manipulations during the French colonial era to ongoing infrastructure development and flood vulnerability. In the second part, I outline the rationale for integrating traditional technologies into flood mitigation and provide references for a selection of technologies. What underlies the exploration of water harvesting and flood diversion technologies is my belief that our communities and future need to operate in a radically different way, re-organizing around the care of water and re-prioritization of life and health. A thesis can begin to identify catalysts for transformative change in our relationship to water.

The intended audience for this work is a broad range of people interested in decentralized water infrastructure as a response to climate crisis. I write as a student of landscape architecture, and hope that this work will engage others in design fields and provide alternative modes of thinking about climate adaptation, as well as a reminder that ecology is not apolitical. This work may also be interesting to those interested in water technologies as part of a valuable process of knowledge transmission and an example of skillful adaptation to environmental context. My primary inspiration is the rallying cry of the Standing Rock Sioux and the #NoDAPL movement of water protectors: "*Mni Wiconi,* water is life."[26]

OPPOSITE:
Figure 1.6 View of Tunis from the Paris Hotel, 1899.
Source: Library of Congress.

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LIST OF FIGURES

(images are my own unless indicated otherwise)

02. ALTERING THE URBAN FORM

Figure 2.1 Looking north over Avenue Habib Bourguiba and a street grid established at the turn of the century.
Source: Hansueli Krapf/Wikimedia Commons

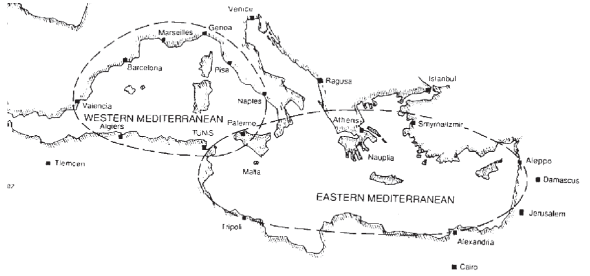


Figure 2.2. Tunis at the junction of the two Mediterannean basins. Image: J.S. Woodford.

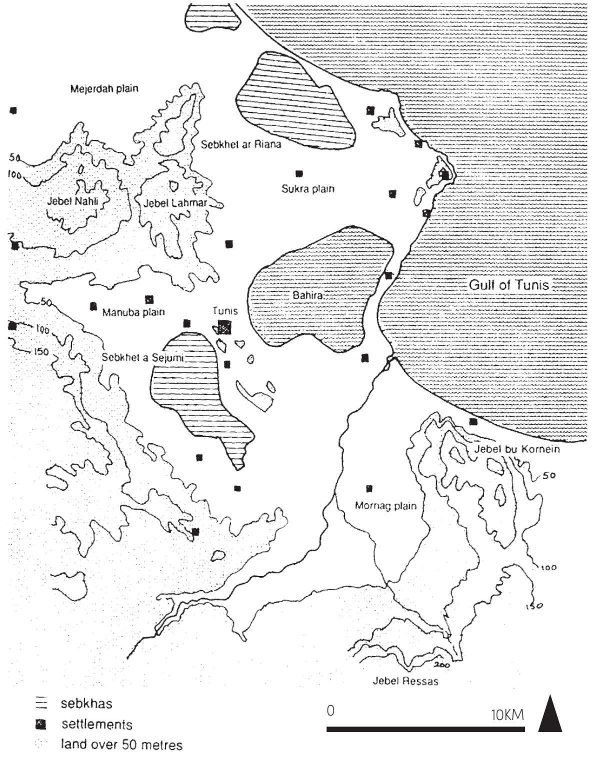


Figure 2.3. Natural features of greater Tunis. The settlement of Tunis is located between 'Bahira' or the Lake of Tunis, and the Sejoumi salt pan. Image: J.S. Woodford.

THE CAPITAL CITY تونس العاصمة

Tunisia has seen successive waves of empire crash over the shores of the Mediterranean, primarily because of its strategic position between the eastern and western basins of the Sea, and the coast's close proximity to Europe and West Asia. The culture and people indigenous to North Africa are Amazigh (also known as Berber, a word many consider pejorative), and today many Tunisians are of Arab-Amazigh descent.[1]

Situated on a hill between salt lake Sebkha Es-Sijoumi, and the brackish lagoon Al Bahira (the Lake of Tunis), Tunis is the capitol city of present-day Tunisia. There is archaeological evidence of Amazigh settlement in the ancient city from the 4th century AD.[2] To the city's northeast is the ancient Punic city of Carthage, now a banlieue of the city proper. The Medjerdah River, the country's largest river, and one of its only perennially flowing watercourses, is also to the northeast.[3]

The walled city at Tunis's core, known today as the Medina, was built in the 7th century by Arab settlers. While the capitol's boundaries have sprawled far beyond its' walls in the intervening eight hundred years,[4] the Medina has maintained a significant role in the city.[5] The structures of the Medina bear evidence of palimpsest and adaptation over hundreds of years. Stone walls built with earthen mortar are patched with contemporary bricks and cement. Electrical wiring and satellite dishes snake through streets and onto rooftops.

The complex spatial organization of the Medina, though near incomprehensible to outsiders, reflects a rich web of social, cultural, spiritual, and economic relationships encoded in the city's labyrinthine passageways. Despite Orientalized depictions of the Medina as disordered, unplanned, or chaotic, the city is in fact laid out with clear organizational principles.[6]

One navigates the walled city by noting topography – sites on higher ground and closer to the center, such as the Zaytuna Mosque, are those accorded greater value in the city's physical hierarchy. Embedded within the Medina's vernacular architecture, there is a parallel ecological infrastructure of the city – climate-adaptive design produced by hundreds of years of settlement. Situated on a hilltop, water flows out of the city towards the Lake of Tunis, to its East, or the Sebkha es-Sijoumi to its West. Streets have runnels built into them to facilitate water movement and drainage away from businesses and residences. Houses are built with a *majel*, or structurally integrated cistern, to collect rainwater falling on rooftops. Tall, thick earthen walls painted white remain cool in the Mediterranean heat, inviting a breeze to the narrow streets on hot summer days, and insulating structures during the winter.

Figure 2.4. An example of a preserved North African hill town's spatial planning and vernacular architecture. Openings in the tops of structures are the impluvia of cisterns for rainwater harvesting. Beni Isguen, Algeria.
Source: George Steinmetz (used with permission)

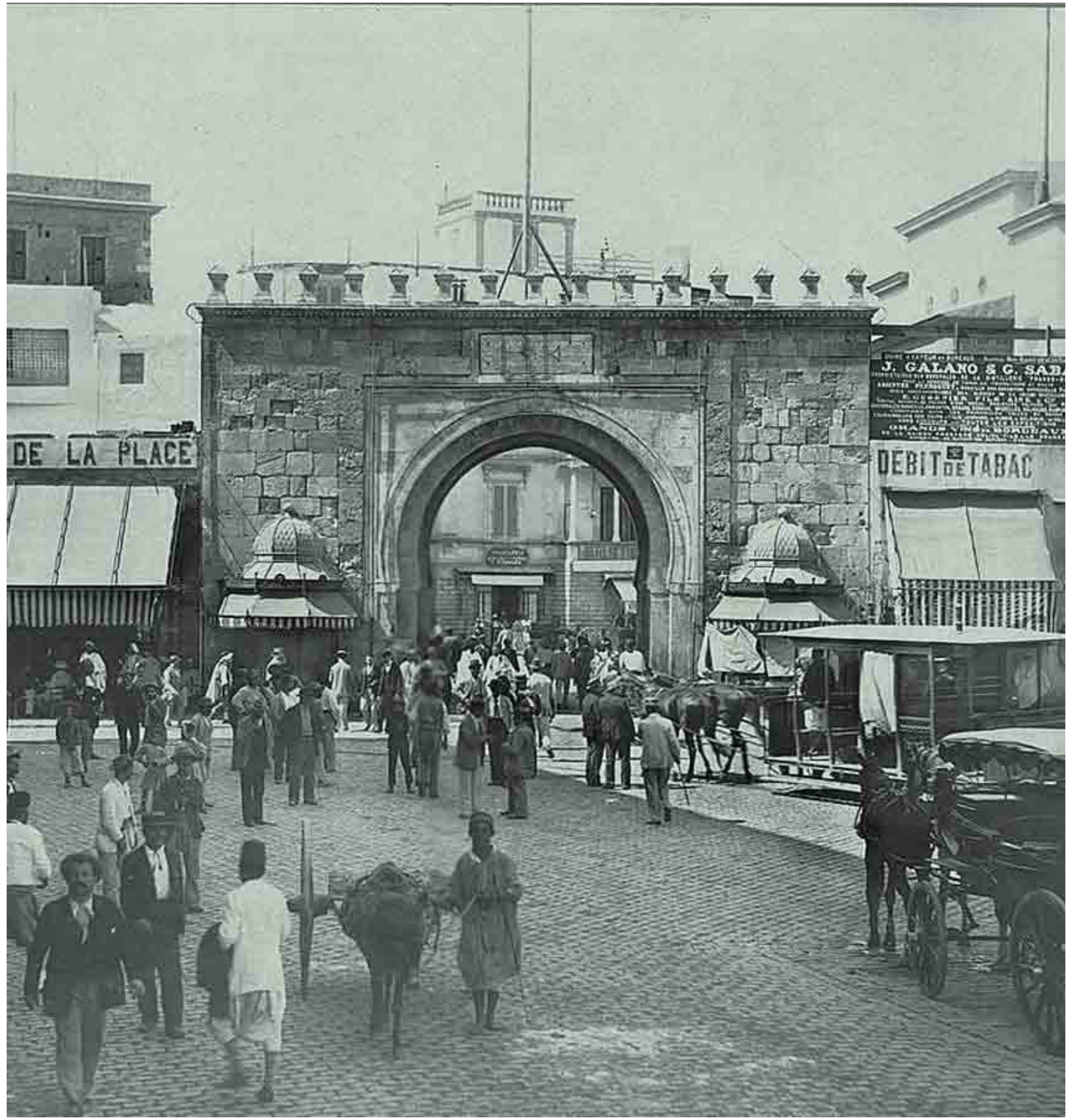
Figure 2.4 Medina rooftops, 2017. From the rooftops of the Medina, a landscape of adaptation emerges: wild plants and satellite dishes take root in the crevices of historic flat rooftops.
Source: Tycho Horan (used with permission)

THE MEDINA AND THE VILLE CONTEMPORAINE

From 1881 until Independence in 1956, French colonial rule was imposed on Tunisia, with the empire's administration located in Tunis for strategic control of a Mediterranean port.[7] During this time the form of Tunis changed dramatically. The Medina's modes of construction, in concert with the elements and climatic cycles of the year, were upended by later development beginning during the French colonial era.

The *Bab el Bhar* (Door to the Sea), one of the walled city's gates, is one entry point to assessing pre-colonial and post-colonial relationships to water in the urban form. The gate is not the original structure but a free-standing Arabesque interpretation of the original doorway destroyed and rebuilt during the French colonial era.[8] Today, a small altitude marker is set into the stone of *Bab el Bhar* : "7.000 M. AU DESSUS DU NIVEAU MOYEN DE LA MER." At seven meters above sea level, the gate is one of the lowest points in the old city.[9]

The gate presently serves as a pivot between the historic Arab city (medina) and the so-called Ville Contemporaine,[10] or the European quarter built during the French colonial era. The European quarter has now become the city's Centreville, or downtown,



and the *Bab el Bhar* faces out to a kilometer-long stretch of Avenue Habib Bourguiba, a bustling commercial and administrative corridor lined with shops, cafes, and droves of locals and tourists.

In the midst of two distinct typologies of urban density, the crowded market of the old Medina and the congested traffic of the downtown, the gate's reference to the sea is strange. Though it faces the "little sea" or Lake of Tunis, and the Mediterranean Sea beyond it, nothing about the contemporary arrangement of the city suggests it is the Medina's waterfront gate. A clue can be found in the 1860 Plan de Colin, a map attributed as one of the earliest maps of the city of Tunis[11]. In the map, narrow water channels reach from near the *Bab el Bhar* to the Lake of Tunis, west of the archway.[12] These channels may be *khandaq*, or ditches that served as either moats surrounding the city walls or drainage channels from city sewers to the lake.[13] Patches surrounding the water appear to be agricultural land just outside the boundary of the historic city.[14]

OPPOSITE:
Figure 2.5. Bab el Bhar, 1895. Source: Personal collection of Bernard Bouret/Wikimedia Commons.

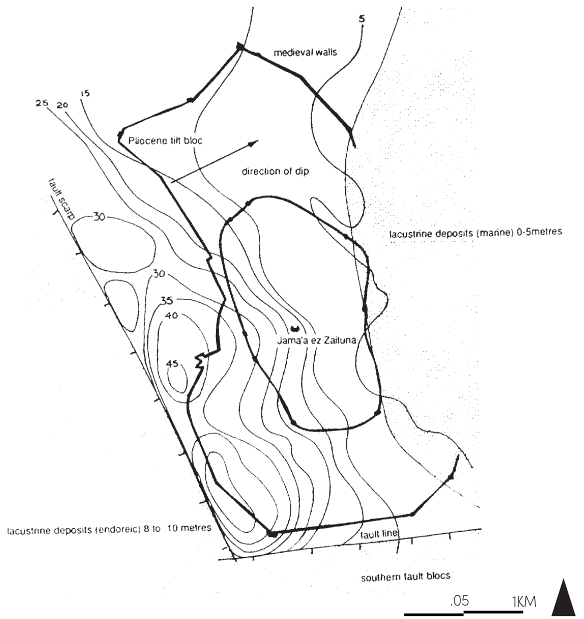
LEFT:
Figure 2.6. Bab el Bhar, 2014. Credit: Dan Sloan/Wikimedia Commons.

DRAWING LINES

Following colonization, marshy areas surrounding the historic city were infilled and built upon, literally paving the way for increased flood vulnerability by altering the historic city's landscape.[15] New development forged a connection between the Mediterranean Sea and the capitol, becoming a port for the export of goods to France.[16] On the French restructuring of the city, Rene Millet, French resident-general of Tunisia from 1894 to 1900, stated:

> *In Tunis the Arab town has not been submitted to any attack. It is around it, without damaging it anywhere, that our engineers created the boulevards they needed for carriage and tram circulation. It is outside it, between its old fortifications and the port, where there used to be unhygienic beach, that the European city is built, with its high structures in stone, it's large, perhaps too large, streets, its avenues planted with mimosas and ficus trees, its botanical garden and beautiful Belvedere Park... Tunis la blanche has preserved its oriental character.*[17]

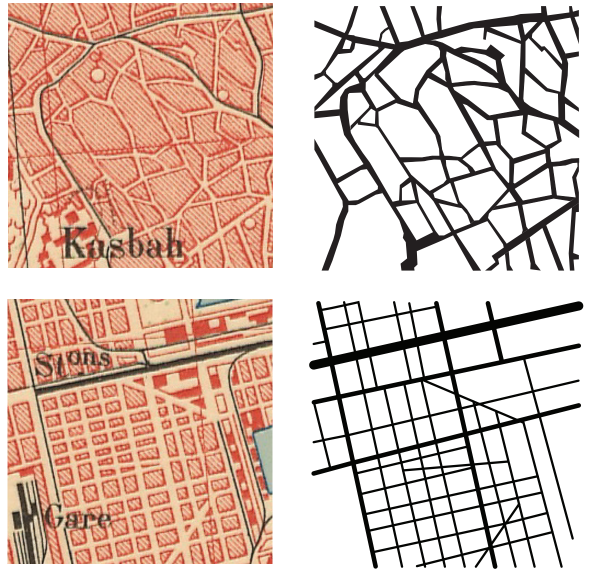
Millet paints an image of Tunis' colonization as benevolent in comparison to the French presence in Algiers, which involved the destruction of much of the historic city and markets. The Arab City (*Tunis la blanche*, referring to the vernacular white architecture) remained mostly structurally intact, if not socially and economically.[18] The "unhygienic beach" Millet refers to is the intertidal marshland between the Lake of Tunis and the Medina, described in historian Jerome Woodford's study of the genesis of the Ville Contemporaine. East of the gate, lacustrine soil deposits stretch to the edge of the lake of Tunis, indicating geologic evidence of lake waters rising just to the edge of the Arab city.



ABOVE:
Figure 2.7. Basic geology of old city of Tunis, showing Medina walls, contour lines, and location of lacustrine deposits.
Source: J.S. Woodford.

RIGHT:
Figure 2.8. Street layout in the Medina (above) compared to the Ville Contemporaine (below).
Source: Mapster (left), Fatema Maswood (right)

The "perhaps too large" streets Millet references were wide boulevards designed in the image of French cities – a design that proved to be ill-adapted to the hot climate, providing little shade or respite from the summer sun. Throughout the city of Tunis, spaces that were intentionally left undeveloped prior to the French colonization of the city, many of them low-lying areas prone to flooding, were filled in to create new neighborhoods for European settlers.[19] In plan view, a stark contrast is evident between indigenous and colonial methods of building and planning urban settlement: the enclosure of the walled city surrounded by rigidly gridded street plans. The street grid established during the colonial era imposed top-down order on the environment, in contrast to the cellular structure contained within the Medina's walls.



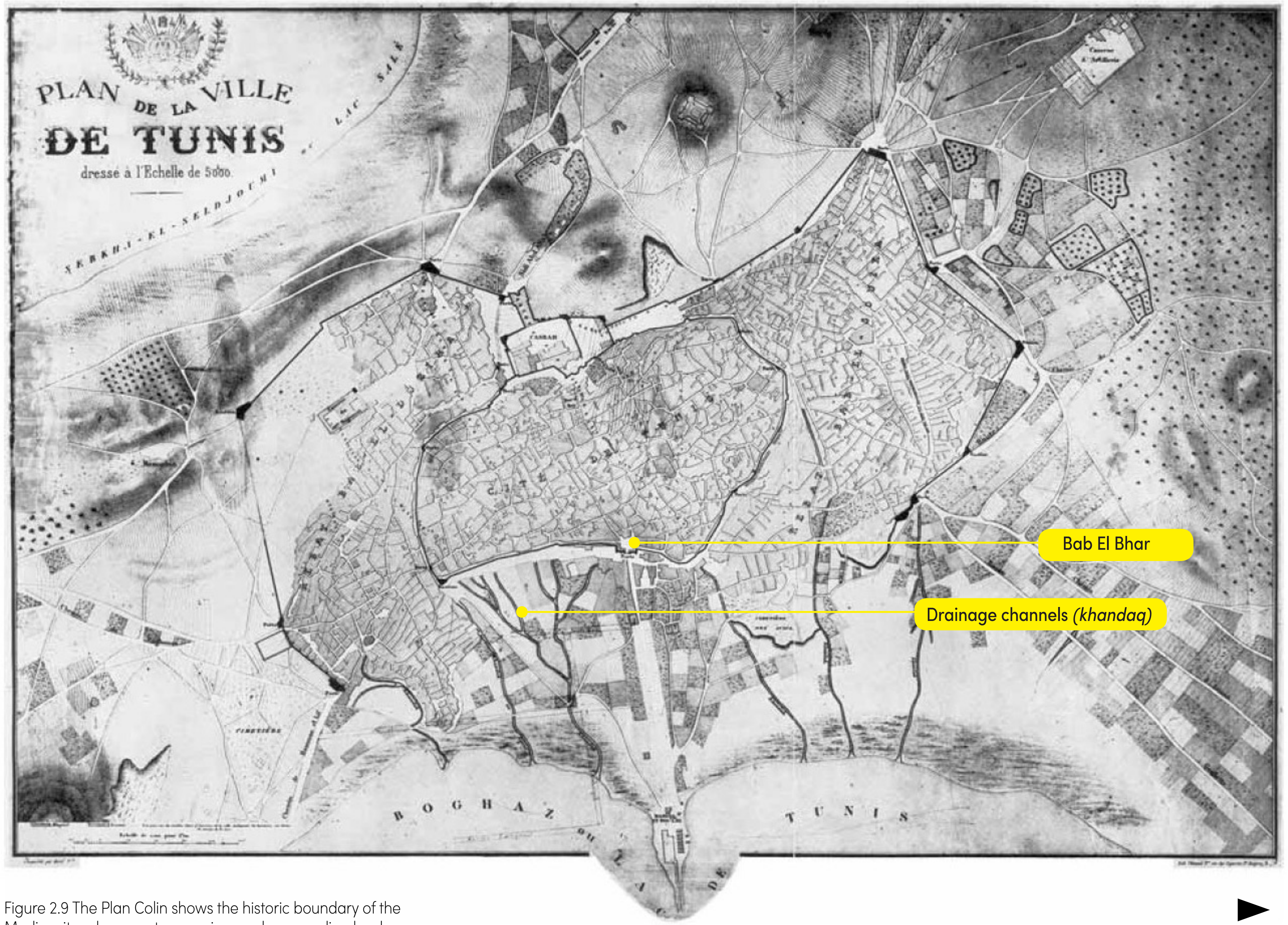


Figure 2.9 The Plan Colin shows the historic boundary of the Medina, its subsequent expansion, and surrounding land use prior to formal French colonization. 1860.
Source: Jean-Luc Arnaud

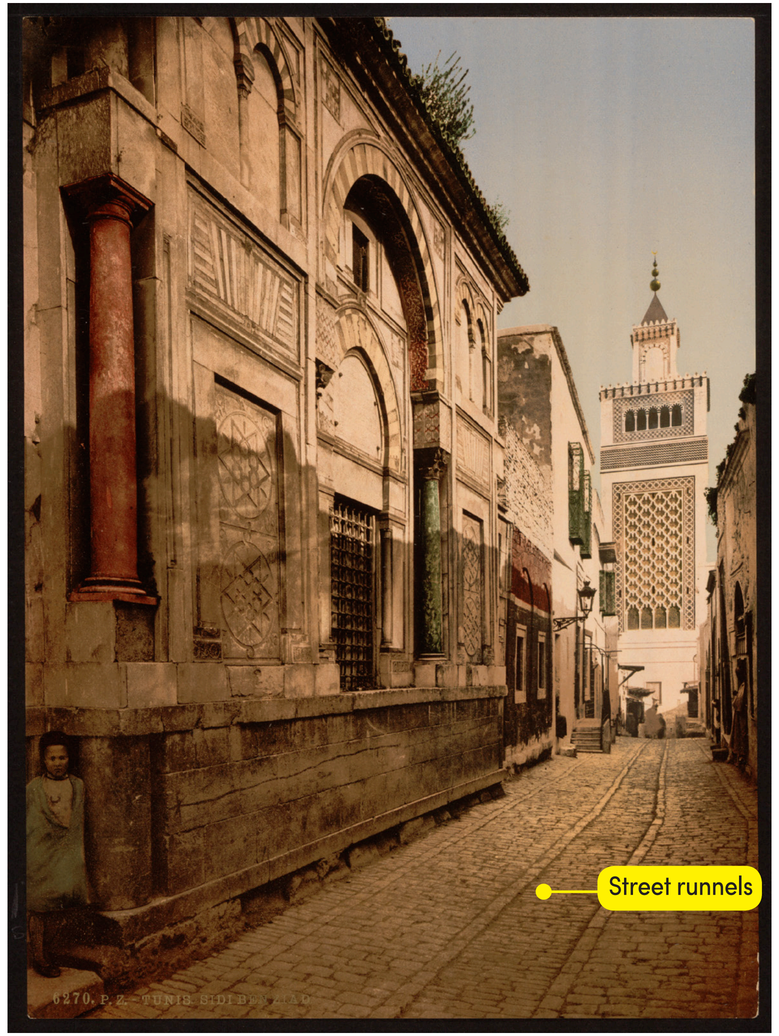


Figure 2.10. Embedded water management and street level drainage systems in the Medina.

Source: Library of Congress

Figure 2.11. Evidence of rooftop water harvest on a house in Sidi Bou Said, north of the city of Tunis. 1889.

