ENCOURAGING FLOOD-RESILIENCE IN OCMULGEE NATIONAL MONUMENT, MACON, GEORGIA

by

ZONGYING PENG

(Under the Direction of Alfie Vick)

ABSTRACT

With global warming and extreme weather, flooding has been an increasing problem in many urban cities. Within the scope of a highly urbanized city, there is limited open green space that could be designed for flooding protection. Ocmulgee National Monument, in Macon, GA, is an important cultural heritage site and a natural floodplain, and it experiences periodic flooding. Applying the flood resilience concept and GIS technology, this thesis analyses the hydrological dynamics of Ocmulgee National Monument and recommends intervention that can help mitigate urban flooding issues in this area while incorporating aesthetics, and thereby preserving the cultural heritage. Exploration was conducted through two case studies and projective designs.

INDEX WORDS: flood-resilient, flood-resistant, sediment, erosion, Ocmulgee National Monument

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CHAPTER 1

INTRODUCTION

Ever since Hurricane Sandy wrought havoc on the East Coast, “Resilient Design” has become a critical topic worldwide. According to the Resilient Design Institution, *“Resilience is the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance”* (Resilient Design Institute, 2019). Working with nature rather than opposing it helps communities become more resilient after disruptive natural events. One of the most frequent disasters is flooding, and there are many flood-resilient landscape planning and design strategies that can help communities adapt