Source: Wikimedia Commons

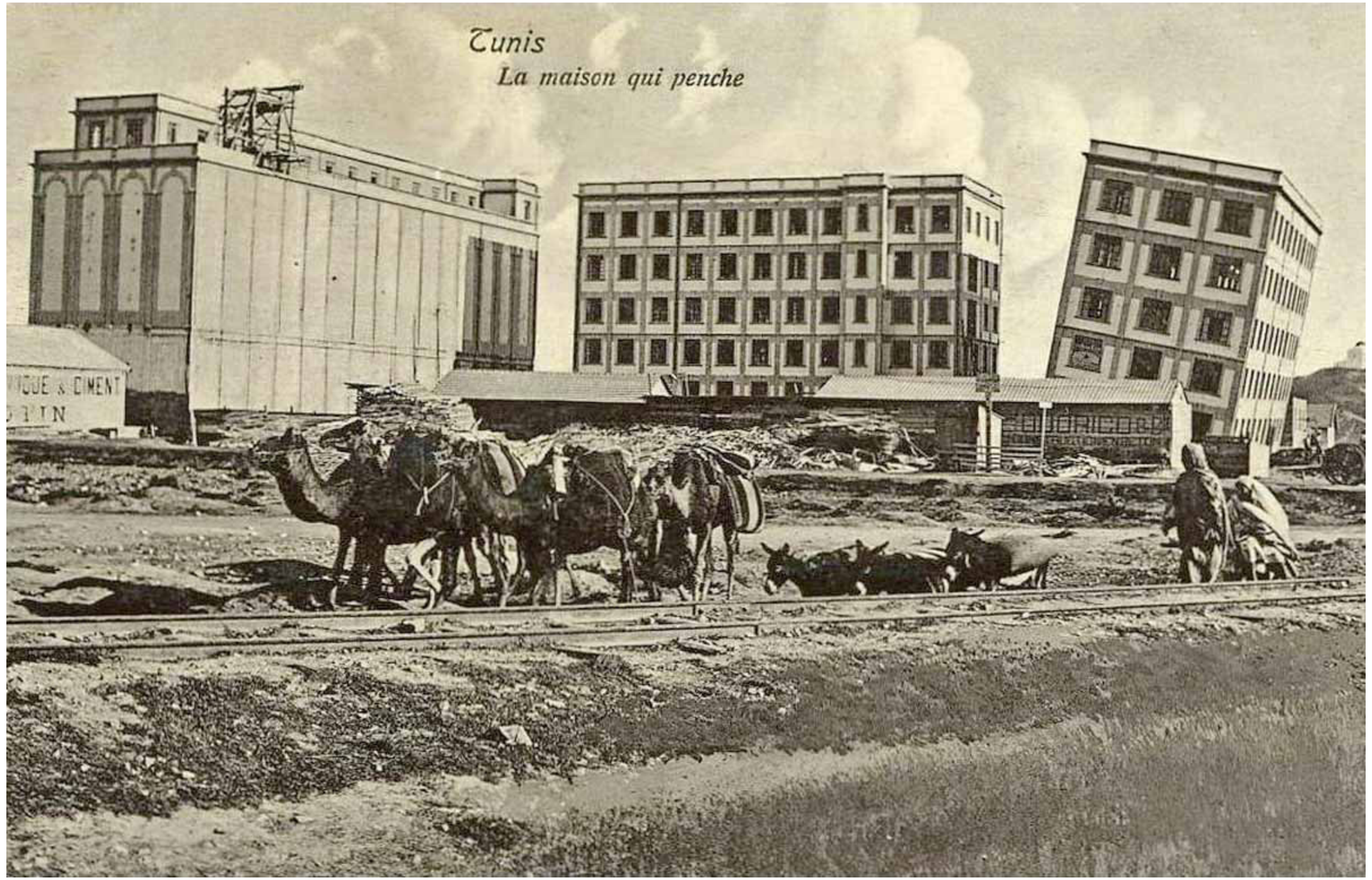


Figure 2.12. The outcome of construction on a shifting, swampy landscape in the Little Sicily area of the Ville Contemporaine. This postcard is captioned "la maison qui penche" or "the house that sunk". 1906.
Source: Collection personnelle Bertrand Bouret / Wikimedia Commons.

Figure 2.13. Avenue Habib Bourguiba, then Avenue de la Marine, in 1891. Source: Bertrand Bouret/ Wikimedia Commons

Figure 2.14. Avenue Habib Bourguiba in 2006. Source: Wikimedia Commons.

DEVELOPING AFRICA

The erasure of marshland and sebkhet (salt lakes or salt pans) from the landscape was part of the colonial project's imprint on the city of Tunis, in tandem with a broader set of strategies that exerted control via manipulation of the landscape. Dominion was tied to landscape and ecological features – not only engineering the landscape for economic development, but for the manipulation of ecological systems to create a European climate in North Africa.

In 1891, the same year the Ville Contemporaine was built over infilled marshland, geographer Arthur Silva White and cartographer Ernst Georg Ravenstein published "The Development of Africa". Silva White, a founding member of the Royal Scottish Geographical Society, presents a level-headed strategic assessment of how to assert "European Dominion" over African lands for economic gain. The text presents an example of the relationship between the exploitation of the landscape and indigenous populations for purposes of colonial gain. Silva White writes

> *The African Question is in the main a geographical problem. In its initial stage – the conquest and development of African lands – we have to deal not so much with political as with geographical conditions. It is only after the latter are understood that we can effectually control the former.*[20]

Maps within the text visualize ecological and geographical exploration of inroads to resource wealth, identifying sites for European colonial settlements built upon expropriated African lands.

While this mapping and analysis uncovers the ways that 'economic development' has historically been at the expense of African people, it also calls out methods of environmental manipulation that remain significant. The presence of marshlands in a North African climate were considered a deterrent to the successful settlement of Europeans:

> *Climative [sic] conditions... have in the main exercised the most potent repellent force against the expansion of European political rule and the extension of European settlement. The climate of coastal lands, being the most dangerous for Europeans, and the least favourable for their acclimitisation, has generally paralyzed or crippled the settlements that have been established thereon.... European colonization of the coastal lands within the Tropics has been proved to be impossible without (1) the institution of sanatary [sic] precautions, such as the draining or flooding of marsh-lands...only the people of Southern Europe show an increase of the birth-rate over the death-rate in Temporate North Africa.*[21]

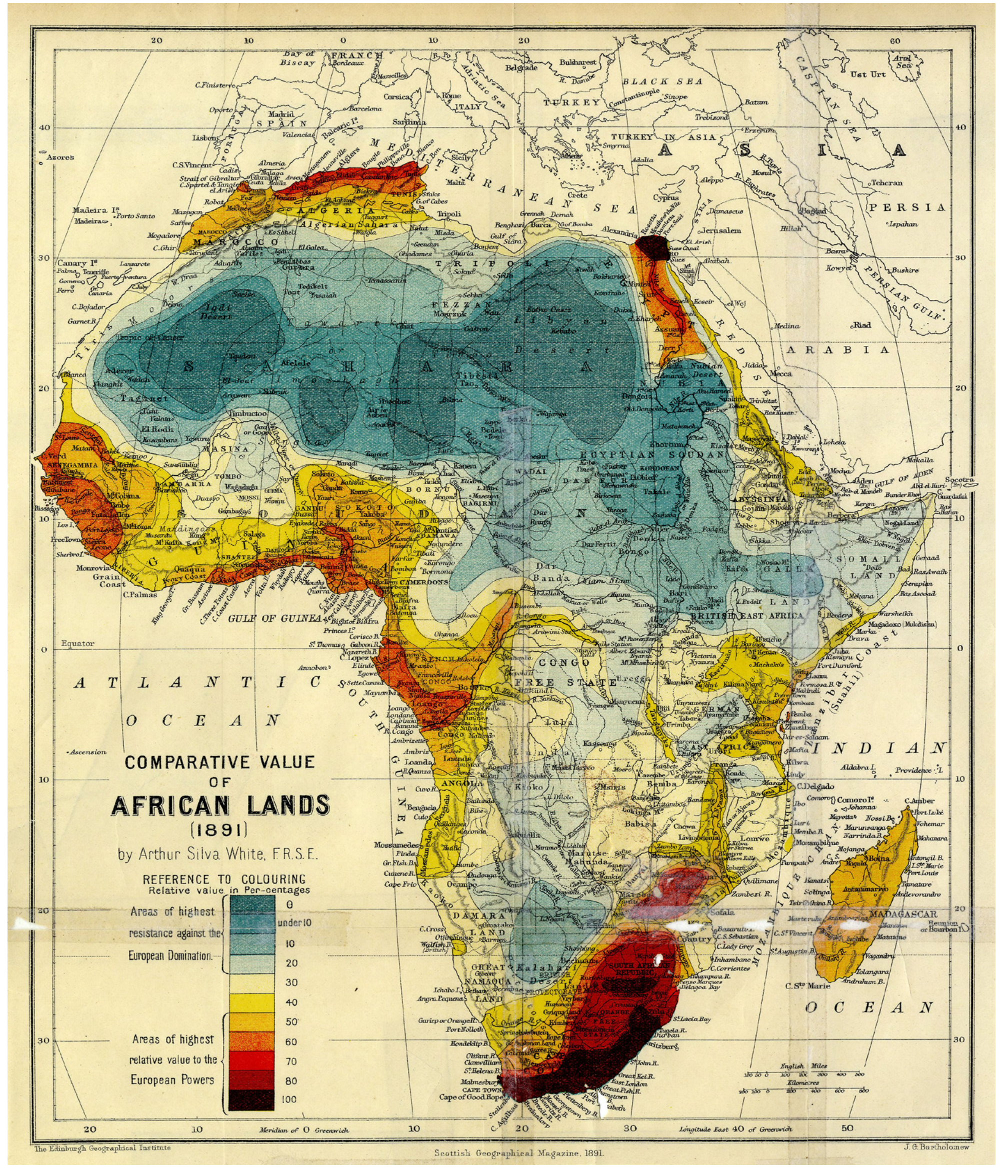


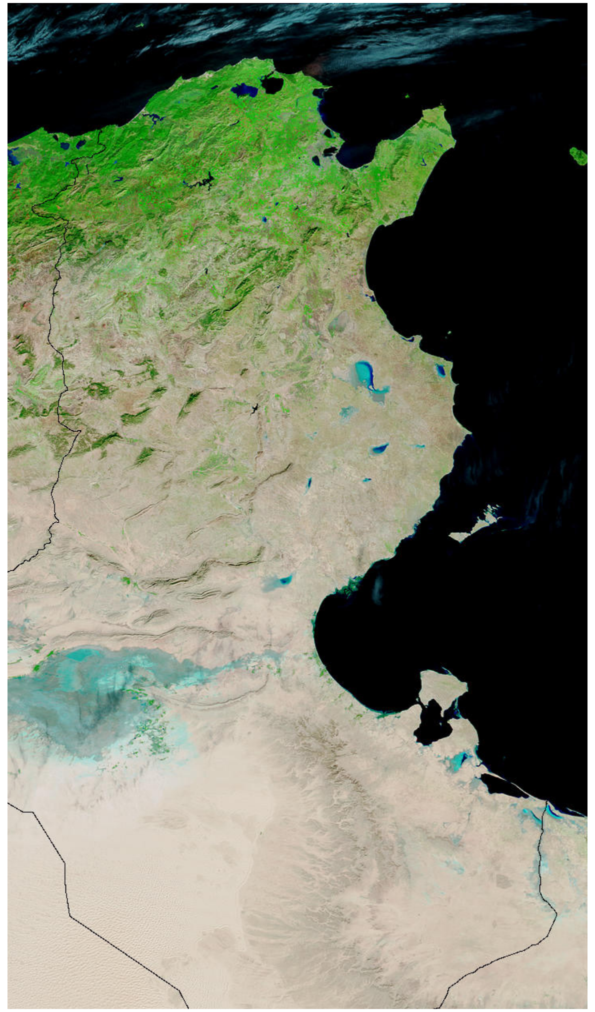
Figure 2. 15. "Comparative Value of African Lands." The map establishes areas of value and resistance to European invasion based on features of the landscape. A belt from Tunis, Tunisia to Oran, Algeria merits a deep red, representing a site highly valuable to the European Powers.

Source: E.G. Ravenstein/University of Illinois.

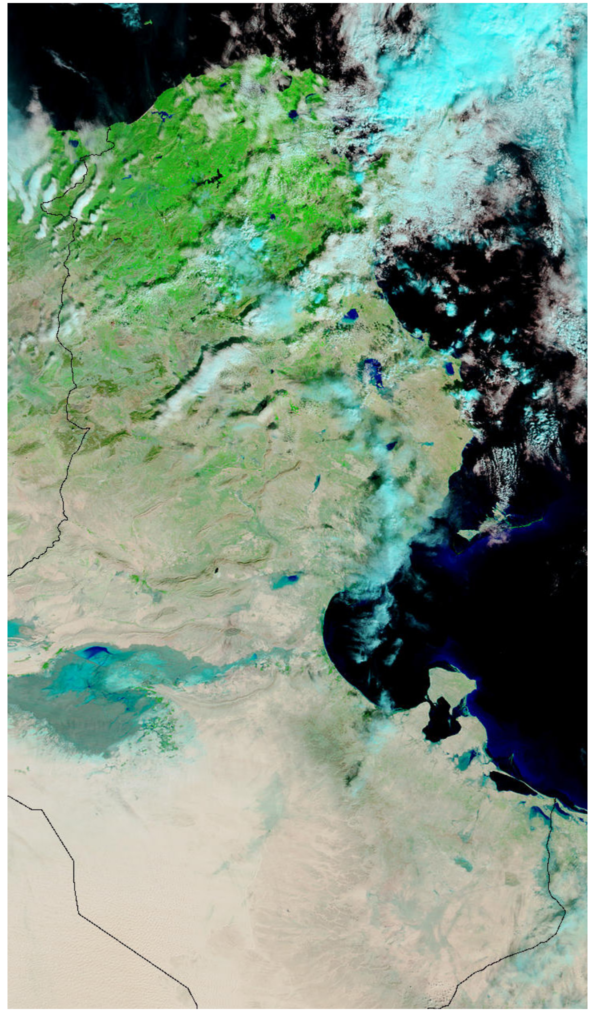
THE ERASURE OF WETLAND ECOLOGY

Hearkening to Millet's description of Tunis's marshland as "unhygienic," Silva White calls for the institution of "sanatary" [sic] precautions to make coastal cities suitable to European settlement.[21] Their comments are laden with the perception that salt pans and marshland required 'sanitization' and 'hygiene' in the form of infill and pavement to create an inroad to civilization. Allowing wetland ecology to remain intact indicated a lack of ability to maximize land value through large-scale environmental engineering projects.

This history is significant in assessing contemporary flood risk because protection of wetlands is an essential component of flood control.[22] Far from unhygienic, wetlands and marshy areas are highly productive ecosystems that typically improve water quality and house abundant biodiversity. Wetlands and salt marshes function as "natural sponges", absorbing storm surges and slowing water movement during a flood. They serve as a "critical barrier and protection for coastal flooding."[23] The infill of salt lakes and intertidal marsh constitutes a loss of an essential buffer valuable for mitigating the effects of increased precipitation.



BEFORE: JAN 4, 2003



AFTER: JAN 19, 2003

Figure 2.16. Comparison of salt pans (sebkhet) in Tunisia before and after January 2003 flooding. Salt pans normally contain little to no water, but are full of water, coded blue and black, after the floods. Clouds are pale blue and white. Source: NASA Earth Observatory

The effects of wetland alteration in downtown Tunis are evident, especially when comparing the Medina and the Ville Contemporaine. The historic city's location on a hilltop allows heavy precipitation to drain to two aquatic ecosystems, leaving space for a natural cycle of flooding to rise to the edges of human settlement. Today, in the bustling downtown that was the Ville Contemporaine, whole streets are submerged on a day of average winter rain.

Changes in the physical environment initiated during the French colonial era established patterns of urbanization through sanitization. Sebkhat, or salt lakes, began to be infilled during the colonial era, resulting in ongoing repercussions in the city's infrastrucure, layout, and hydrology. This pattern of claiming land from salt lakes or marshland as sanitizing projects continues to the present in real estate development, notably in Tunis's high-end Lac neighborhood, an area constructed on infilled marshland surrounding the Lake of Tunis[24] within the past two decades.[25] Continuing outward sprawl of the city and urbanization have aided alteration of the landscape, which continues to remove existing approaches to stormwater management embedded in the native ecology.

Figure 2.17 Flooded downtown Tunis following average winter rain. Source: Robin Worldwide

Figure 2.18. Flooded TGM metro station in downtown Tunis following rain in November 2012. Source: Robin Worldwide

END NOTES

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FIGURES

(Images are my own unless indicated otherwise)

Figure 2.1. Looking north over Avenue Habib Bourguiba. Source: Hansueli Krapf/ Wikimedia Commons. https://commons.wikimedia.org/wiki/File:2013-01-04_08-06-47_Tunisia_T%C5%ABnis_-_B%C4%81b_al_Jaz%C4%ABrah_3h.jpg.

Figure 2.2 Tunis at the junction of the two Mediterannean basins. Source: Woodford, Jerome S., The City of Tunis : Evolution of an Urban System. Cambridgeshire: Middle East and North African studies, 1990.

Figure 2.3 Natural features of greater Tunis. Source: Woodford, Jerome S., The City of Tunis : Evolution of an Urban System.

Figure 2.4. An example of a preserved North African hill town's spatial planning and vernacular architecture. Openings in the tops of structures are the impluvia of cisterns for rainwater harvesting. Beni Isguen, Algeria.
Source: George Steinmetz (used with permission), https://georgesteinmetz.com/archived-collections/algeria-oasis/.

Figure 2.5. Bab el Bhar, 1895. Source: Personal collection of Bernard Bouret/Wikimedia Commons.

Figure 2.6 Bab el Bhar, 2014. Credit: Dan Sloan/ Wikimedia Commons.

Figure 2.7. Basic geology of old city of Tunis, showing Medina walls, contour lines, and location of lacustrine deposits.
Source: J.S. Woodford.

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Source: Library of Congress

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Source: NASA Earth Observatory

Figure 2.17 Flooded downtown Tunis following average winter rain. Source: Robin Worldwide

Figure 2.18. Flooded TGM metro station in downtown Tunis following rain in November 2012.
Source: Robin Worldwide

03. FLOODING IN CONTEXT

Figure 3.1 Looking over the Lake of Tunis to the city.
Source: Wikimedia Commons
Modified by author.

DEFINING FLASH FLOODS

Floods are among the most common of natural disasters.[1] **Flash floods** are induced by heavy precipitation events, 100 mm or more, with a duration that is typically very short, between one and 24 hours. The affected areas are often relatively small, with rapid hydrological shifts. Generally less than six hours' delay occurs between peak rainfall intensity and peak discharge downstream.[2] Flash floods take place with little warning, producing rapid rises in water levels and associated debris. They are the cause of most flood-related deaths.[3] The increasing frequency and intensity of downpours threatens many coastal cities; a combination of altered hydrology and high populations in dense urban settlements creates circumstances in which more people and infrastructural systems are at risk.

Extreme rain events are not unprecedented in Tunisia – in the Mediterranean region, the morphology of the Mediterranean coastline "force the convergence of low-level atmospheric flows and the uplift of warm wet air masses...thereby creating active convection," and periodic intense inundations.[4] Still, levels of precipitation and destruction stemming from flooding is ever-increasing. Though researchers state that data collection is not yet comprehensive or consistent enough to effectively construct spatial patterning and climatology of flood events surrounding the Mediterranean, data collection at this point indicates increased urban flood events around the sea's western basin. Urgency around the question of flooding has been building since at least 2003, when severe country-wide flooding inundated many regions in the aftermath of three years of drought. Furthermore, fatalities resulting from floods are increasing as a result of denser settlement in flood-prone coastal areas, increasing the social and economic cost of these disasters.[5]

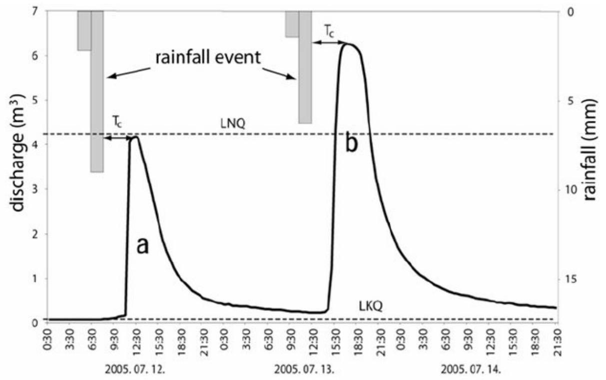


Figure 3.2. Hydrograph of a typical flash flood (a) and that of a flood event with saturated soils (b). T c = time of concentration;

LNQ = maximum discharge; LKQ = minimum discharge. Source: Flash Flood Hazards, January 2012, Dénes Lóczy/ ResearchGate.

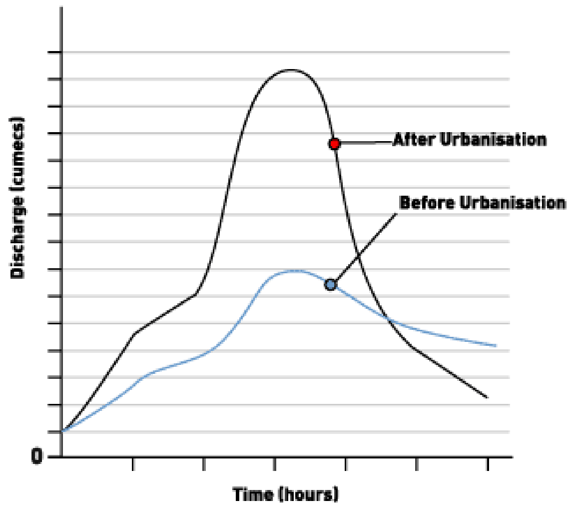


Figure 3.3 Hydrograph showing typical influence of urbanization peak flows following precipitation. Source: BBC Rivers.

Fiigure 3.4

Sequence of stills from a cell phone recording of flash flooding in Nabeul, September 2018.
Source: "Extreme flood in Tunisia - Nabeul 23-09-2018," Aizen Sowski, Youtube.com.

THIRST, DROUGHT, POLITICAL CLOUT: EXISTING RESPONSES TO FLOOD RISK

"The dam-building industry in the First World is in trouble and out of work. So it's exported to the Third World in the name of Development Aid, along with their other waste like old weapons, superannuated aircraft carriers and banned pesticides."
– Arundhati Roy[6]

In 2011, the Tunisian Revolution saw dictator Zine El Abeddine Ben Ali deposed by popular revolt and the institution of democratic elections, a political transition widely hailed as a victory for the Arab Spring. Despite its successes, the shift has brought its own unfolding tumult for many Tunisians. Eight years after Ben Ali's ouster, working-class communities continue to protest the inequitable distribution of resources under new governance. Political scientist Larbi Sadiki notes that, "the shift from popular uprising to institutional politics has not been smooth and has benefited the few...often at the expense of the immediate interests of citizens throughout Tunisia's various regions."[7]

Climate disaster magnifies difficulties of the country's post-revolutionary reconstruction. In 2016 widespread protests regarding water security in rural areas prompted threats of a "thirst uprising".[8] As a response to unrest, the Tunisian political administration fast-tracked construction plans for dams and desalination plants, large-scale infrastructure reliant on costly loans from foreign governments.[9]

In Tunisia, large dams continue to be presented as the solution to a multitude of water concerns, including increased flood risk. Dams are considered a flood mitigation approach because the structure's height and breadth provide additional water storage capacity, reducing possible devastation from single peak floods. With limited capacity for hydropower in Tunisia, dams have typically been constructed with the goal of reducing flooding and developing irrigated agricultural areas downstream of the dams. These structures replace historic systems that utilized small-scale hydraulic works at strategic locations, such as stone check dams measuring tens of meters across.[10]

Following heavy rains in 1990, the Sidi Saad dam in Kairouan, a city south of Tunis, proved effective in flood control just a few years after it was built, preventing high water levels from rushing downstream. But gains are short-lived: the probable service duration of the Sidi Saad dam has been calculated at 87 years, though statistical uncertainty is high. Storage capacity is limited over time as a result of sedimentation. In an arid region with friable soils, sediment movement occurs during heavy rain events and decreases the dam's storage area. Meanwhile, the surface area of water exposed to evaporation remains the same, reducing water storage capacity for irrigation and other uses. The dam is rendered less efficient over time.[11]

Another stated advantage of large dams is that increased water yield, available through the use of irrigation rather than harvested rainwater, allows farmers an alternative to subsistence lifestyles. However, the Sidi Saad dam was calculated to have "produced an irrigated area 1/30th of the size of the previous decentralized systems at ten times the cost" for farmers that previously relied on rainfed agricultural systems.[12]

In 2018 the Tunisian government permitted the construction of another dam. SinoHydro,[13] a state-owned Chinese hydropower and construction engineering company enshrouded in controversies around the globe,[14] was contracted to build what will be the largest dam in Tunisia. SinoHydro was previously contracted to build the dam that indigenous activist Berta Caceres was protesting in Honduras when she was murdered in her home in 2016,[15] the same year the company was suspended by the World Bank for "Fraudulent Practices".[16]

In January 2019, following the major flooding in Autumn 2018, a loan granted by the Arab Fund provided funds for the construction of additional dams in Tunisia, adding 195 million Tunisian dinars to a mounting loan debt to the Kuwaiti government.[17] At that point, three dams were under construction in Tunisia, and three more were slated to begin construction, joining 33 existing dams around the country.[18] If this number seems low compared to the 1200 dams in Washington state in the United States, an area of comparable area to Tunisia,[19] consider that Tunisia has only two major river systems to exploit with dam infrastructure, the Medjerda and the Miliane. Most river tributaries are typically dry during the summer.[20]

Elsewhere in the country, the construction of dams has resulted in rural populations unable to access water that was once abundant. Their development is part of a pattern in which centralized control of water and resources is considered more effective than self-management through decentralized approaches, which was the historic norm in many parts of the country.[21] In a 2015 interview, Abdeljalil Chargaoui, a member of the Association of Rural Development in Toghzaz, near the Sidi El Barrak dam in Northwestern Tunisia said,

> *The region is rich in water. We've had it here—free and constant—for a long time. Not only have we been deprived of our lands and potable water, but now we are obligated to pay for irrigation water and are forbidden to dig wells using our own resources.*[22]

Dams framed as strategies to support communities suffering from drought and flood disaster offer only limited benefits. These solutions are costly and often inappropriate for the questions they purportedly address. From afar, they read as appeasement of legitimate concerns rather than intentional and well-considered responses to flood risk in vulnerable communities.

Large infrastructural solutions often amount to top-down restructuring of the landscape, imposing order of a colossal scale that brings greater risk than reward. Despite possible advantages of modern dam developments, "an almost total break from natural environmental oscillations is made in the short term...This can lead to environmental disequilibrium over longer durations in the form of depleted aquifers and possible soil salinization."[23] With limited benefits and high risk, it is difficult to understand why resources continue to be channeled into dam construction.

PREVIOUS:
Figure 3.5 Sidi Salem Dam near Testour, Tunisia, with low water levels during a drought, August 2016.
Source: SkyNews

LANDSCAPE ARCHITECTURE AND DISASTER RESPONSE

Fortunately, landscape architecture offers robust alternatives to the costly centralized flood management approach that dams exemplify. Exacerbated flood risk in cities around the world has prompted invigorated flood mitigation planning done in collaboration with landscape architects. Recognizing the value of "soft engineering"[24] that "mimics pre-disturbance hydrologic processes"a number of cities have developed frameworks for highly populated regions that have experienced severe flooding events. Redesigns arise out of recognition that urbanized areas (particularly coastal ones) produce conditions that are multipliers of disaster.

Green stormwater infrastructure (GSI), or urban surface runoff capture systems designed to mimic ecology, are growing in popularity with recognition of the multiplicity of benefits they bring beyond merely capturing stormwater. Examples include rain gardens, vegetated swales, bio-retention planters, and green roofs. Green infrastructure limits strain on so-called "grey infrastructure," or conventionally engineered sewage systems by absorbing water or slowing its movement. [25]

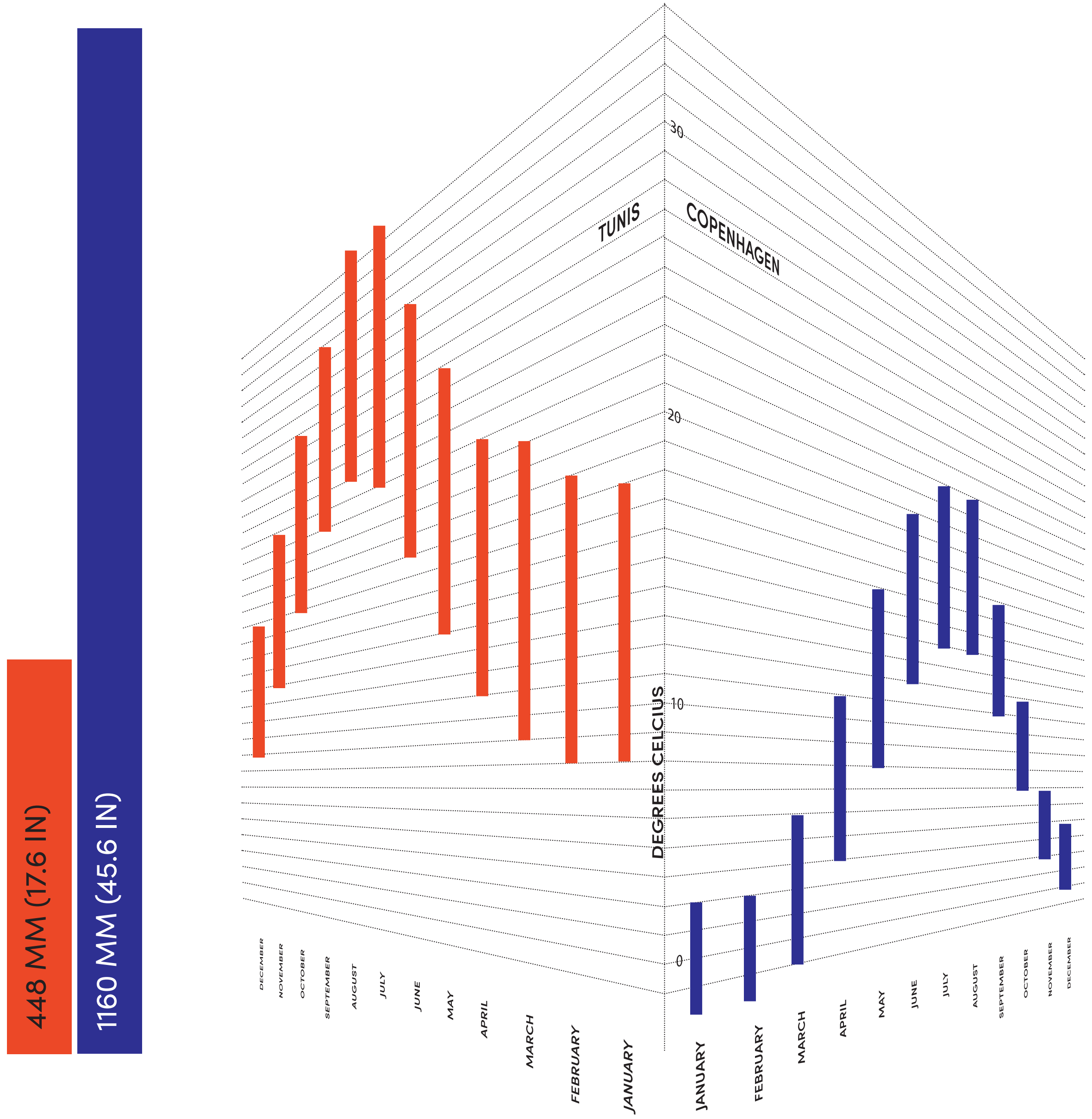
Integrating systems that collect water, filter it, and reintegrate it into the public sphere exemplify the idea of layering functions in components of a system. For example, infrastructure that encourages surface water flow to infiltrate allows natural hydrologic recharge to be re-introduced into areas that were previously impervious. Urban heat island effect can be mitigated through evapotranspiration of vegetation in green infrastructure systems. Pollution caused by surface runoff or sewer overflows caused by rain events is reduced.[26] During large storm events water can be diverted or slowed, preventing it from assuming a destructive capacity. These benefits uplift the health of an entire ecosystem, benefitting human and non-human actors.

There are global examples of large-scale retrofits integrate soft engineering and green infrastructure into urban areas, but few available precedents for urban stormwater infrastructure in semi-arid to arid climates. In the field of landscape architecture, examples in Portland, Oregon; Seattle, Washington; or Copenhagen, Denmark are often presented as case studies. These models are effective, small-scale approaches for the co-existence of water and densely settled urban environments, and in some instances, have been monitored to collect data. The pilot of Street Edge Alternatives, or SEA Streets, in Seattle, WA reduced impervious surfaces on a residential street by 11% , and was able to capture 99% of stormwater leaving the street.[27] Vegetated swales lining the residential street provided habitat and some of the well-documented benefits of nearby nature in urban settings.[28]

Copenhagen's Cloudburst Management Plan, responding to an extreme rainfall event in 2011 presents climate adaptation and mitigation measures to protect Copenhagen against future flooding. The plan integrates a number of "blue and green" measures to drain water at the street level or create areas for water to collect, minimizing damage and disruption.[29] For example, parks are designed to hold floodwater, absorbing water or detaining it to prevent the conventional overflows in the conventional storm drainage system. Adaptive measures respond to an event similar to the recent disasters in Tunisia: urban flash flooding at an unprecedented scale.

Though the Cloudburst Management Plan is an excellent model of a city-wide initiative for comprehensive flood management, looking to it as a precedent for the city of Tunis raises questions on how transferable success in one context is to another. At a glance, city-wide planning and implementation of green infrastructure come at a cost that is unprecedented for Tunisian infrastructural projects. The cost of the Cloudburst Management Plan is approximately 11 billion Danish Kroners,[30] which translates to approximately 5 billion Tunisian Dinars. While Tunis has no comparable comprehensive long-term flood mitigation plans, the closest available parallel concerning flood adaptation for the city of Tunis, the Greater Tunis Flood Control Project,[31] relies primarily on a loan from the Japan Bank for International Cooperation. A handful of flood adaptation measures is estimated to cost just above 9 million Japanese Yen,[32] in the neighborhood of 250,000 Tunisian Dinars. Detailed documents for flood mitigation measures are not available. The plans are only ambiguously referenced with a few lines of text on the web portal for the Tunisian Ministry of Utilities, Housing and Land Management (MEHAT),[33] a familiar pattern in seeking out data regarding public works in Tunisia.

Beyond questions of financing, climatic considerations are significant. Though there are commonalities in considering flood management and challenges presented by urbanization in different cities, the context of a semi-arid city presents distinct challenges for infrastructure performance. With much higher average temperatures throughout the year, much lower annual precipitation, and more concentrated precipitation events, Tunisia presents a distinct set of climatic conditions and challenges. References designed in other climatic, political, and economic contexts, including those of the Pacific Northwest or Scandinavia, seem worlds away from viable infrastructure for Tunis.



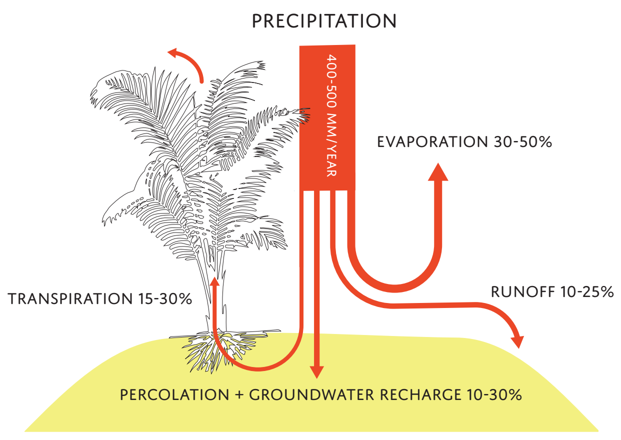
There are a handful of available sources on green stormwater infrastructure in an arid or semi-arid context. Available research examining GSI in the southwest United States, a region that also has a long dry season and a rainy season characterized by short duration, high-intensity rainfall, offers some parallels and metrics for a North African context. In research conducted for the United States Environmental Protection Agency, researchers recommend the use of rainwater harvesting, detention ponds, green roofs, vegetated swales, and media filters (such as sand filters) as possible drylands green infrastructure approaches, but conclude that more research on green stormwater infrastructure design in semi-arid to arid urban regions is required due to the limited amount of reviewable case studies.[34] One notable component of the research is that the selection of technologies contained under the umbrella of GSI is quite limited, perhaps drawing from a limited pool of contemporary green infrastructure precedents with monitored data to look to. Their research draws upon existing models of GSI used in more temperate climates to assess their efficacy in the Southwest, but leans upon a grouping of approaches that are not necessarily generated from a drylands context. The introduction of different approaches can reinvigorate discourse around green infrastructure by prioritizing place-based typologies.

Figure 3.6. Comparison: Annual average precipitation (LEFT) and temperatures (RIGHT) between Copenhagen and Tunis.

While Copenhagen has frequent precipitation distributed throughout the year, with more than 1000 mm annually, Tunis has a brief rainy season and approximately 400-500mm of rain annually.

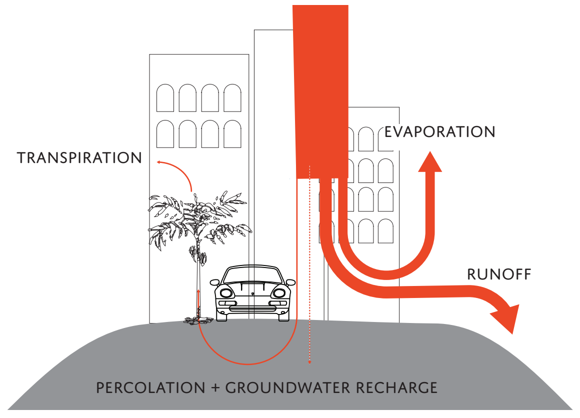
DRYLANDS STORMWATER INFRASTRUCTURE

HYDROLOGICAL CONDITIONS IN SEMI-ARID ENVIRONMENT



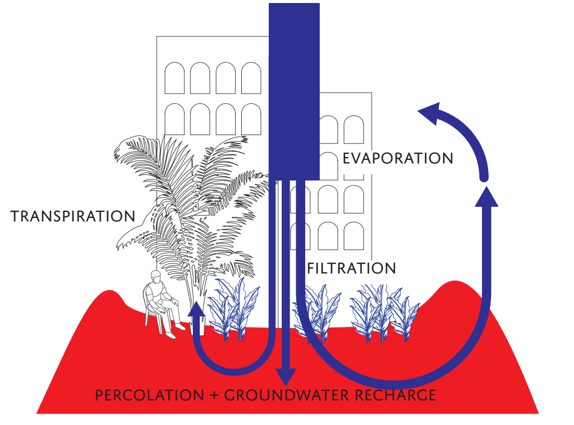
In semi-arid environments, the majority of precipitation evaporates or dissipates in runoff. Traditional rainwater harvesting seeks to transform the tendency of an arid landscape to promote surface runoff by instead creating conditions for infiltration and water storage within the soil profile. (Adapted from Prinz, Dieter, Ahmed Yousif Hachum, and Theib Yousef Oweis, 2012.)

CHALLENGES EXACERBATED BY URBANIZATION



In urban contexts, the challenges of drylands settings are multiplied, with impervious surfaces, pollution, heat island effect, and lack of water collection infrastructure resulting in rapid runoff. In a heavy precipitation event, flood risk is increased without intentional efforts to capture and store water.

GREEN INFRASTRUCTURE + WATER COLLECTION



The goal of green infrastructure and the integration of rural water harvesting structures into an urban setting is to mitigate surface runoff and thereby create co-benefits for ecological and habitat health. Stormwater infrastructure can limit demands on conventional drainage system to prevent overflows, absorb water in heavy precipitation events, and regulate temperature in public spaces. Some methods also create the possibility of storage for potable and non-potable water uses during the dry season.

Figure 3.7. Comparing semi-arid hydrological conditions, urbanization, and opportunities presented by green infrastructure.

In reports immediately following the Autumn 2018 flash flooding in northeastern Tunisian cities, local residents lamented poorly maintained *wadi* as a cause for the inundation's severity.[35] *Wadi* are ephemeral streams that typically bear water only during the rainy season. In both rural and urban settings, *wadi* are typically a naturally-occurring valley or riverbed maintained or modified to divert flood waters away from human settlements. They are traditional flood diversion structures that have been used in the region for 3,000 years or longer.[36]

In early phases of researching flash flooding in Tunisia, it was a surprise to find so many references to maintenance of a traditional flood diversion mechanism. It was evident that, of those interviewed, many had faith that appropriate maintenance of existing vernacular structures was an important component of integrated flood response in urban areas where flood damage had occurred.

Other contexts and communities provide precedent for utilizing traditional technology to mitigate contemporary disasters. In Puerto Rico, in the aftermath of Hurricane Maria, farms utilizing traditional and agroecological methods fared better in the storm than large-scale monocrop farms.[37] Similarly, decentralized micro-grid energy production was more effective and resilient in the hurricane, and able to function shortly after the storm.[38]

In another case study, traditional technology is adapted to a historically disaster-prone climate in Japan's Kofu Basin. The success of 400-year-old flood control mechanisms maintaining their effectiveness in the present is attributed to "formulating countermeasures using the whole basin instead of trying to control flooding with a single flood control structure."[39] In the Kofu Basin, maintenance of flood diversion structures remain part of a communal social structure, and regular maintenance is embedded in the region's religious practice, community gatherings, and celebrations.[40]

Looking to the success of time-tested water management technologies in other contexts provided inspiration for a deeper exploration of the role of Traditional Ecological Knowledge (TEK) in urban flood mitigation in North Africa. An existing framework for looking to knowledge rooted in place, TEK is defined by Potowatami botanist and philosopher Robin Wall Kimmerer as the following:

> *The knowledge, practice, and belief concerning the relationship of living beings to one another and to the physical environment, which is held by peoples...with a direct dependence upon local resources (Berkes 1993). Traditional ecological knowledge...is born of long intimacy and attentiveness to a homeland and can arise wherever people are materially and spiritually integrated with their landscape (Kimmerer 2000). TEK is rational and reliable knowledge that has been developed through generations of intimate contact by native peoples with their lands (Mauro and Hardison 2000).*[41]

Technologies rooted in traditional knowledge call upon available materiality, long-held understanding of ecological systems, and social relationships structured around the care of water. They rely upon local resources and patterns of the landscape as a tool for reconfiguring (or re-membering) water movement in the landscape. Models of passive water collection and conveyance are an established component of drylands agricultural adaptation. Subsistence in the landscape requires successful methods for water collection, particularly in an arid climate in which rainfall is one of very few available water sources. In "Indigenous Water Harvesting Systems in West Asia and North Africa," researchers from the International Center for Agricultural Research in the Dry Areas (ICARDA) argue that indigenous knowledge is dynamic and innovate rather than static and dated, representing ongoing knowledge acquisition in response to the environment that is an inherent component of food security,

Figure 3.8. Jessour system in use in Southern Tunisia. Silt collects behind retention walls built across the valley floor, creating fertile agricultural land using floodwater diversion. Image: Observatoire du Sahel et du Sahara. Modified by author.

health, and resource management in drylands. Moreover, indigenous methods are effective in multiple facets of limiting environmental stress; for example, utilizing traditional rainwater harvest also plays a role in limiting the encroachment of desertification by retaining water in the soil profile.[42]

Highly sophisticated soil and water conservation works have been in place in Tunisia for generations.[43] In research with communities that utilize traditional water harvesting in Matmata, a region in central Tunisia, geographers Jennifer Hill and Wendy Woodland interviewed farmers to understand frameworks for their relationships to water:

> *Rainwater harvesting in the region was largely decentralized in nature. Sites were managed on a collective and community basis following local custom and enforced by Islamic law. Under such systems, water is considered a communal property with just enough consumed to meet community needs without waste. The systems utilize indigenous technological knowledge, on a small scale, with relative independence from central authorities. Local expertise is anchored in an awareness of the reciprocal relationship between surface water and groundwater. ...interviewees highlighted the necessity of replenishing... underground water supplies in order ensure water for community use in future seasons.*[44]

Water collection and use is embedded in a framework of waste-free consumption and regeneration. This philosophy begets technologies that are effective over long periods of time, efficiently adapting to environmental systems; for example, systems operate by making space for anticipated floods, and redirecting flows to distribute water over agricultural plots, turning a potential hazard into an asset. Water management technologies exemplify vernacular knowledge and craft derived from an intimate knowledge of place over time, as effective technologies are generationally transmitted. Many farmers integrate agroecological farming approaches to intensively farm fruit trees, staple crops, and fodder crops for livestock.

The study of traditional systems and their value counters what political ecologist Diana K. Davis has written of as the "declensionist narrative" of indigenous stewardship of the Maghreb. Described as "a colonial environmental narrative that blamed the indigenous people ... for deforesting and degrading what was once the highly fertile 'granary of Rome' in North Africa," the declensionist narrative was wielded as a tool for the expropriation of land from North Africans during the French colonial era. Land theft was framed as environmental stewardship by Europeans to prevent degradation at the hands of locals. Davis argues that there is no foundation to this narrative found in the geologic or historic record of the Maghreb.[45]

Figure 3.9. Long-distance water conveyance through the desert in the form of mkayel, underground wells that tap into aquifers and daylight in oases. Sahara Desert, Algeria. Source: George Steinmetz.

Figure 3.10. Earthen water meter directing water to different stakeholders and locations. Beni Isguen, Algeria. Source: George Steinmetz.

> *"The next day we went to the Matmata Mountains, which till the sky in the Tunisian steppe. There were no artesian wells to irrigate the arid lands. Instead, a water-harvesting system called the jisr dominates. Jessour are small check-dams, wherein water concentrates from the rocky hills, cascading onto flat earth plots held up by a retaining wall. The soil and wall are safehouses for storing scarce water. A lower plane of dirt sits below that mini-plateau, and sometimes another, then another, with water percolating from one to the next. During these lands' intermittent inundations, water flows freely over them.*
>
> *The fecund soil and greenery in the steppic landscape seems surreal until one sees that it is everywhere. A patch-work of light and dark greens, the milk chocolate of moist soil, the silver shimmer of sun-licked water on earth after the last week's deluges, amidst more monochrome tan escarpments, blankets one small valley after another in life. Even without much extension work from the state agronomic research institutions, which have devoted huge amounts of funding to white elephant mega-dams [rather than] studies of the jessour, such small-scale infinitely renewable systems allow enough water for date and olive trees, and, in exceptional years, vegetables."*[46]

Systems that are continuously maintained, as they have been for generations, speak rather of the value and longevity of indigenous ecological stewardship. In communities that rely on traditional water harvesting technologies, even harsh and unpredictable environments "are not perceived as risk-laden but as reliable"[47] by virtue of closely observed and carefully adapted response mechanisms. Writing on the relationship between traditional rainwater harvesting and modern dam irrigation, geographers Hill and Woodland write that:

> *Traditional water management advantageously partitions the continuum dividing hazards and resources through subtle manipulation of the environment. A potentially hazardous environment is rendered secure by resourceful water management based on community action and cumulative knowledge. This practice minimizes community dependency and local economic imbalance.*[48]

Adaptive design and local materiality prove their value over rigidly engineered approaches in flood events. For example, retention walls with spillways made of earth and stone were more effective in flood events in central Tunisia than physically rigid concrete overflows. Stone and earthen structures were able to erode to the appropriate level of hydraulic pressure produced by flood waters. Erosion occurred locally, around the mouth of the spillway, allowing the rest of the retention wall to remain intact. In contrast, concrete overflows were unable to erode at the overflow site, and therefore resulted in significant retention wall structures rupturing when experiencing a high volume of water.[49] Concrete, despite being a more costly material, is less effective because its strength is its rigidity rather than its dynamism.

Dynamism in extreme climate conditions, including droughts and floods, prompts acknowledgement of water existing on a resource to risk continuum, and adapting accordingly. Thus, the value of indigenous technologies, particularly when compared to costly contemporary approaches, extends to flood diversion and mitigation.

PREVIOUS:
Figure 3.11. Farmer constructing Jessour in southern Tunisia. Source: ICARDA.

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FIGURES

(Images are my own unless indicated otherwise)

Figure 3.1 Looking over the Lake of Tunis to the city. Source: Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Lac_de_Tunis_(04).jpg. Modified by Fatema Maswood

Figure 3.2. Hydrograph of a typical flash flood (a) and that of a flood event with saturated soils (b). Tc = time of concentration; LNQ = maximum discharge; LKQ = minimum discharge. Source: Flash Flood Hazards, January 2012, Dénes Lóczy/ResearchGate.

Figure 3.3 Hydrograph showing typical influence of urbanization peak flows following precipitation. Source: BBC Rivers. http://www.bbc.co.uk/scotland/education/int/geog/rivers/hydrographs/

Figure 3.4. Sequence of stills from a cell phone recording of flash flooding in Nabeul, September 2018.
Source: "Extreme flood in Tunisia - Nabeul 23-09-2018," Aizen Sowski, https://www.youtube.com/watch?v=GfzF4RLqtBE.

Figure 3.5 Sidi Salem Dam near Testour, Tunisia, with low water levels during a drought, August 2016.
Source: SkyNews, https://news.sky.com/story/thirst-uprising-fears-as-tunisia-suffers-severe-drought-10585272

Figure 3.6. Comparison: Annual average precipitation and temperatures between Copenhagen and Tunis.

Figure 3.7. Diagram comparing hydrology in semi-arid climate, effects of urbanization, and goals of green stormwater infrastructure.

Figure 3.8. Jessour system in use in Southern Tunisia. Silt collects behind retention walls built across the valley floor, creating fertile agricultural land using floodwater diversion.
Source: Observatoire du Sahel et du Sahara, http://www.oss-online.org/en.
Modified by Fatema Maswood.

Figure 3.9. Long-distance water conveyance through the desert in the form of mkayel, underground wells that tap into aquifers and daylight in oases. Sahara Desert, Algeria.
Source: George Steinmetz (used with permission)

Figure 3.10. Earthen water meter directing water to different stakeholders and locations. Beni Isguen, Algeria.
Source: George Steinmetz (used with permission)

Figure 3.11. Farmer constructing Jessour in southern Tunisia. Source: ICARDA, https://www.flickr.com/photos/cgiarconsortium/34073770396.

FIGURE 4.1. A hillside in Korbous, Tunisia.
Source: Fatema Maswood

04. WATER HARVESTING TECHNOLOGIES

EARTHWORKS, MICRO-TOPOGRAPHIES, MACRO-CATCHMENT & FLOODWATER DIVERSION FOR URBAN DRYLANDS

The following pages contain a selection of pre-colonial and indigenous water management technologies from North and West Africa. This chapter is presented as part of a guidebook to water harvesting technologies, in part because there is an element of demystifying the design process embedded in the creation of a manual. As an educational tool, a guidebook is rooted in an ethos of self-reliance and direct action; it provides a means for non-experts to understand new methods or instigate a project by gaining expertise independently. In my own process, researching technologies to integrate into a manual allowed me an opportunity to break down methods to simple elements to facilitate my own understanding of how they function. Representations are diagrammatic and feature exaggerrated slopes for visualization purposes. Following descriptions of specific technologies is a matrix summarizing salient points of each technique and noting site specifications.

I refer to methods of water harvesting as "technologies" intentionally to indicate that non-extractive adaptation to the environent is "the application of [knowledge dealing with the mechanical arts and applied sciences] for practical purposes."[1] I also refer to them as "methods," "approaches," "techniques" or using more specific terminology to avoid redundancy, but the intention remains the same. In Figure 4.22, *majel*, or rooftop water harvesting structures, are referenced as a typical urban technology, but are not explored further because I have opted to highlight landform manipulations rather than architectural methods of water harvesting in this document.

The intention of exploring these techniques is to consider their application as responses to urban stormwater management, particularly in environments with limited water for significant portions of the year. I hypothesize that the following methods have the potential to be successfully replicated in urban contexts, as adaptations to marginal sites or large installations. I propose that structures and earthworks for rainwater harvesting rely on local materiality and site-specific knowledge that can be adapted to urban settings in semi-arid to arid cities, referred to here as urban drylands. These techniques primarily fall under the umbrella of **rainwater harvesting** (RWH) which refers to **the collection of rainfall from a catchment area in order to induce its collection or infiltration into another area.**[2]

Drylands are defined as areas in which average annual evapotranspiration exceeds average annual precipitation.[3]

Catchment refers to the area which precipitation is collected from in order to be redirected to storage in the form of cropping (agricultural cultivation) or a structure (vault or cistern).[4]

RESEARCH

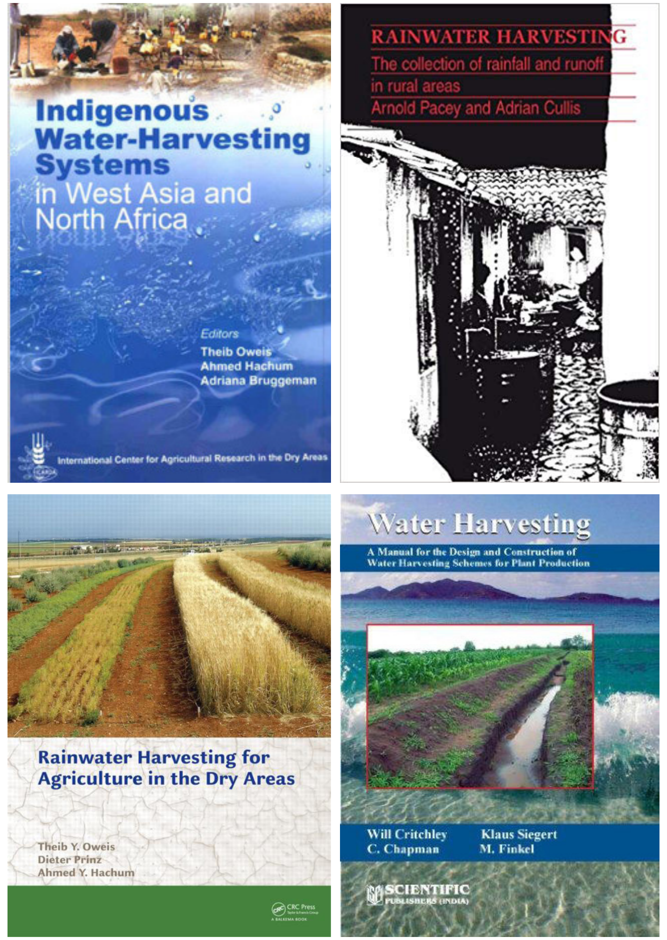


Figure 4.2. Research texts were primarily from literature for rural development in drylands contexts. The above texts were the primary resources used to diagram and model technologies.

SELECTION CRITERIA

1. History of usage in North Africa. Intimate adaptation to the landscape and its particular extremes and/or evidence of resilience in historic flood events.

2. Rely primarily on local, repurposed, or in situ materials.

3. Produce co-benefits beyond those produced by conventional 'grey' infrastructure . For example, improved soil fertility, establishment of vegetation, grazing land, urban public space.

4. Primarily topographical manipulations such as earthworks rather than structural methods such as tanks, or vaults.

5. Possible to integrate into networked system of flood harvesting technology. Decentralized approaches present fewere opportunity for large-scale failure.

6. Challenge colonial history of top-down models for flood response and infrastructure by functioning without causing further harm upon the landscape

Figure 4.3. Technologies selected for further analysis displayed the above criteria.

Traditional rainfed agriculture and water harvesting serve as a valuable precedent for water management in a semi-arid to arid climate, providing mechanisms for capturing stormwater, slowing its movement, and storing it for human use or in the root system of plants. Reliance upon rainwater as a primary source of potable, domestic, and agricultural water usage is common in the history of drylands regions throughout the world.[5]

Rainfed agriculture relies on the collection, concentration, and transference of rainwater to cropped areas. Successful methods create a "rainfall multiplier"[6] which refers to the ratio of land that is designated as 'catchment', where water is collected from, and area designated as 'cropping', where water is directed to. In short, rainfall is concentrated in designated areas to multiply the amount of water available to enhance soil and vegetation in those areas. Crops are grown in a smaller area, but benefit from more water than crops grown without water harvesting systems in place.[7]

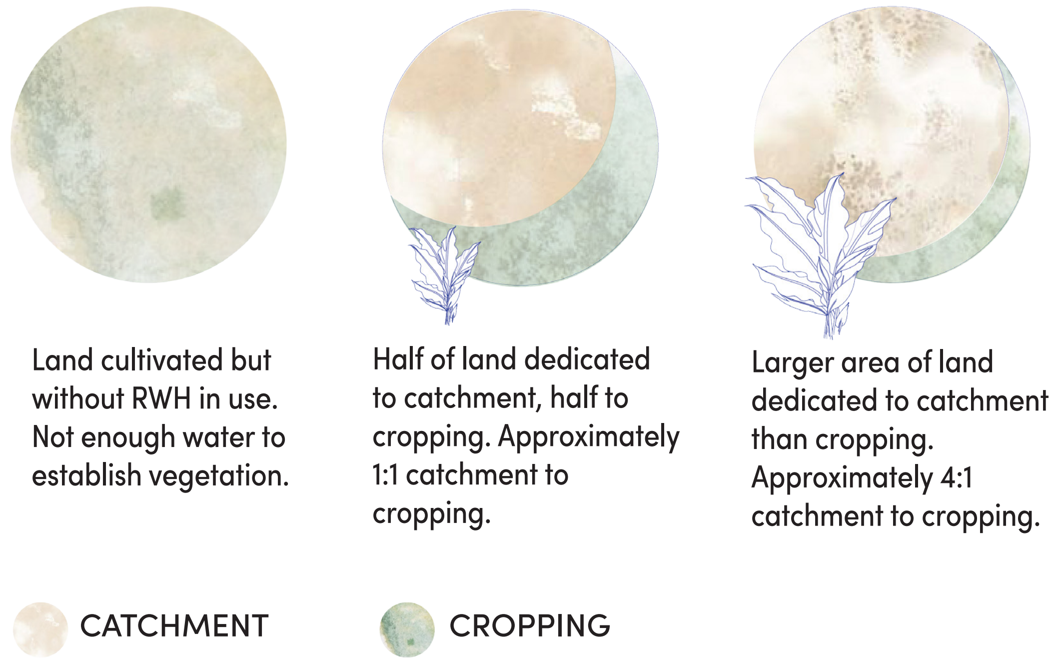


Figure 4.4. Catchment to cropping ratio diagram.

Methods assessed here broadly break down into macrocatchment and microcatchment.

Microcatchment methods typically harvest sheet flow from a small collection area (1-1000m^2) and are typically most effective on sites with up to 5% slope. On steeper sites more earthworks are required and run-off is more likely to be distributed unevenly, presenting greater challenges and costs. Furthermore, provisions for water overflow must be integrated into steeper slopes. Soils best suited to microcatchment harvesting have some amount of fertility, or at least an infiltration rate lower than rainfall intensity. Sandy soils can be a limitation because water infiltrates rather than being induced to runoff into particular regions.[8]

Macrocatchment draws upon a larger catchment area (>1000m^2) and includes floodwater diversion techniques, such as redistributing and spreading water from *wadis*, or ephemeral streams, or using hillside conduits that redirect water moving downslope into cultivation systems. More variability is possible in terms of slope. Irrigation that relies on the redirection of floodwater is known as spate irrigation[9], and is an established method for harnessing a flood and transforming it into a resource.

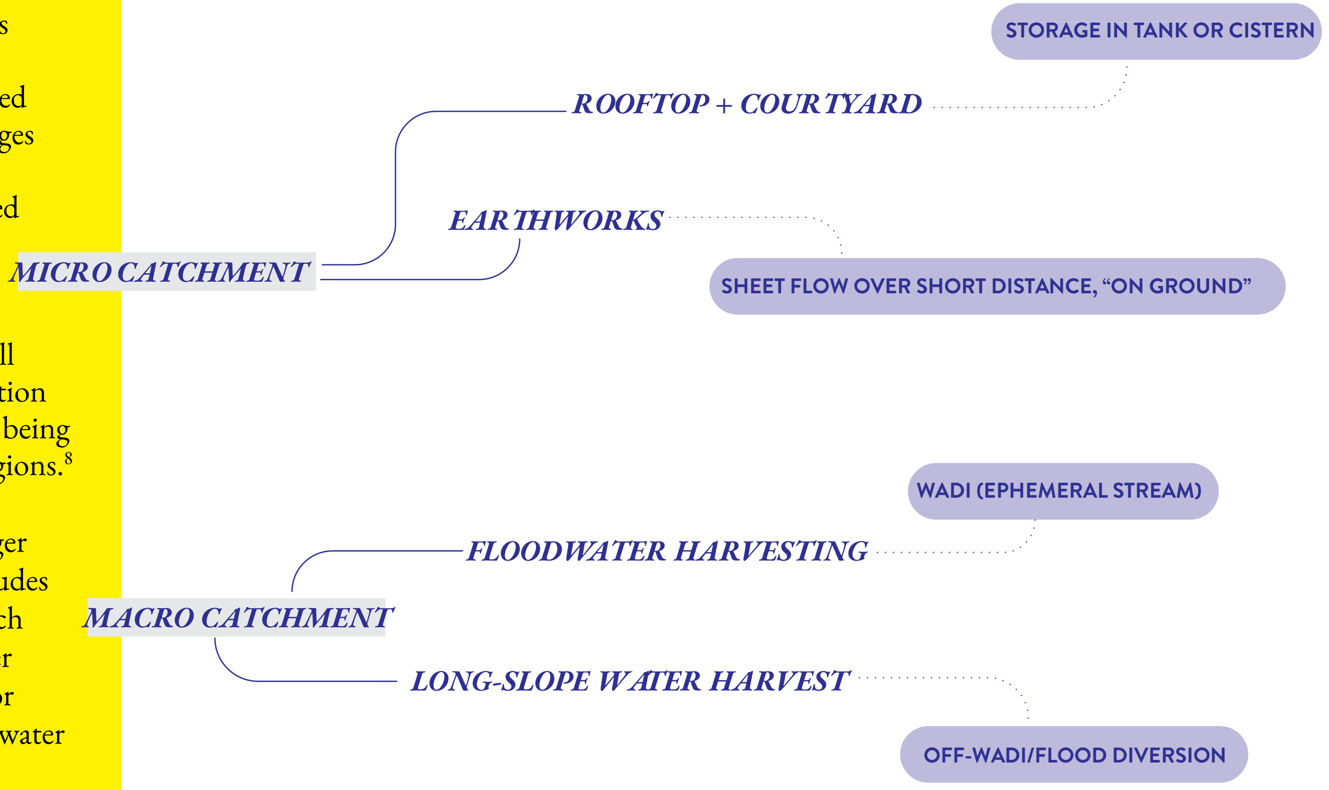


Figure 4.5. Breakdown of rainwater harvesting methods.

GRIDDED MICROCATCHMENT

01 Compacted earthen berms shaped as diamonds with point facing downslope, aligned to contours.

02 Area within earthen berm is the catchment area, collecting runoff and directing it to the planting pit.

03 The planting pit, where vegetation is placed, is located at the lowest point of the diamond.

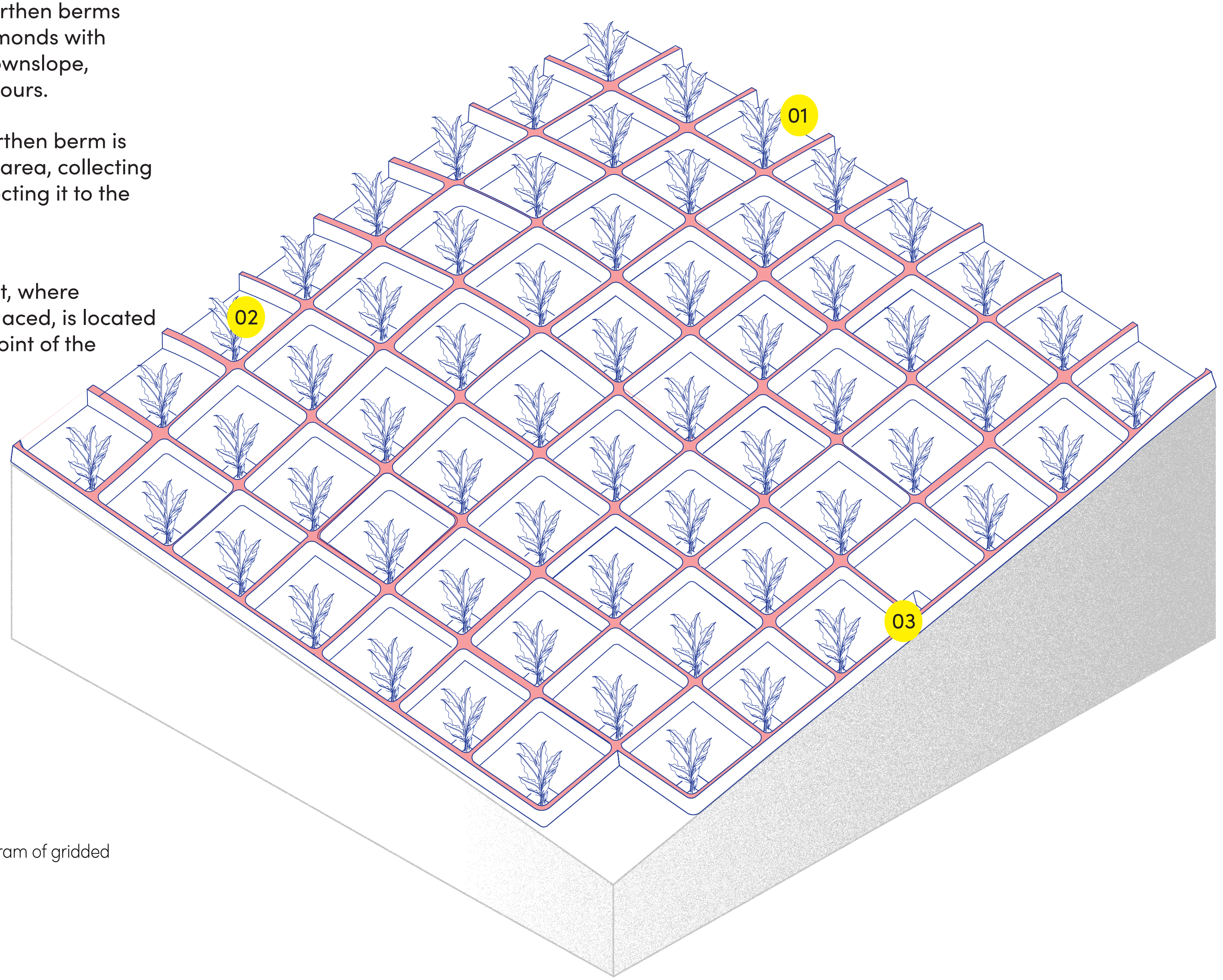
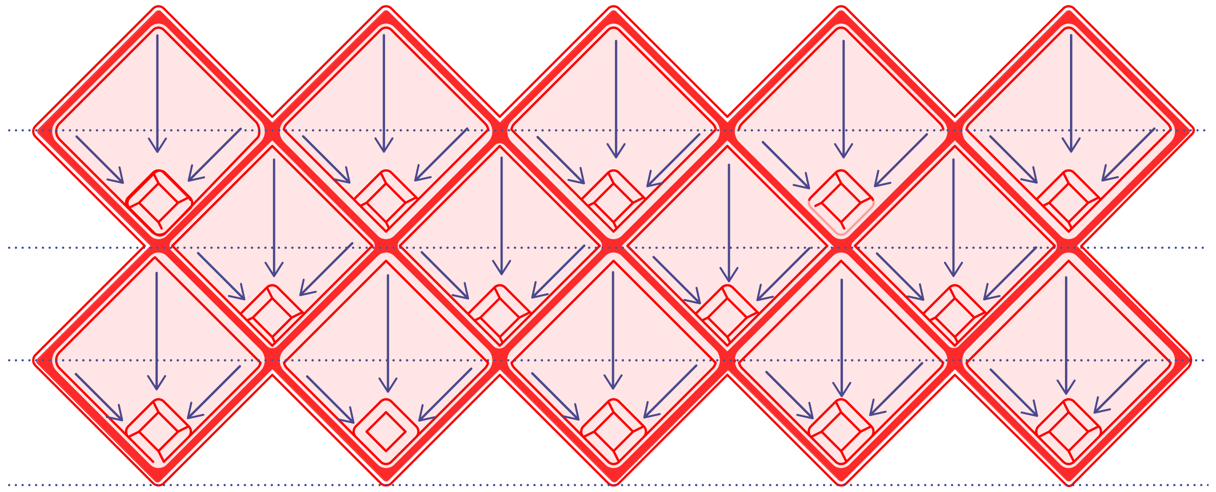


Figure 4.6. Schematic diagram of gridded microcatchments.

DESCRIPTION:

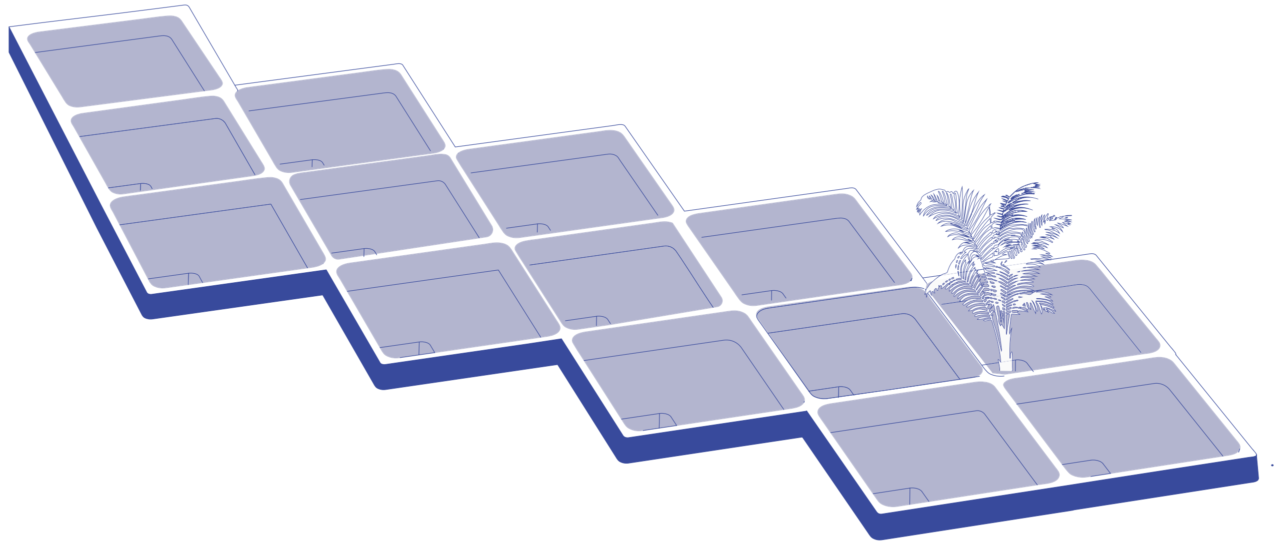
Gridded microcatchments, also known as negarim, are diamond-shaped basins that cascade down a slope. They are used in southern Tunisia, and are found in drylands in other parts of the world.[10]

Earthen berms surround a pit, creating a catchment area that directs water to an infiltration pit at the downslope corner of the basin. The pit is typically used to establish a more valuable crop, such as a fruit tree. Points of the diamonds are aligned to contours, [11] and the structures function best on slopes that are less than 5%, ideally around 2% and relatively even.[12]



ABOVE:
Figure 4.7. Schematic diagram of gridded microcatchments. Water flow is directed to planting pits

BELOW:
Figure 4.8. Water fills individual cells in the grid during rain events.



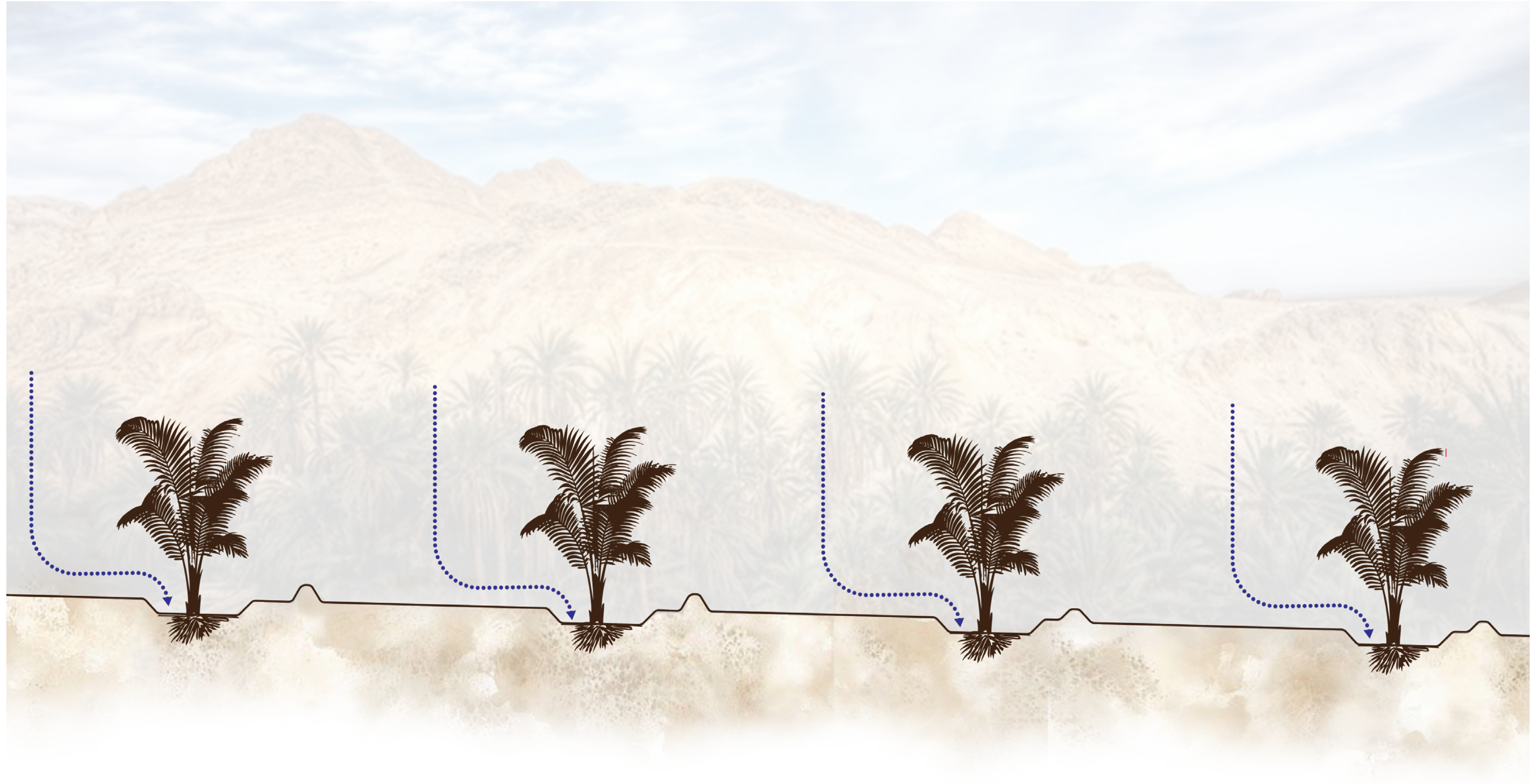


Figure 4.9. Section of gridded microcatchment. Arrows indicate water collection in planting pits.

MESKAT: CONTOUR BENCH TERRACES

01 Stone retention wall *(tabia)*

02 Bench terrace + cropping area *(manqaa)*

03 Sloped catchment area directing runoff to terraces

04 Lateral spillway to allow for overflow when water rises above retention wall height.

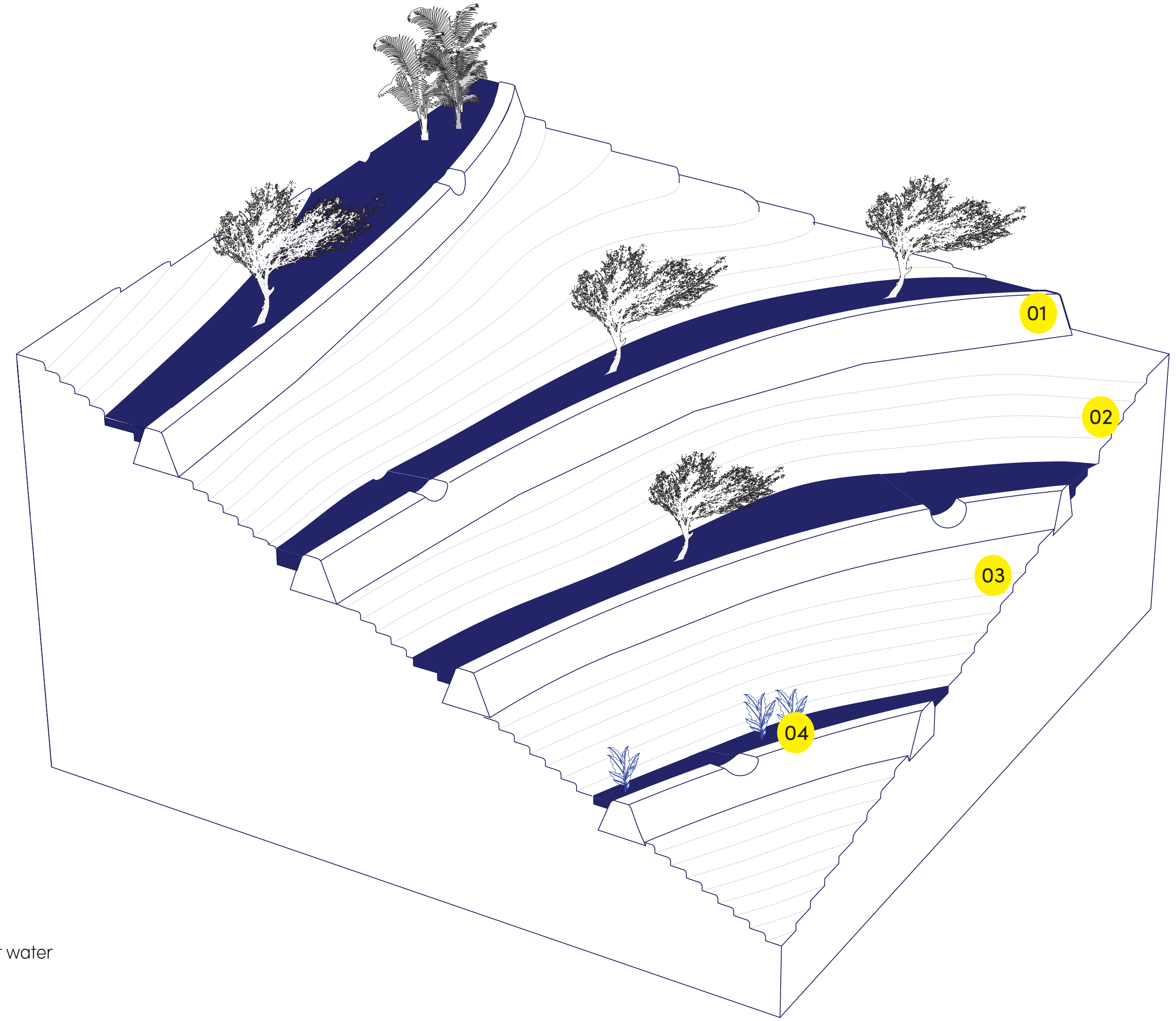
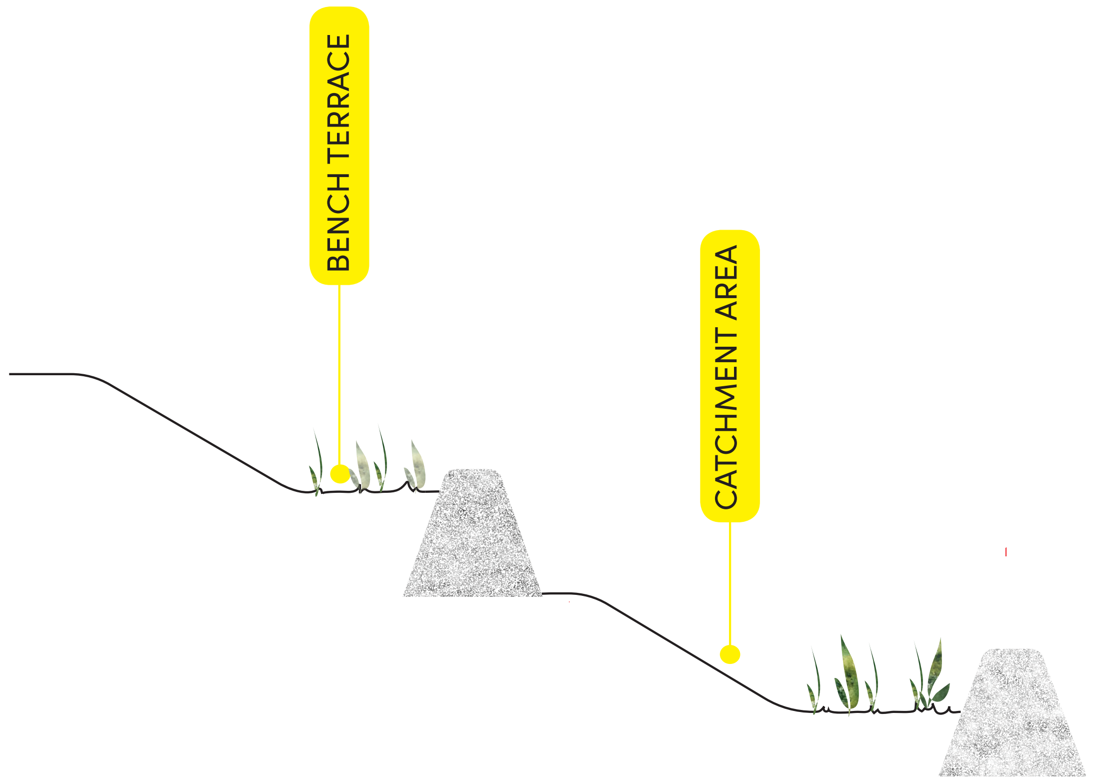


Figure 4.10. Diagram of meskat microcatchment water harvesting system.



DESCRIPTION:

Meskat are used in southern Tunisia and other parts of North Africa for the cultivation of olive trees and other valuable tree crops[13] on slopes steeper than 5% and up to 20%.[14] Part of the sloping area between contours is used for runoff, and part of it terraced for cropping. Stone retention walls with spillways are built along contours. Catchment to cropping area ratio is typically 2:1.[15]

Figure 4.11. Section diagram of meskat microcatchment water harvesting system.

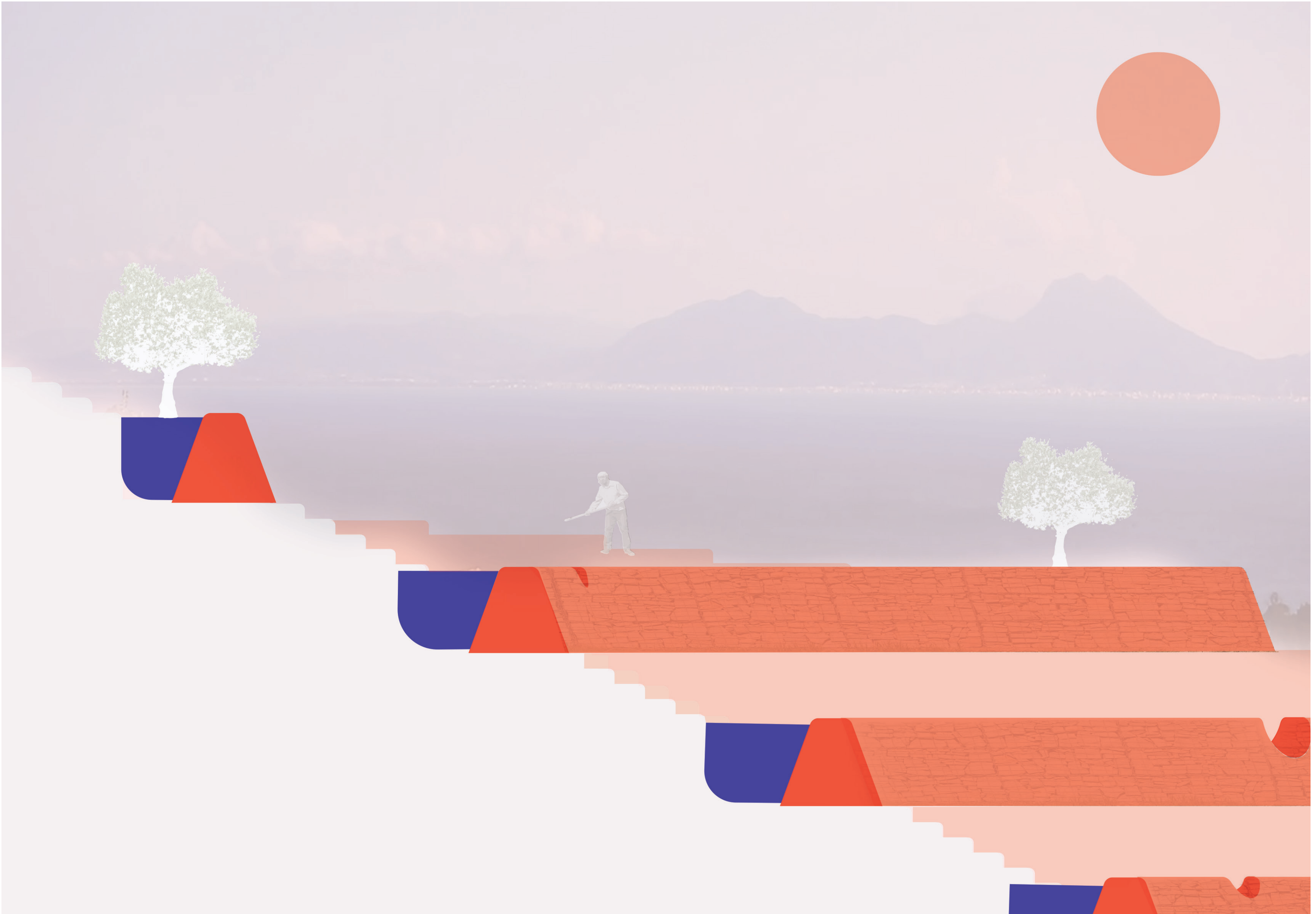


Figure 4.12. Section diagram of meskat microcatchment water harvesting system.

ZAI + SEMI-CIRCULAR BUNDS

01 Zai pits, variant

02 Another variant on zai pitting with soil from the pit forming a small berm downslope.

03 Semi-circular bunds aligned to contour lines

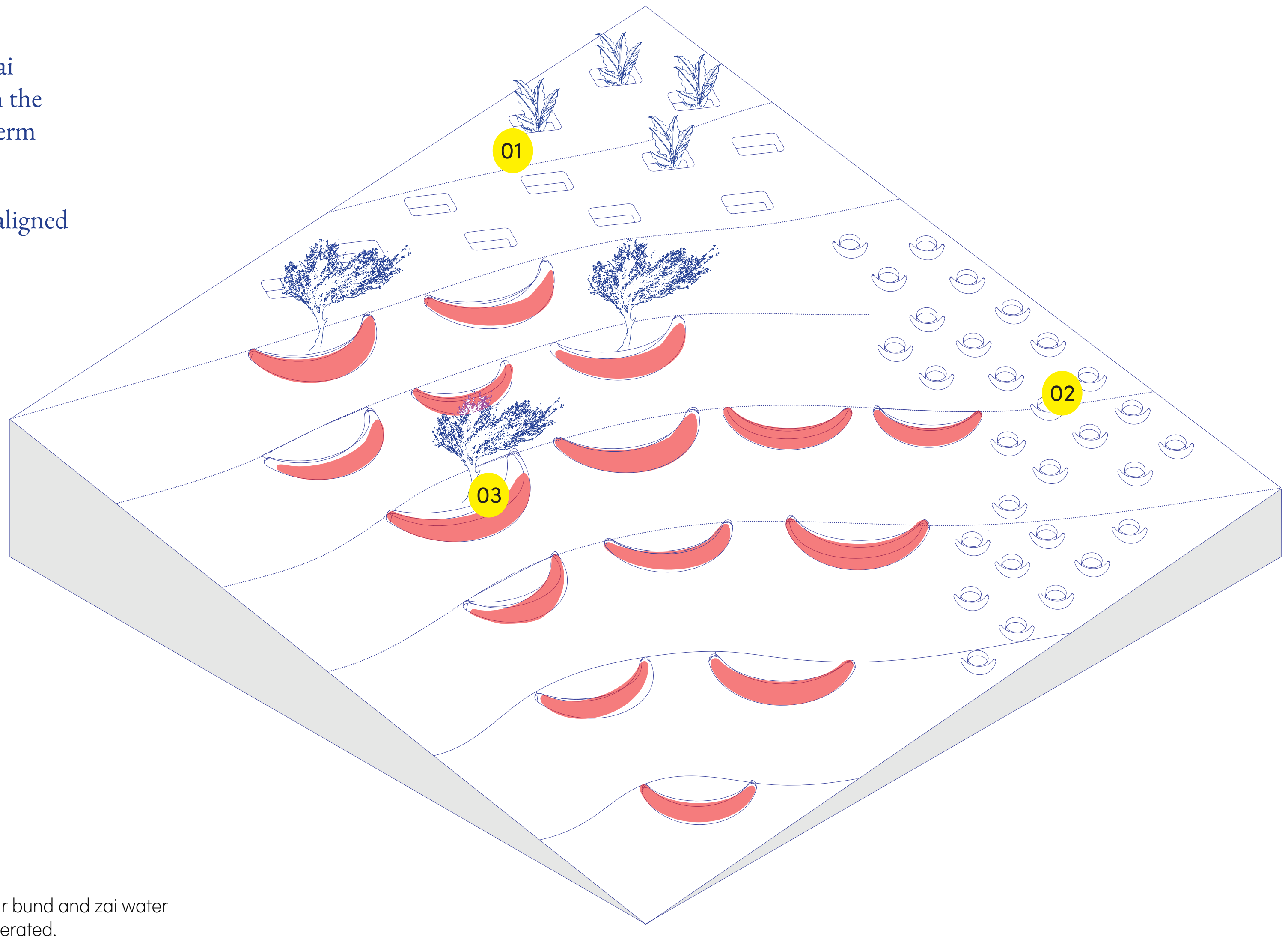


Figure 4.13. Diagram of semicircular bund and zai water harvesting systems. Slope is exaggerated.

ZAI

Zai are pits evenly spaced on shallow slopes or flat sites, amended with compost, and planted with an annual or perennial crop. Pits are amended with compost and gather rainwater while also attracting termites and beneficial insects that enrich soil over time. On a slope, soil from the pit can be formed into a small downslope berm that improves water retention. Originating in Burkina Faso, zai are highly effective techniques in very arid areas with heavy, compacted, or encrusted soils. [20]

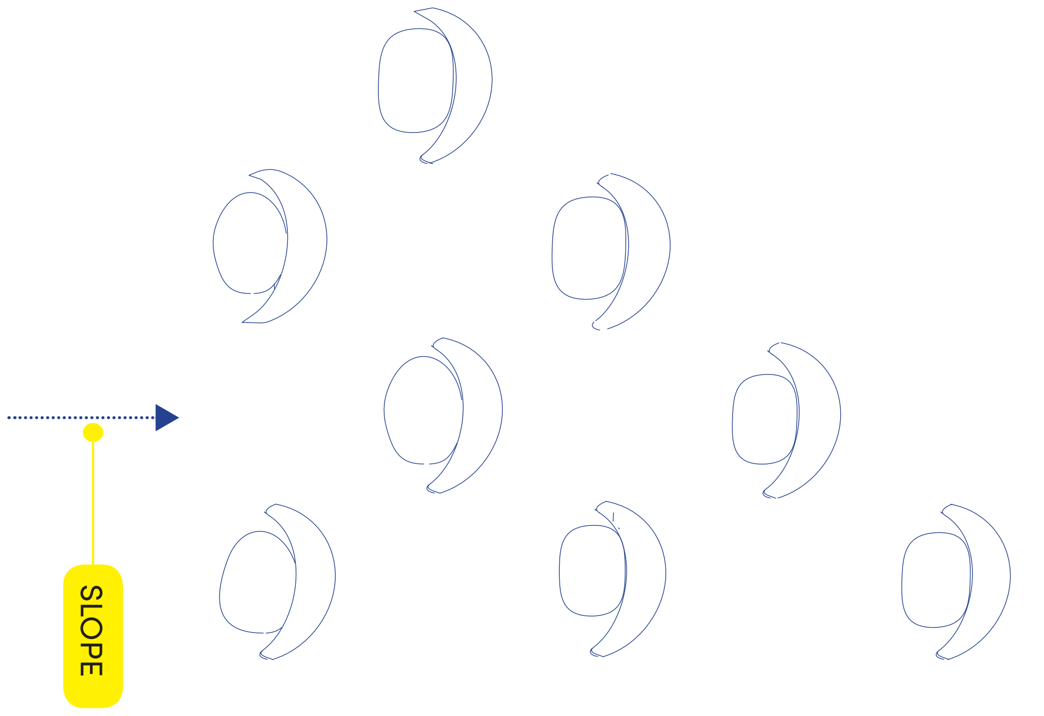


Figure 4.14. Zai slope diagram.

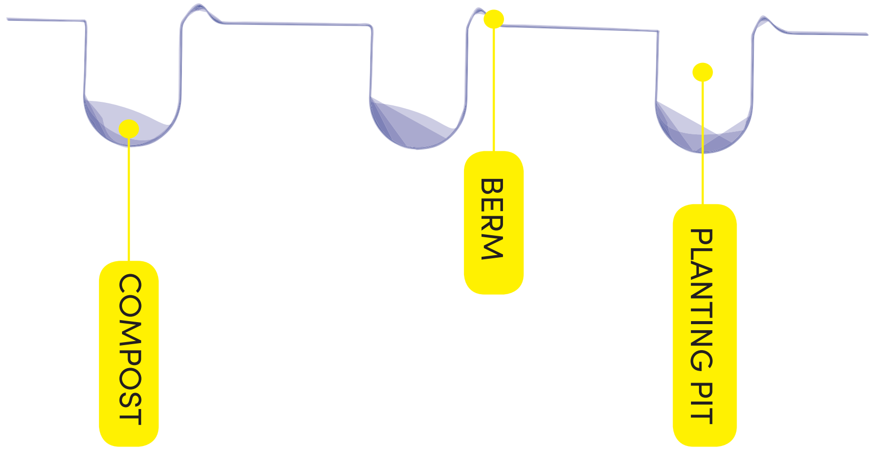


Figure 4.15. Zai section diagram.

SEMI-CIRCULAR BUNDS

Semi-circular bunds arranged on slopes of 2-5% are aligned to contour lines, slowing movement of water and allowing it to gather around tree crops planted in each semicircle. Bunds are typically made of stone. Areas within the bunds act as silt traps, gathering sediment and debris moving downslope to create fertile planting areas. [19]

Figure 4.16. Semi-circular bunds aligned to contour lines.

CONTOUR BUNDS | WADI | JESSOUR

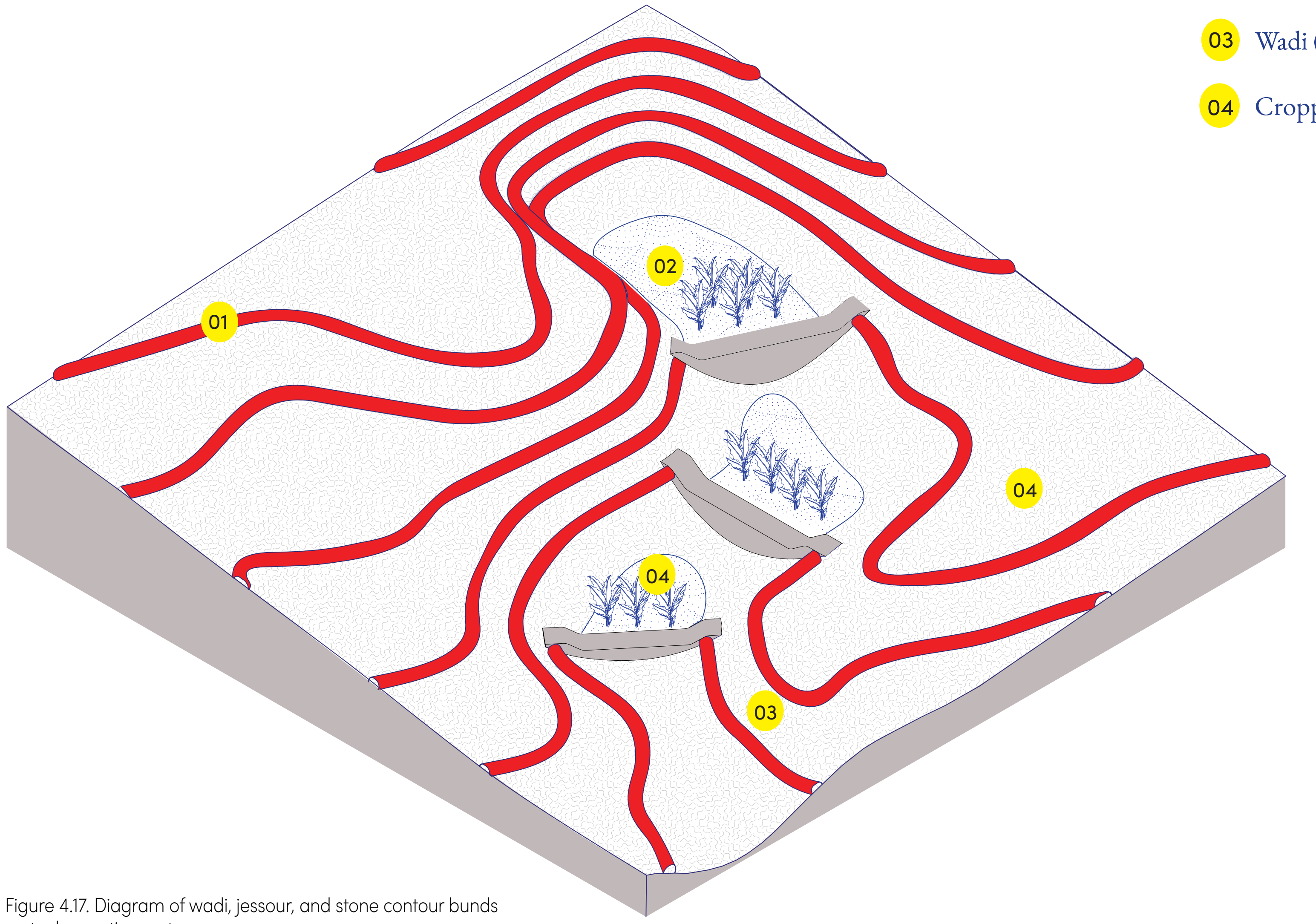


Figure 4.17. Diagram of wadi, jessour, and stone contour bunds water harvesting systems.

STONE CONTOUR BUNDS:

Stone contour bunds are low stone walls built along contours that spread water upslope while allowing it to percolate slowly through the stone barriers. They can be planted to form living barriers. Low walls can be constructed along contour lines by heaping stones. While stone bunds do not require even slopes or spillways, earthen bunds require considerations for overflow and work best when evenly spaced and relatively parallel.[16]

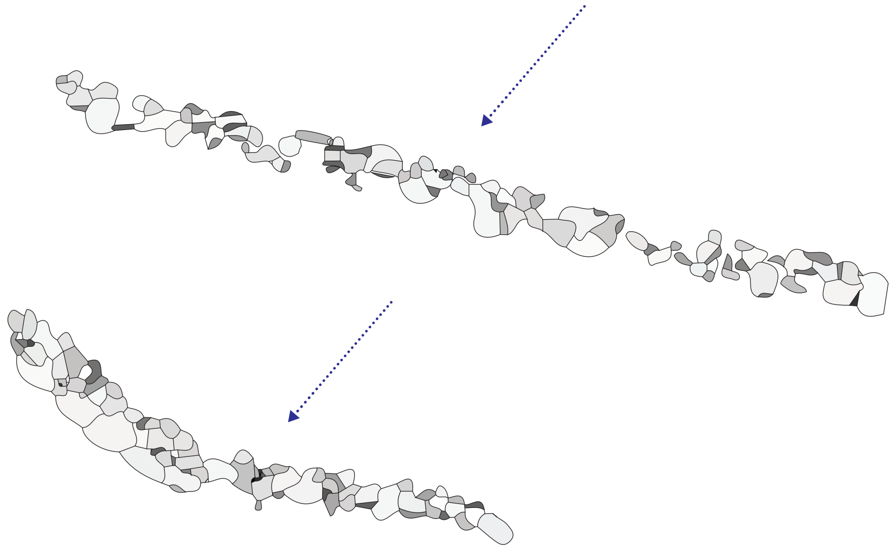


Figure 4.18. Water moving downslope through stone contour bunds .

Figure 4.19. Section diagram of stone contour bund. Adapted from Critchley (1991).

JESSOUR:

Jessour (plural Jesr) are stone check dams built across wadis/valley floors. Jesr slow water movement through wadis, preventing erosion of gullies, and are typically used to trap silt and create fertile agricultural land upslope of the check dam. Jesr measure several meters across and typically have spillways built into the wall structure. [17]

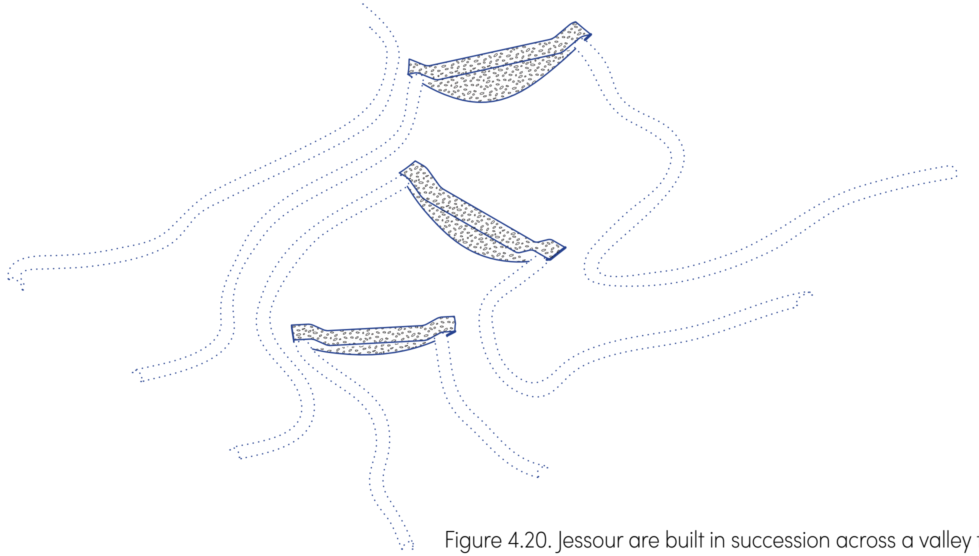


Figure 4.20. Jessour are built in succession across a valley floor.

Figure 4.21. Water travels through the wadi during the rainy season.

WADI:

Wadi are ephemeral streams that are only full with water during the rainy season. They are used as a flood diversion method and are typically maintained to facilitate movement of water away from human settlement and towards cultivated areas. Wadi must be maintained in order to function successfully as flood diversion structures. [18]

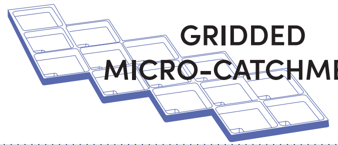
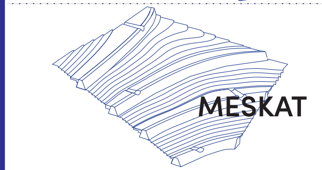
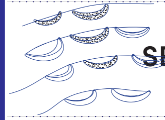
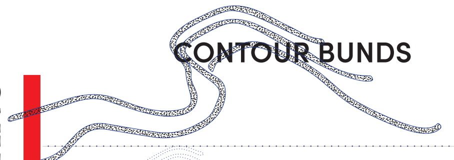
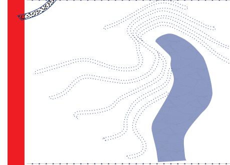
	SYSTEM	WHAT	TYPICAL USE	IDEAL CONDITIONS	VARIATION	TRANSLATES TO URBAN?	ADVANTAGES	LIMITATIONS
MICRO-HARVESTING	MAJEL/FESGUIA *not represented	Tank or cistern collecting water from a rooftop or impluvium integrated into a built structure.	Urban and rural applications, traditionally integrated into residential structures, including homes in the Medina.	Collecting household water from sheet flow, slopes up to 50%.	Majel can collect water for a home or for an external vault or cistern.	Yes, already used in urban settings	Long-held precedent in urban setting, can provide potable water.	Limited collection capacity; oriented toward individual or family use, but limited capacity to implement as public structures
MICRO-HARVESTING	 GRIDDED MICRO-CATCHMENT	Diamond-shaped basins surrounded by low earth bunds. Lowest point of the diamond is aligned to contours and planted.	Rainfed cultivation of tree crops (pistachio, apricot, almond, olive). First documented uses in Southern Tunisia (Pacey and Cullis, 1986). Also known as negarim.	Best on slopes less than 10% in regions with 150-500 mm annual rainfall. Useful in sites requiring soil improvements.	Vary in size and bund height.	Yes, suitable for establishing vegetation.	Once established, system can remain in place for many years with minimal maintenance. Supports soil conservation as well as water harvesting.	Difficult to construct on slopes steeper than 10%. Sandy soils with rapid infiltration not well suited.
MICRO-HARVESTING	 MESKAT	Bench terracing along contours; stone retention wall traps silt creating cropping area upslope. Spillways allow overflow to move to next terrace.	Rainfed cultivation of olive trees on sloped terrain in Southern Tunisia. Can draw water from both on-field and external catchment.	Agricultural cultivation in semi-arid to arid environments to direct surface flow from steep slopes into terraced cropping areas.	Similar to terracing but with approximately 2:1 ratio of run-off area to cropping area.	Yes, suitable for steep sloped areas, embankments, etc.	Improves soil over time, high success rate for establishing vegetation in regions with low precipitation. Stone wall can be replaced by gabions.	Retention wall height and construction must accommodate appropriate amount of water for site conditions.
MICRO-HARVESTING	 ZAI/PITTING	Regularly spaced pits on flat to shallow slopes amended with organic matter (OM).	Rainfed cultivation of annual or perennial crops, particularly in compacted, encrusted, or filled soil unamenable to infiltration. Originates in Burkina Faso.	Agricultural cultivation on flat to moderate slopes. Water retention in average to heavy rain events.	Pits can be round or rectangular, can vary in size or distance, and can function on a range of slopes.	Yes, suitable for poor soils common to urban conditions	Low-cost, low risk, encourages soil health and fertility over time. Low labor requirement. Good for highly encrusted and compacted soils.	Not well-suited to mechanization unless deployed as "imprints," involving compacting the soil into pits rather than digging them.
MICRO-HARVESTING	 SEMI-CIRCULAR BUNDS	Semi-circular stone or earthen bunds with tips on contour lines.	Rainfed cultivation of trees, shrubs, crops, and rehabilitation of grazing areas.	Slopes up to 5% with rainfall between 200-750mm annually.	Bunds can be trapezoidal or rectangular depending on site conditions.	Yes, suitable for establishing vegetation.	Bund traps silt, improving soil over time. Technique is effective for helping trees become established.	Difficult at steeper slopes because bund height and stability requires more engineering.
	 CONTOUR BUNDS	Stone ridge along contour lines of a slope	Rainfed cultivation of trees, shrubs, crops, and rehabilitation of grazing areas.	Evenly sloped areas with slopes less than 5% and rainfall of 200-750 mm annually.	Variants of earthworks along contour lines include contour furrows, earthen contour bunds with stone spillways, living contours planted with perennial grasses.	Yes, suitable for establishing vegetation on gentle slopes or seeding living vegetated structures	Stone bunds do not require a spillway and allow water to percolate through; adaptable technique with very efficient water capture	Requires learning basic surveying techniques for finding contours.
MACRO-HARVESTING	 WADI	Valley or ephemeral stream, filled during rainy season or a heavy rain. Can be naturally-occurring or constructed.	Landscape feature in North Africa and other drylands regions. Used as floodwater diversion on its own or part of a floodwater harvesting system.	Varies.	N/A	Yes, present as technique to direct water away from urban settlements. Could be modified and/or constructed.	Effective method of redirecting flood waters, can have other floodwater diversion and microcatchment embedded within wadi structure.	Requires maintenance to keep valley clear and also to prevent erosion; structures within wadi require engin
MACRO-HARVESTING	 JESSOUR	Permeable stone check dam across valley floor/wadi. Wide structure approx. 1 m tall set into trench and constructed of stone.	Structures allow silt to gather upslope creating cultivable land, limit erosion of valley floor, and allow water to percolate through wadi evenly.	Slope of approx. 2% with rainfall between 200-750 mm annually.	Gabion can be used but stone walls are more effective.	Possible.	Flood harvesting technique equipped for larger water flows and even water distribution across a cultivable area. Once established requires minimal maintenance.	Must be engineered carefully. Highly site specific.

Figure 4.22. Comparison between different water harvesting technologies referenced in this chapter.

END NOTES

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4. Ibid.

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9. Prinz, Dieter, Ahmed Yousif Hachum, and Theib Yousef Oweis. Water Harvesting for Agriculture in the Dry Areas, 2012.

10. Critchley, Will, Klaus Siegert, and C. Chapman. "A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production," 1991.

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12. Critchley, Will, Klaus Siegert, and C. Chapman. "A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production," 1991.

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16. Critchley, Will, Klaus Siegert, and C. Chapman. "A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production," 1991.

17. Prinz, Dieter, Ahmed Yousif Hachum, and Theib Yousef Oweis. Water Harvesting for Agriculture in the Dry Areas, 2012.

18. Pacey, Arnold, and Adrian Cullis. Rainwater Harvesting: The Collection of Rainfall and Run-off in Rural Areas, 1986.

19. Critchley, Will, Klaus Siegert, and C. Chapman. "A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production," 1991.

20. Prinz, Dieter, Ahmed Yousif Hachum, and Theib Yousef Oweis. Water Harvesting for Agriculture in the Dry Areas, 2012.

FIGURES

(images are my own unless indicated otherwise)

05. MODELING + FLOODING SIMULATIONS

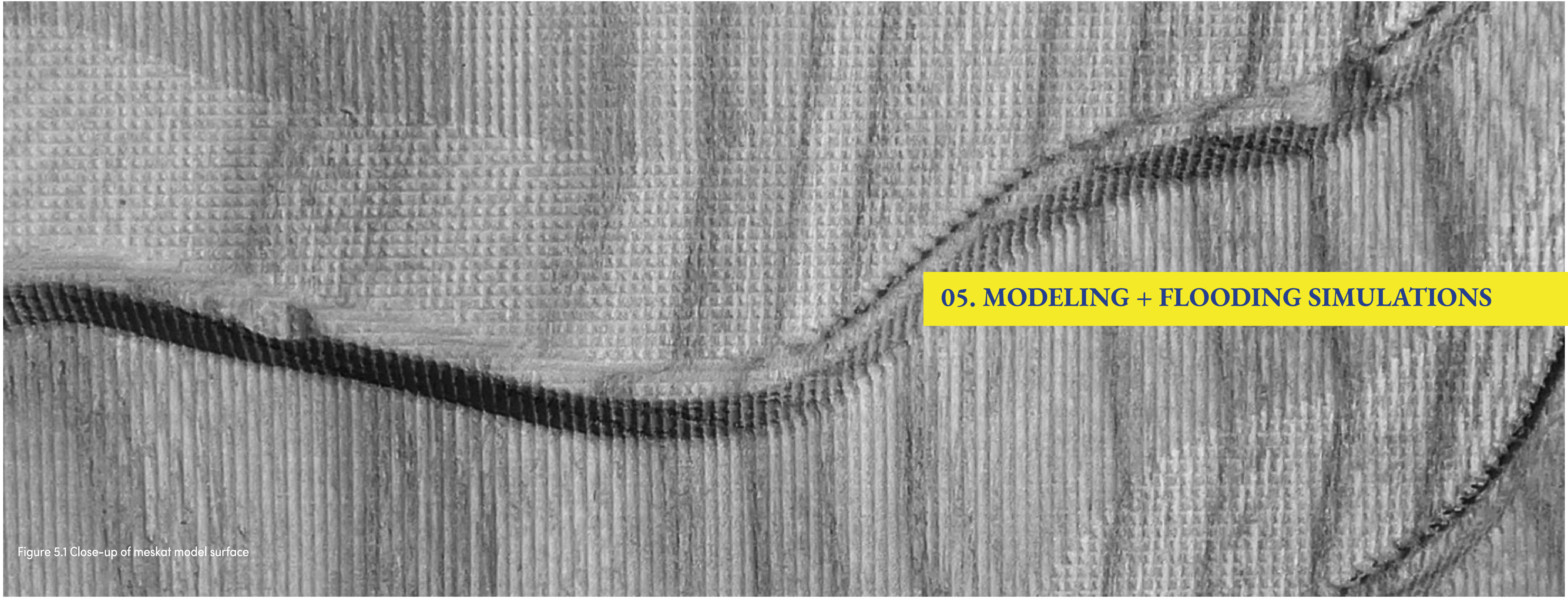

Figure 5.1 Close-up of meskat model surface

MODELING WATER MOVEMENT

There are only a handful of sources with data, clear documentation, and explanations of traditional water harvesting technologies utilized in North Africa. Most of them are rural development texts (Figure 4.2) and none, to my knowledge, are oriented towards designers or urban settings. While many technical resources are rigorous and provide detailed information about site, including soil type, slope, hectares treated, crops grown, and variations on building techniques in drylands agricultural systems, few offered useful information to an audience of designers. Visuals were often low resolution or diagrammatic. In some instances, data and descriptors of particular techniques were different across texts and understanding them required a level of triangulation between research texts and low-resolution images.

Modeling a small selection of technologies allowed me to develop an understanding of techniques, create visuals, and produce physical models as tools for analysis as well as inspiration. These models are my own interpretation and understanding of a variety of technologies. Limited information is available to a researcher in the United States – further study and experimentation will require site-based research, interviews, and documentation. Furthermore, each of these technologies is intimately adapted to its location, the community it is a part of, and the needs it fulfills.

This chapter includes images of models I built as tools for analysis, the fabrication process and translation required to construct those models, and surface flow analysis conducted using an Augmented Reality sandbox – a technology that can visualize contour lines and landform features and simulate conditions of flood or drought at a surface flow level, but is unable to assess qualities such as infiltration. While the technology is limited, using the tool as a preliminary analysis allowed for visualization of where water lingers and what it looks like moving through landscapes.

MODELING

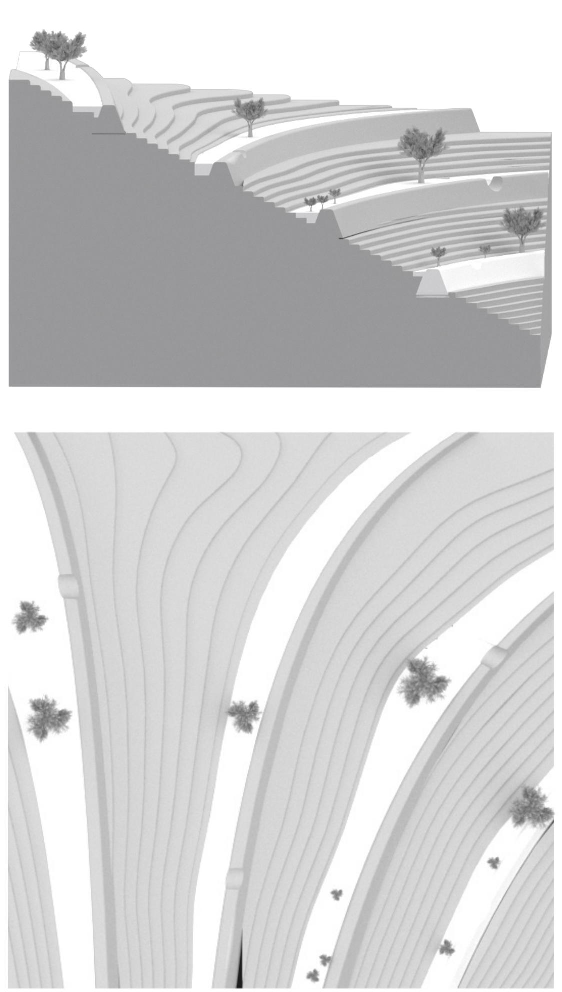

Figure 5.2. Rhinoceros section and plan view of Meskat model above. Models were scaled 1:120 and 3D modelled using Rhinoceros and LandsDesign.

TRANSLATION

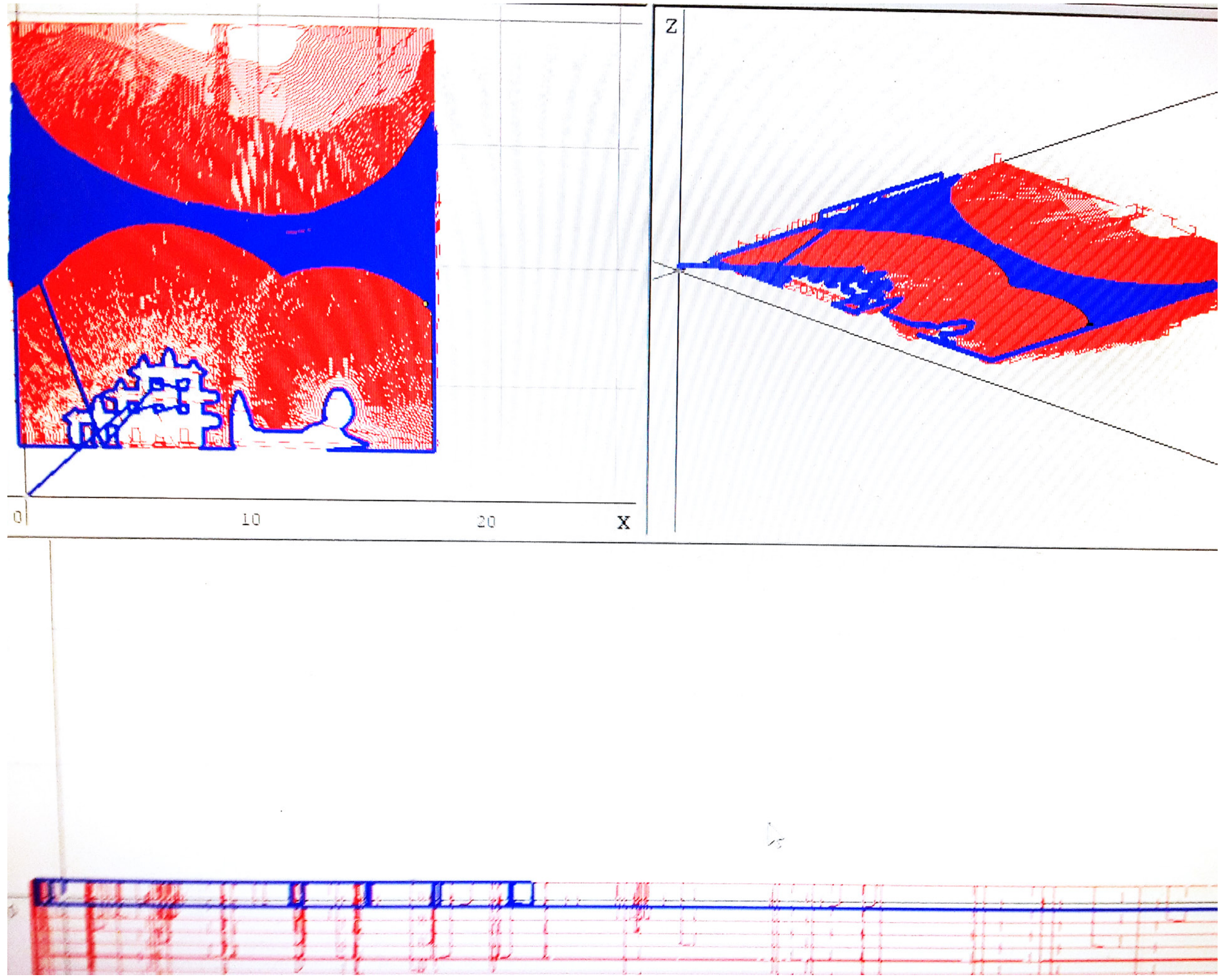

Figure 5.3. Tool paths for diamond microcatchment model. Models were translated through RhinoCAM in order to be CNC routed.

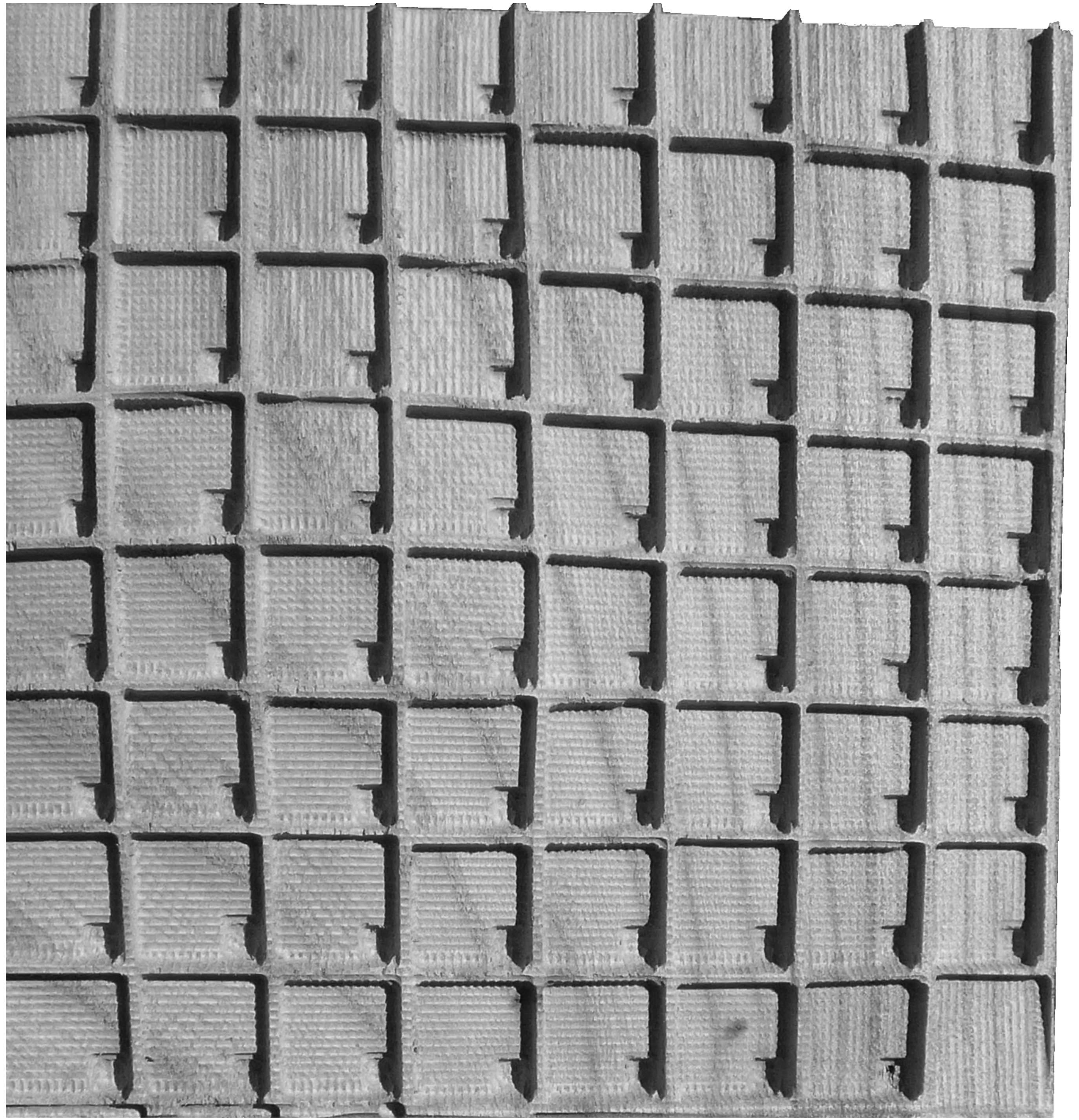

Figure 5.4. Diamond microcatchments.
CNC-routed English Elm.

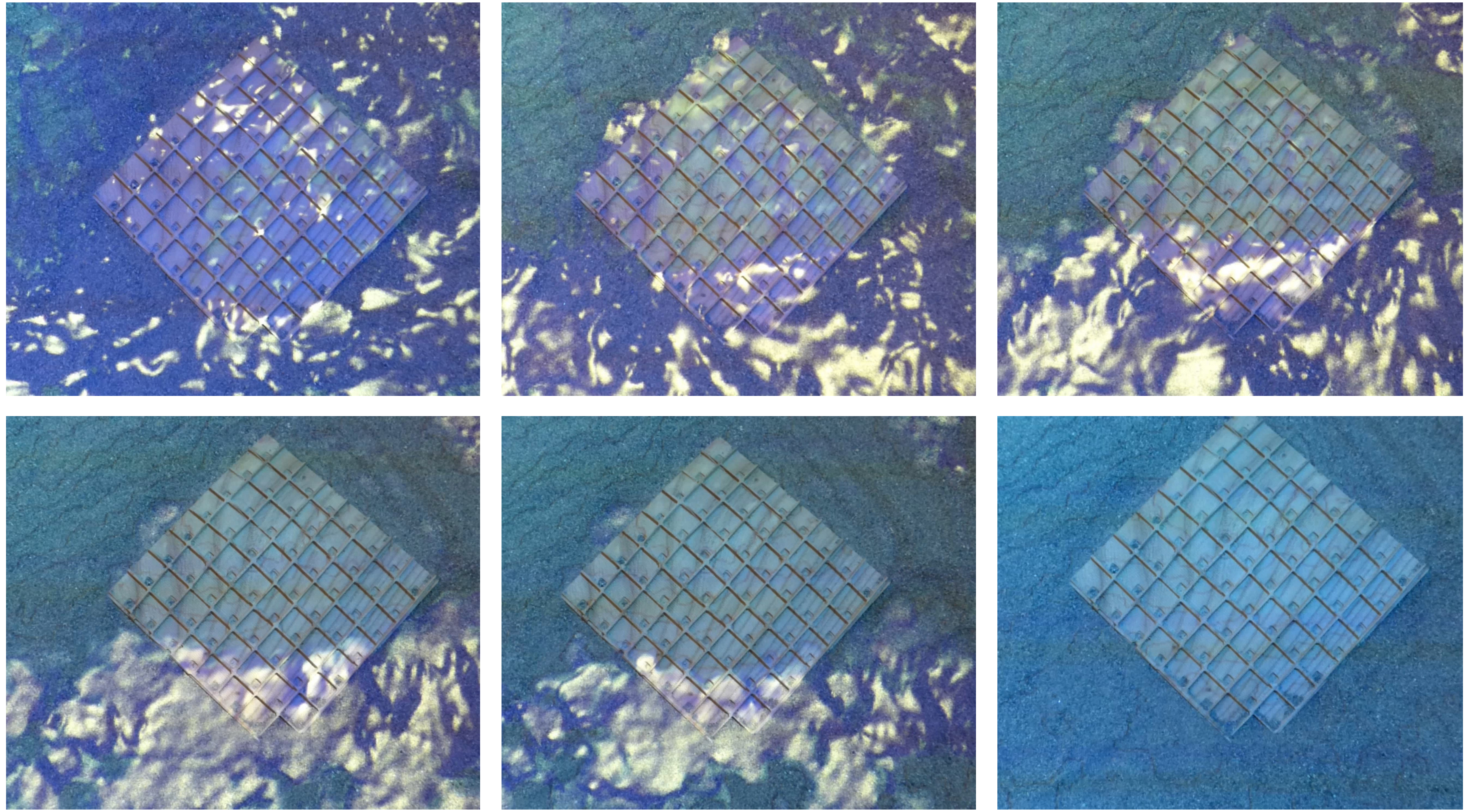

Figure 5.5. Flood simulation in Augmented Reality sandbox. Contour lines were projected into the surface of the model, which was placed downslope of a large mound to simulate water runoff down a slope. Water is shown collecting in individual microcatchment cells, visible as blue and white iridescent coloration.

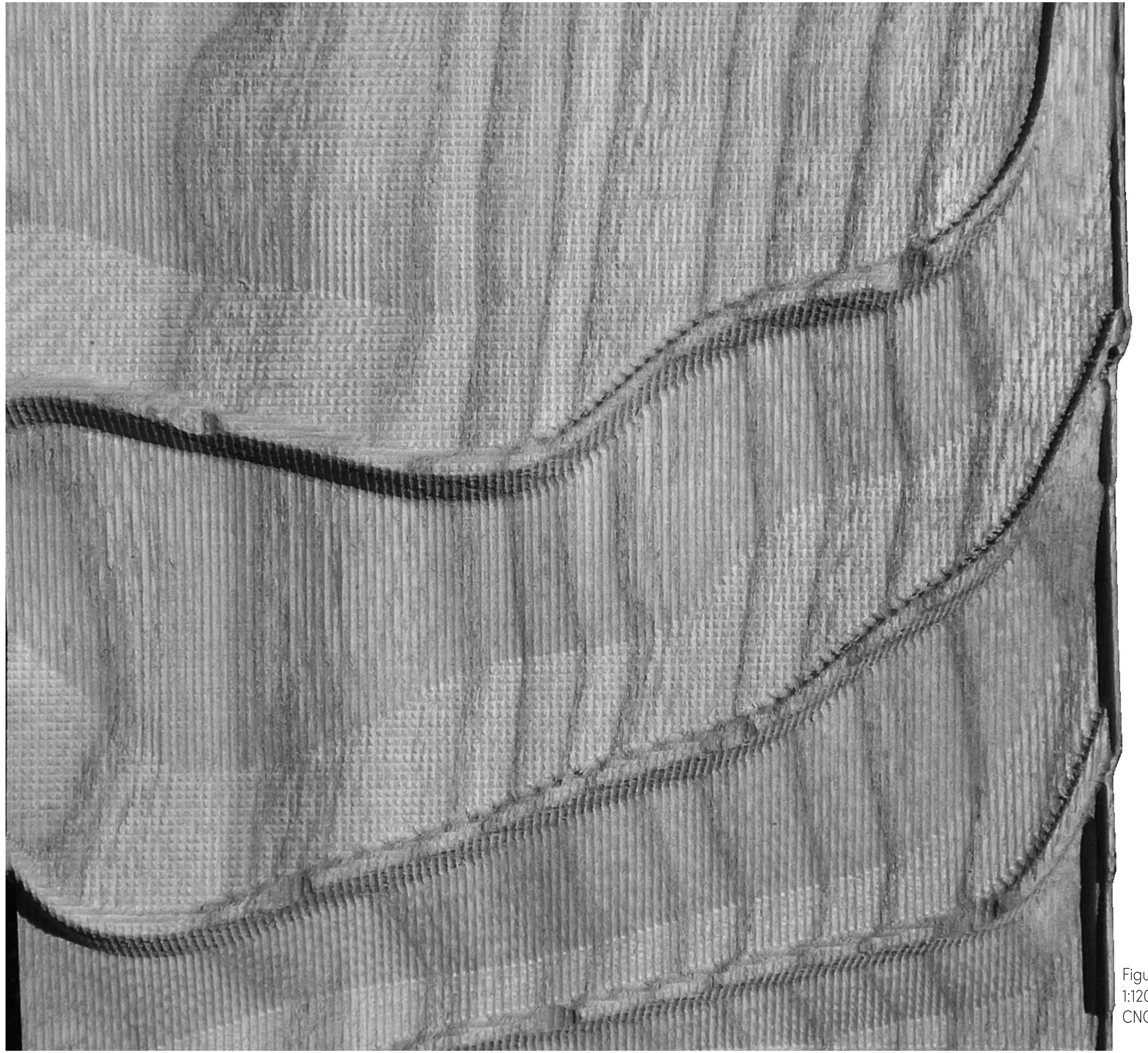

Figure 5.6. Meskat model. Model 1:120. Image not to scale. CNC-routed Elm wood.

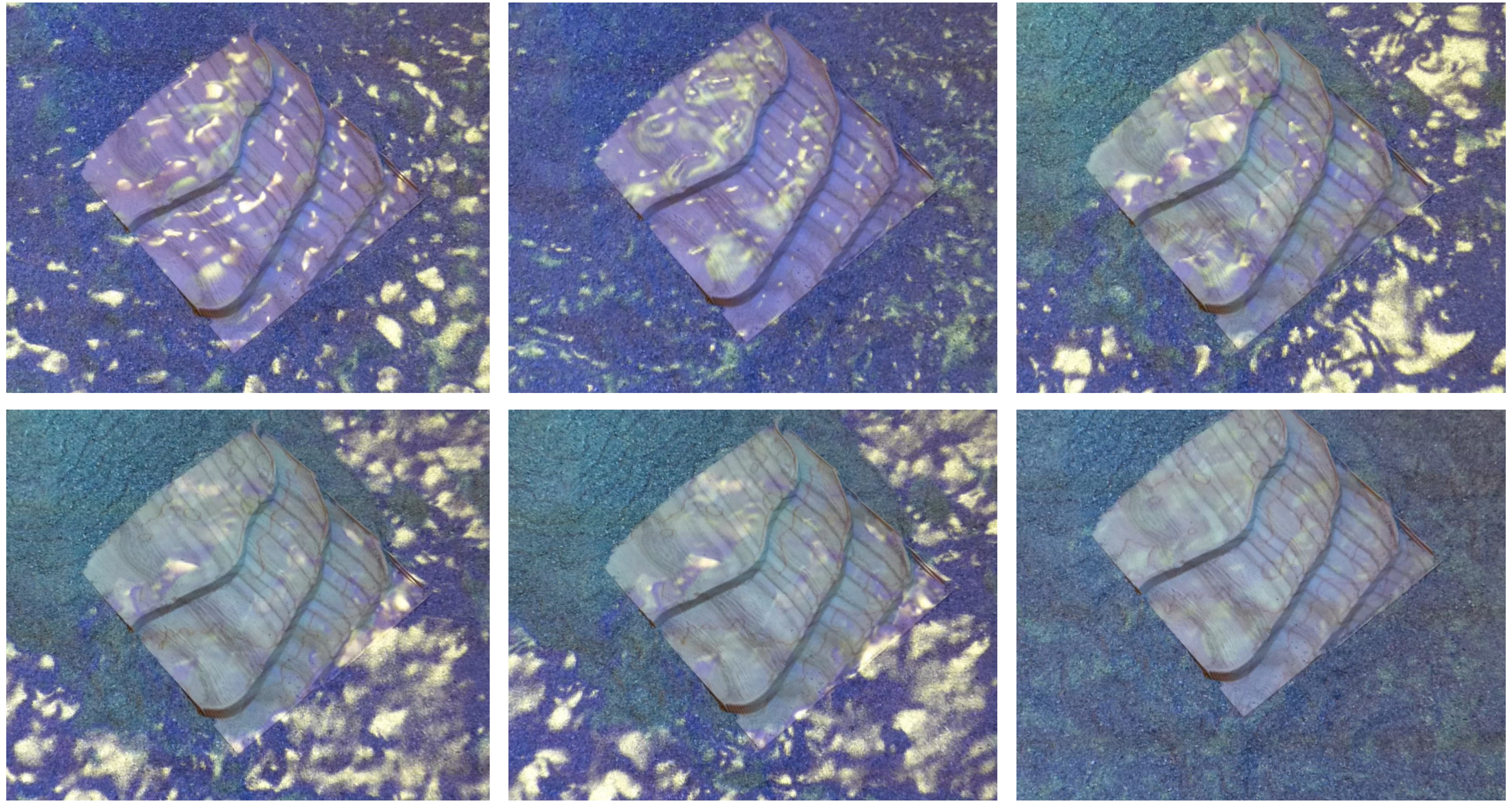

Figure 5.7. Flood simulation in Augmented Reality sandbox. Contour lines were projected into the surface of the model, which was then placed downslope of a large mound to simulate water runoff down a slope. As water falls on the model, it lingers in the terraces behind the retention walls, visible as iridescent white and blue texturing on the model's surface.

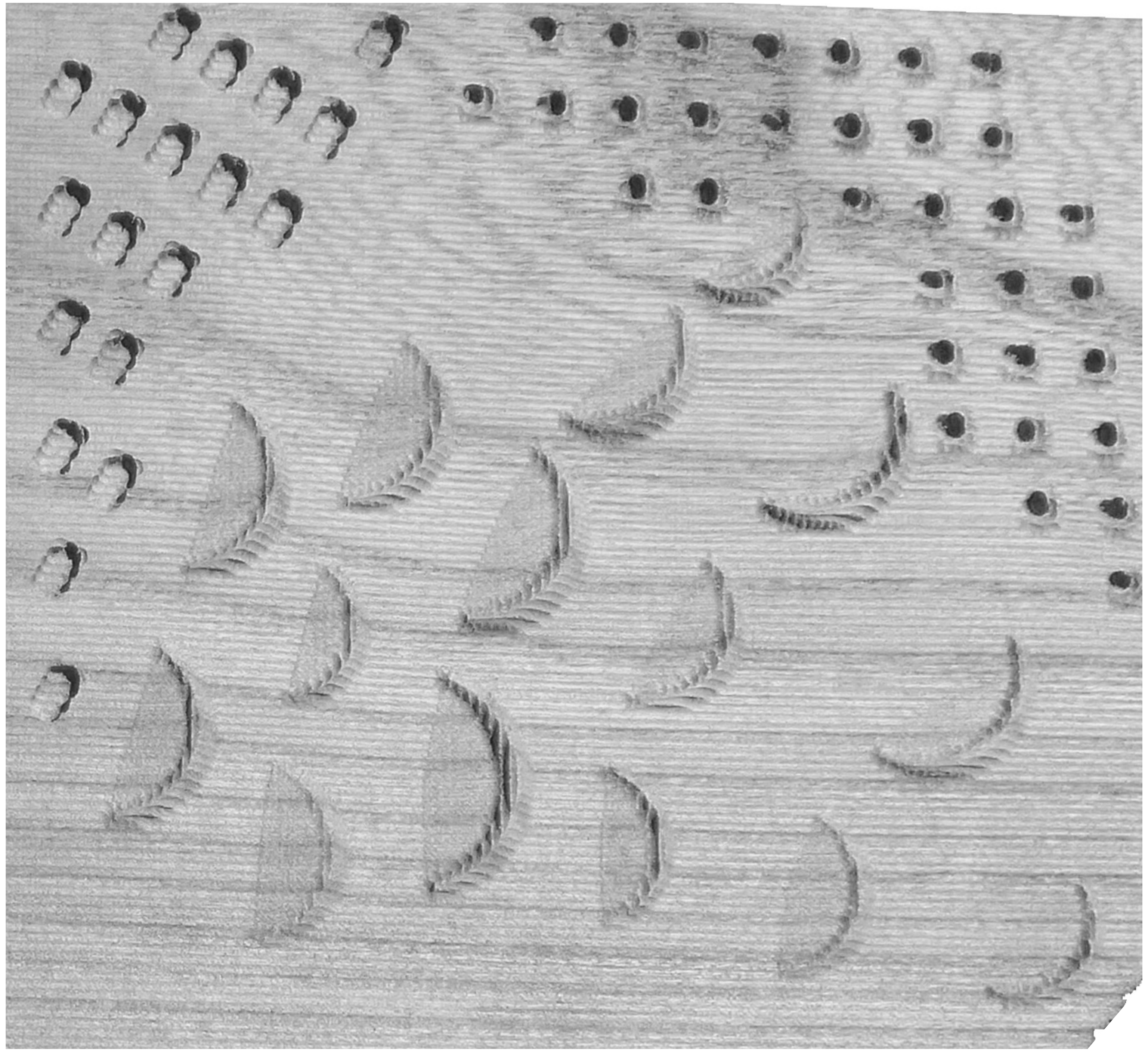

Figure 5.8. Semi-circular bunds and zai. CNC-routed English Elm.

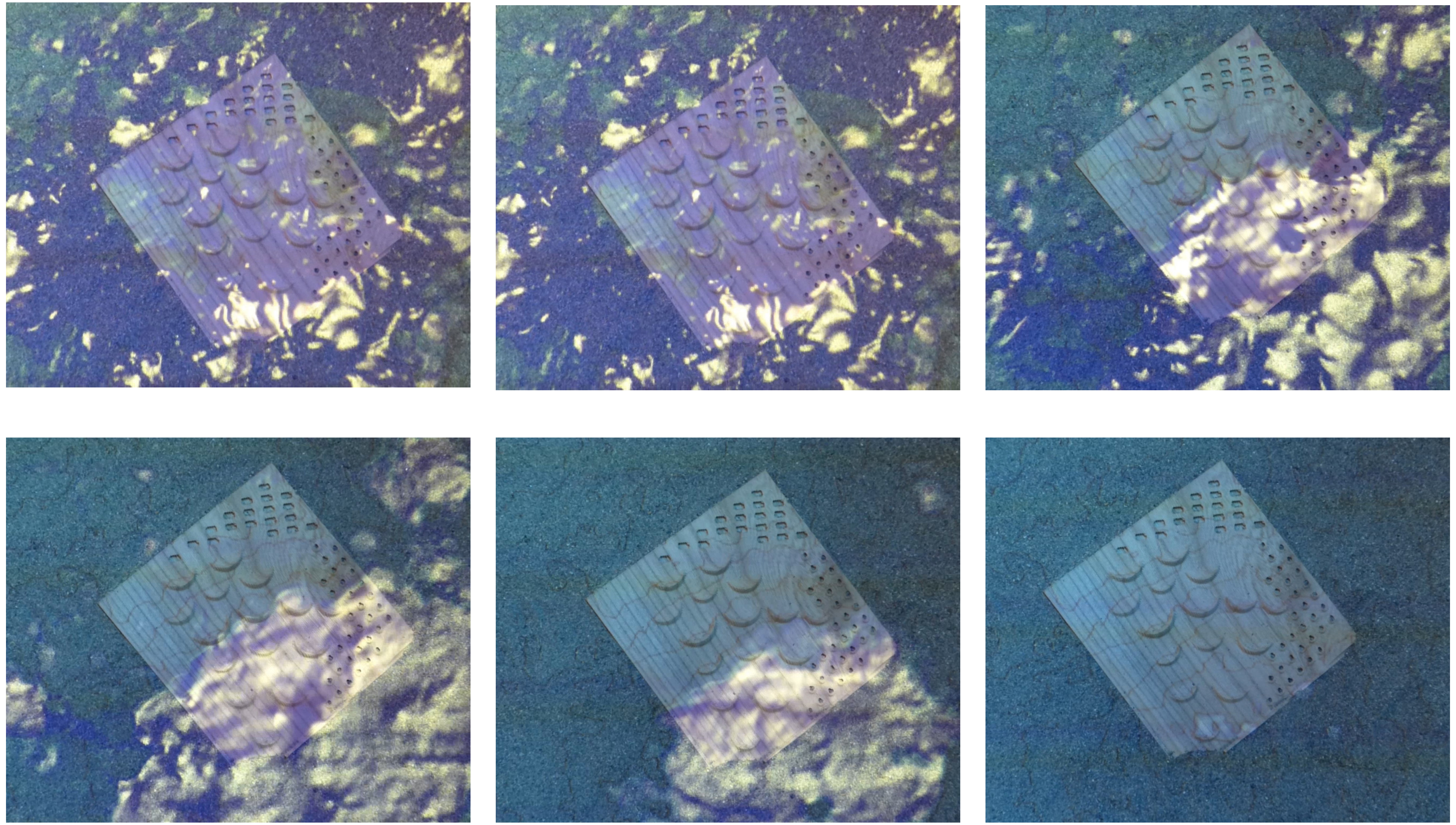

Figure 5.9. Flood simulation in Augmented Reality sandbox. Contour lines were projected into the surface of the model, which was placed downslope of a large mound to simulate water runoff down a slope. The simulation's resolution offers limited information.

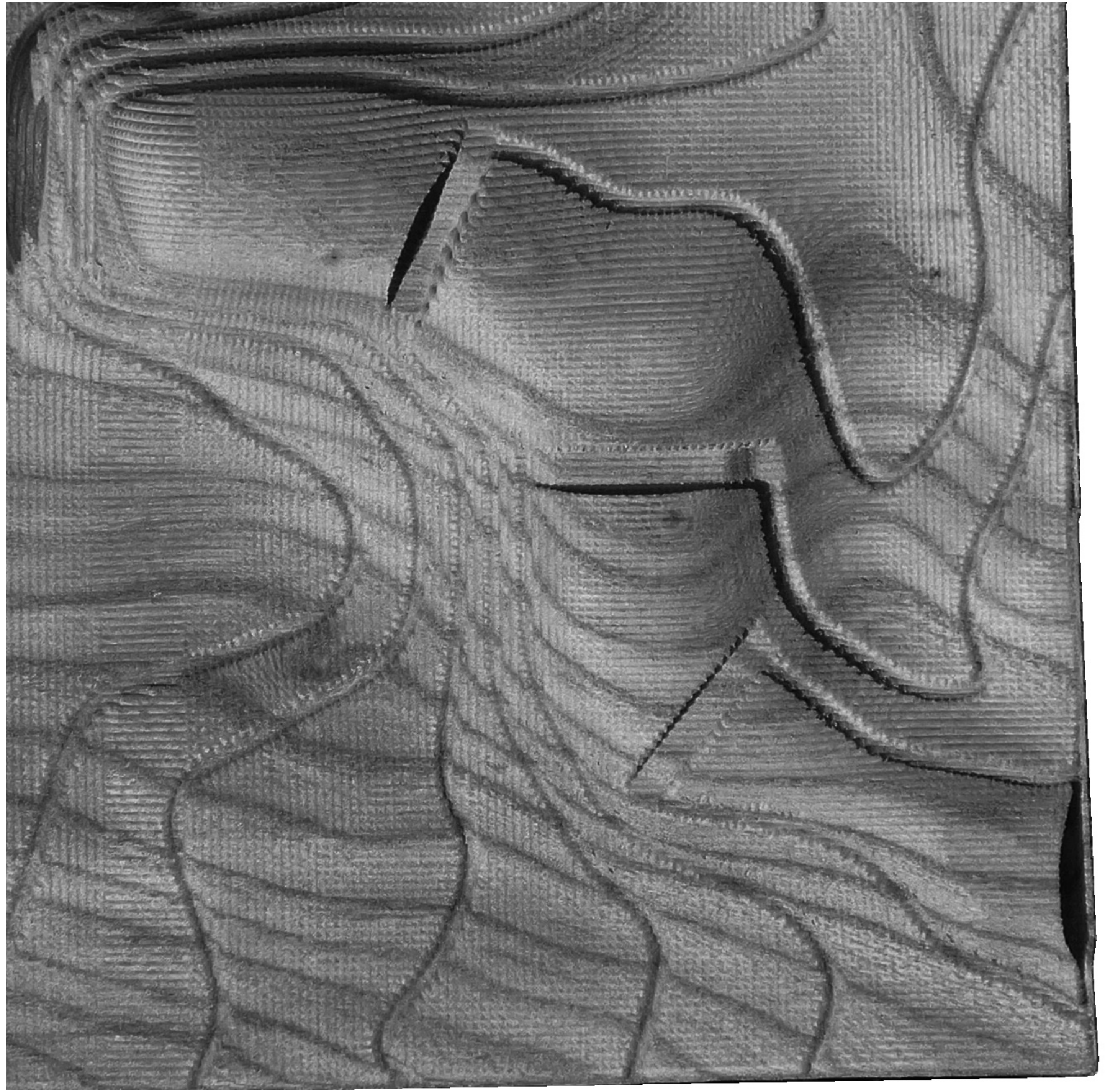

Figure 5.10. Wadi, contour bunds, and jessour. CNC-routed English Elm.

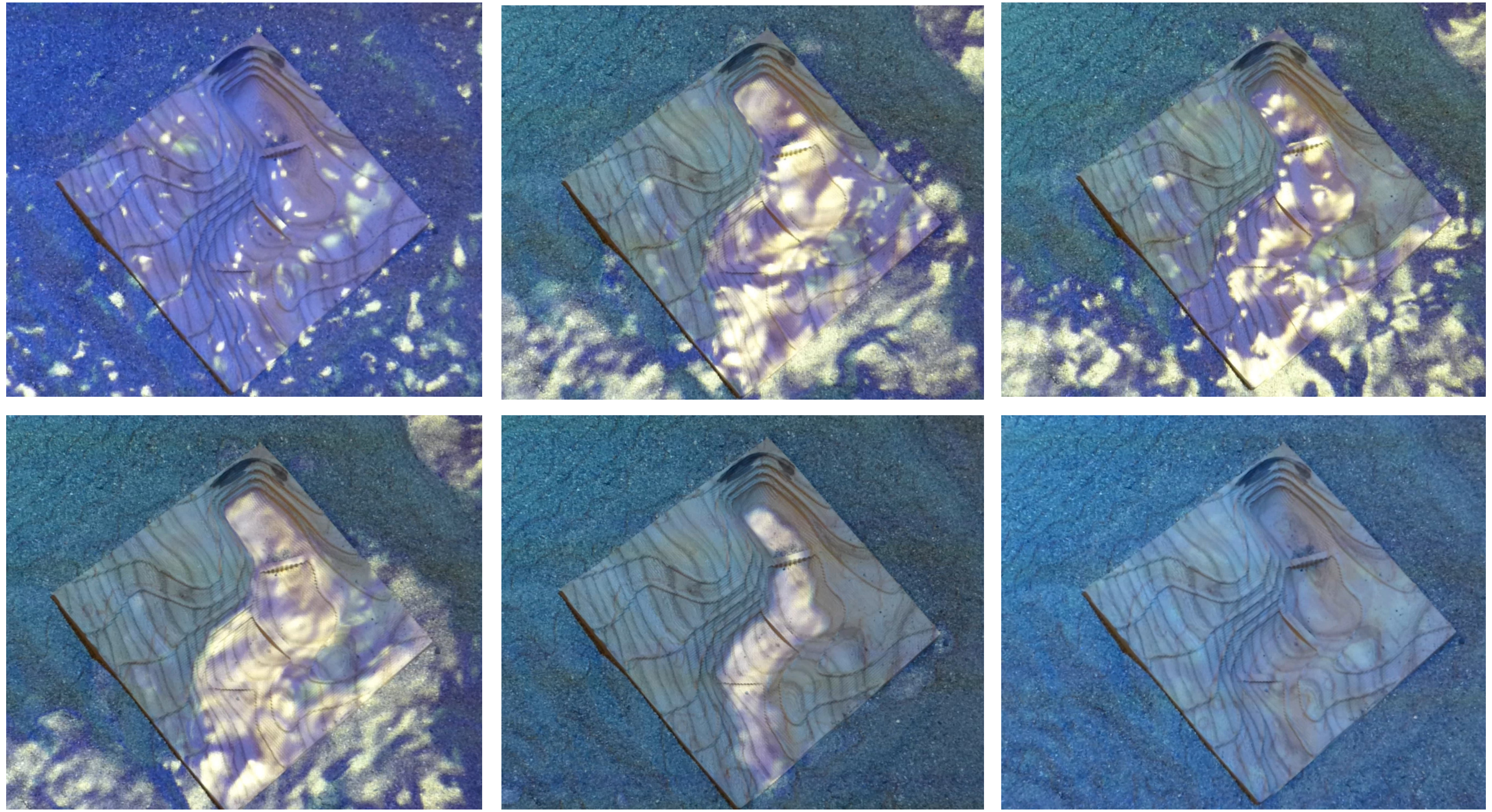

Figure 5.11. Flood simulation in Augmented Reality sandbox. Contour lines were projected into the surface of the model which was placed downslope of a large mound to simulate water runoff down a slope. Water is most visible collecting in the valley and behind check dams, but the simulation's resolution offers limited information.

FABRICATION

Figure 5.12. Reclaimed English Elm being carved on a CNC router. Creating each model required multiple passes with the tool to refine landscape features.

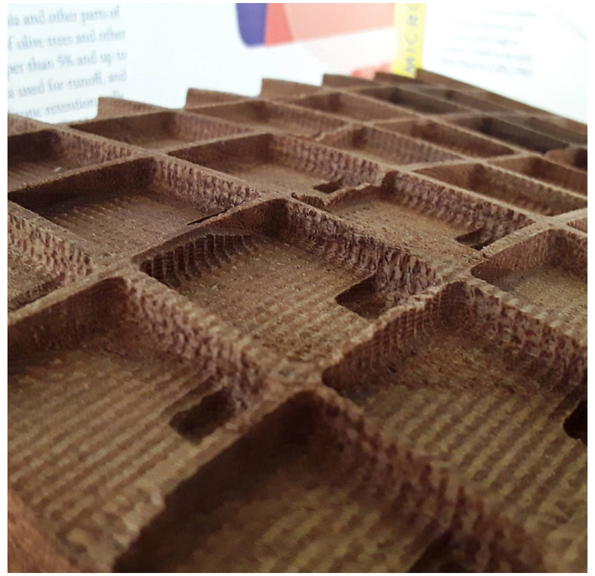

Figure 5.13. Details of completed models.

FLOOD SIMULATION

Figure 5.14. The physical models were placed in an Augmented Reality Sandbox and run through a surface flow simulation to imitate the effects of flooding. The results visualized aspects of surface water movement through each model.

FLOOD SIMULATION

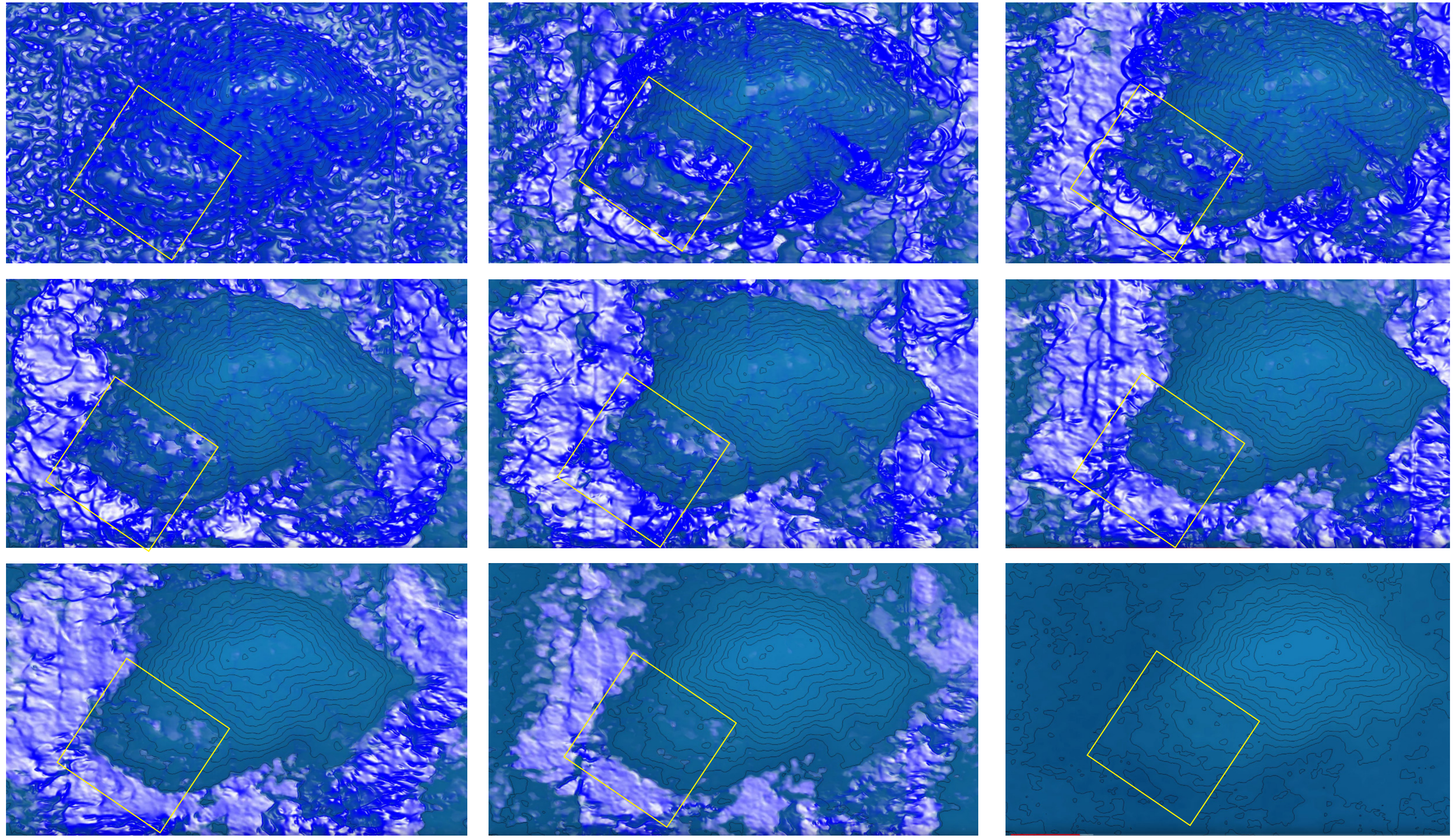

Figure 5.15. Flood simulation software analysis of meskat, computer view. This visual indicates where water lingers on the model's surface. The yellow box indicates the location of the meskat model in the simulation.

END NOTES

Critchley, Will, Klaus Siegert, and C. Chapman. "A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production." Food and Agriculture Organization of the United Nations, 1991. http://www.fao.org/3/U3160E/u3160e07.htm#5.2%20negarim%20 microcatchments.

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FIGURES

(images are my own unless indicated otherwise)

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Figure 5.15. Flood simulation software analysis of meskat. This analysis was completed with each of the physical models but offers limited legible information about performance.

06. CONCLUSIONS

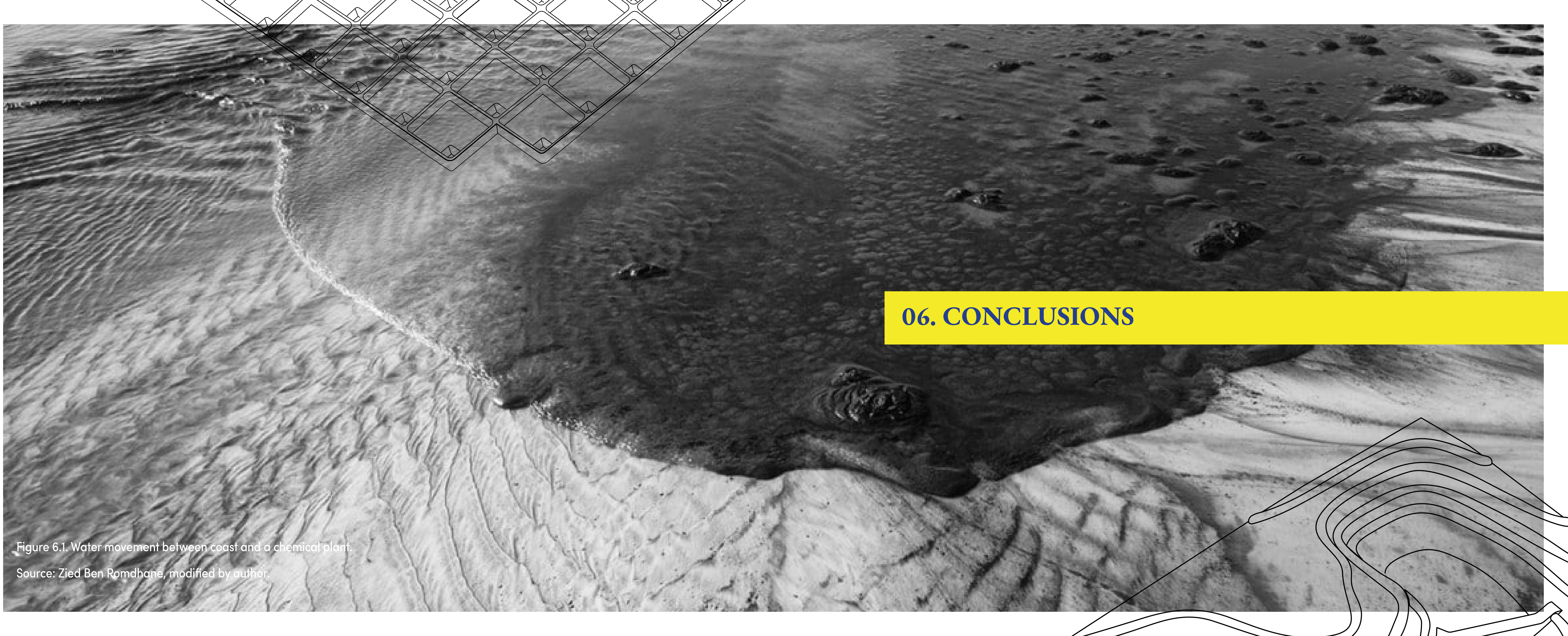

Figure 6.1. Water movement between coast and a chemical plant.

Source: Zied Ben Romdhane, modified by author.

WEAVING INDIGENOUS TECHNOLOGIES INTO THE URBAN FABRIC

"The strict lines of human geometry and production efficiency should be allowed to deform to incorporate, rather than neutralize, biological networks."

– Gary Strang[1]

In this thesis, I have explored sub-systems of a flood, untangling processes implicitly transmitted through colonial history, in order to find alternative approaches to flood response rooted in place. The work in this document is comprised of historical analysis of the built form of Tunis, assessment of existing responses to flood management, and research on and analysis of traditional water harvesting technologies. My intention is to illustrate why the exploration of traditional ecological knowledge addresses shortcomings in urban design and infrastructure as well as ongoing historical harms. Framing the use of traditional infrastructure in the context of colonial landscape alteration underlines that disaster is partially a social construction. Researching from an amalgam of historical sources, maps, technical documents, and physical modeling has been part of my own process of considering how political beliefs and place narratives can factor into a landscape architect's toolkit.

By addressing flooding in the context of interlocked and historical systems, I hope to address ways that water infrastructure can begin to re-align systems that have been disconnected, allowing the natural world to be an ally in mitigating flood's harm. Writing on example of an Inca village ordered around a pre-industrial urban fountain, Gary Strang notes that "the logic of the watershed was evident within the context of the city." Hydrology was not buried, gridded and contained, but rather the defining spatial component of place.[2] A similar logic is evident in the city of Tunis's pre-colonial form.

Examining traditional technologies as flood mitigation tools comes from a very intentional search for examples of human cooperation with physical systems, particularly technologies presently in use. Working with the extremes of an environment over a long timeline depends upon technologies that are adaptive rather than extractive, and approaches that merge cultural resonance with technically efficacy. These methods serve as foundational models not because they call upon nostalgia for traditional society, but because they serve as living reminders that skilful engineering and urban design are neither contemporary nor European inventions. The loss of traditional water infrastructure is part of a process of erasure; uncovering some layers of that process presents an initial step in exploring technologies that are geographically, culturally, and historically appropriate to context.

Though they have a limited presence, traditional water harvesting technologies are not completely absent from Tunisian cities. For example, the *wadi* mentioned earlier are still utilized in both urban and rural areas as an intentionally maintained traditional flood diversion method. And the Medina of Tunis, with its street runnels, structurally integrated impluvia, and rooftop water harvesting systems, retains intact and often functional hydrological adaptation in the urban form. Still, the majority of methods examined in this text are considered primarily rural and agricultural. The particular techniques used in North Africa have few available precedents for contemporary applications in urban settings, yet they provide effective experimental approaches to managing urban run-off at many scales.

DEPLOYING A NETWORK OF RESPONSES

Re-inserting a multitude of rainwater harvesting approaches into the city is a tactic to reintroduce water to its familiar paths, drawing upon existing precedent for climate adaptive design within North African urban form. Integrating traditional technologies like gridded microcatchments, zai, or meskat into the toolbox of green stormwater infrastructure presents the possibility of infrastructural approaches that perform in their context or create a more place-appropriate foundation for further experimentation and innovation. Suitable as part of a flood response systems, networks of small-scale water harvesting also facilitate a more holistic relationship between urban settlement and ecology. The methods examined in this thesis produce stacked co-benefits, supporting soil fertility, creating conditions for vegetation to establish successfully, and encouraging hydraulic recharge of groundwater. These qualities are useful in a productive agricultural landscape as well as one oriented towards stormwater management and flood mitigation in an urban floodplain.

Whereas dams provide a single, large solution that has the potential to fail catastrophically, small-scale decentralized networks are versatile: the failure of one component can be absorbed by another component. Decentralization produces redundancy in a system, with the integration of new systems reducing water management stress on existing infrastructure. Deployed as a network, they become assets in the interim between storm events.

Moreover, small-scale deployment of water harvesting technologies can adapt to sites within the city in which rural and pastoral lifestyles and livelihoods already abutt rapid urbanization -- for example, pastoral herders often graze their herds on public lands between highways in the city of Tunis (Fig. 6.5). As an existing juncture of rural and urban life, these marginal sites present an opportunity for integrating methods that produce fodder crops more successfully while slowing water runoff.

In this thesis, specific placement and design of water harvesting systems has not yet been considered. Future work would involve considering the placement and utility of various technologies in flood-prone areas of Tunis, weaving together threads of place narrative and technical response. This part of the process requires a closer relationship to site than possible when researching from afar. However, sites of significant anthropogenic changes in the built environment and historic form of the city of Tunis present opportunities for strategic water capture and stacked co-benefits. (Figures 6.2-6.5)

OPPORTUNITY SITES:

Figure 6.2. Avenue Habib Bourguiba is a monumental axis of the city built almost entirely atop paved marshland. Paved walkways, medians, and sidewalks present ample opportunities for creating openings in the urban fabric to reintroduce water

Figure 6.4. Flower Market, Avenue Habib Bourguiba. This stretch of flower sellers, located at the eastern end of Avenue Habib Bourguiba, just before the TGM train station, on paved sidewalks along the street and in proximity to a paved median.

Figure 6.3. This highway overpass divides Avenue Habib Bourguiba, creating large swathes of paved area beneath the autoroute infrastructure. Currently decorated with painted columns and often informally used, this presents a long stretch of usable area for water collection.

Figure 6.5. Pastoral herders grazing animals on public lands along autoroutes are a frequent sight in the city of Tunis, often because herders have been displaced or are unable to graze animals on designated conservation lands. Highway embankments and marginal public lands can be grazing areas and stormwater infiltration sites.

MAINTENANCE

Technologies examined in this document, as models drawn from rainfed agriculture, are typically embedded in a web of social relationships out of necessity. In a decentralized system of water management, maintenance is historically grounded in a community structure. Often, this communal structure factors into a system's resilience in extreme events. For example, evidence of communities in Southern Tunisia rebuilding in the aftermath of 1979 flooding indicates the quick response rate of community-driven restoration of damaged structures. *Jesr* and *tabia*, indigenous systems constructed within *wadi*-beds for water spreading and agricultural cultivation were reconstructed more rapidly than larger centralized systems in the region, allowing the surrounding community to return to reliable farming techniques quickly after the floods.[3]

This example is in contrast to one component of the events that prompted this research -- the neglect of *wadi* in cities that experienced flash flooding. In the public eye, lack of municipal maintenance left debris-filled *wadi* unable to sweep away flood waters as intended. While the role or failings of the municipality are difficult to trace without more information, the question raised by comparing maintenance structures is a significant one.

Disaster recovery of all shapes and forms is often most successful with a robust community structure. In exploring community flood risk reduction, McCallum et al. write that small-scale, decentralized systems are effective both pre- and post-disaster for purposes of recognizing local expertise and particular vulnerabilities, responding to disasters in a lightweight and flexible manner, and using past data and experience to better prepare for future events.[4] They suggest relying on participatory mapping, trust-building, community knowledge-based planning practices, and "pro-active" and "re-active" responses. These methodologies counter earlier approaches that do not adequately approach the types of granular knowledge that support long and short-term resilience in the face of disasters. Structures alone, whether they are stone check dams or gargantuan cement dams, cannot replace a social structure of preparedness for unprecedented shocks.

Implementing an earthwork without the structure of social relationships around it presents a significant challenge or breaking point in considering the application of traditional water harvesting approaches in the context of urban green stormwater infrastructure. If, for example, the municipality were to maintain microcatchments or jessour, would it deviate from a framework of traditional ecological knowledge? What is the relationship between the use of traditional technologies and those who have been displaced from land where they might have maintained systems like these? What relationship can a city-dweller encompassed in a different socio-political framework have to water infrastructure? These questions are open-ended, and can only truly be addressed in context.

HYBRIDIZATION

The nature of contemporary urbanization and the unprecedented scale of contemporary storm events also raises the question of whether or not traditional technologies can function as intended. The International Center for Agricultural Research in the Dry Areas (ICARDA) offers some models for contemporary use of traditional technology. ICARDA's research on rainwater harvesting looks to approaches for hybridization of traditional and contemporary water harvesting techniques, recognizing that with a changed climate and social structures, certain methodologies may not work as intended. Possibilities for modernizing technologies are numerous, ranging from using a laser-guided plow to dig furrows along accurate contour lines, to utilizing surface treatments of soil to improve rates of runoff capture within rainwater harvesting earthworks.[5] These approaches typically address efficiency of labor, maintenance, or water redirection, but do not explicitly reference more intense storms or the storage of more precipitation.

Not only do urban settings necessitate a level of transformation, but a changed climate manifests in erratics. Despite being drawn from contexts with climate extremes, it is likely that any traditional technology would require a level of hybridization to current conditions. Earthworks and topographical manipulations may have to be merged with contemporary technology, requiring experimentation as well as shifts in usage. For example, an urban wadi might tie into a conventional urban sewer system, or new materials, such as re-purposed concrete, might be assembled utilizing traditional engineering methods.

NEXT STEPS

In researching water stress in Tunisia it is impossible to ignore the way that institutional politics or centralized measures neglect rural populations, and the ways that pastoral or subsistence agricultural lifestyles are pushed further into the margins. This work does not address the question of potable water, which is a severe concern in Tunisia, nor how climate change continues to create barriers for pastoral and subsistence-based communities to continue their lifestyle. Nor is it a holistic assessment of disaster response, or a claim that small-scale technologies are a complete response to flash flood risk. Rather, this work is an earnest exploration of a site history and series of technologies that I consider beautiful, technically rigorous, and brimming with potential for the transformation of urban sites.

The neglect of place-based appraoches in discourse around ecological engineering and green infrastructures implies that approaches based in traditional ecological knowledge have been evolved out of use, relegating them to the realm of primitive and quaint technologies. As I hope to have shown in this text, these approaches continue to be valuable in a changing context and climate. By proposing components for a network of small interventions, I hope to challenge the idea that the only appropriate way to respond to water stress and the threat of flooding is with large infrastructure or costly solutions designed in a western context.

The field of landscape architecture can re-shape the in-between spaces of urban life more intentionally, building nodes and non-heirarchical networks of ecological health. Landscape interventions are sub-systems in larger place-narratives, requiring ongoing dynamism and adaptation. Responding to ongoing climate disaster necessitates drawing upon a more expanded toolkit of technologies and methodologies, and a more rigorous engagement with assumptions in our profession. I hope that in future explorations of water infrastructure, disaster resilience, and the integration of traditional ecological knowledge into climate adaptation, landscape architects will prioritize an ability to research, look, and listen carefully as much as an ability to imagine and visualize. The work of climate resilience is inextricably bound up with a process of decolonization -- not only of political systems, but of landscapes and minds.

Figure 6.7. There are many more agricultural and water harvesting methods to explore. This technique was seen in Ghar el Melh, Tunisia in 2017.

END NOTES

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2. Ibid.

3. Hill, Jennifer, and Wendy Woodland. "Contrasting Water Management Techniques in Tunisia: Towards Sustainable Agricultural Use." Geographicalj The Geographical Journal 169, no. 4 (2003): 342–57.

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FIGURES

(images are my own unless indicated otherwise)

Figure 6.1. Figure 6.1. Water movement between coast and chemical plant. Source: Romdhane, Zied Ben, and Kenneth Dickerman. "Tragically Beautiful Images Show the Effects of Phosphate Mining in Tunisia." Washington Post, June 27, 2016, sec. In Sight. https://www.washingtonpost.com/news/in-sight/wp/2016/06/27/tragically-beautiful-images-show-the-effects-of-phosphate-mining-in-tunisia/.

Figure 6.2. Avenue Habib Bourguiba. Source: Wikimedia Commons

Figure 6.3. Beneath autoroute overpass, Tunis downtown. Source:

Figure 6.4. Flower Market, Avenue Habib Bourguiba. Source: https://i.pinimg.com/originals/4e/d2/d2/4ed2d235e7daca2628415171c4482727.jpg

Figure 6.5. Pastoral herding along autoroute. Source: Tycho Horan.

Figure 6.6. Agricultural technique, unknown, Ghar el Melh, Tunisia.

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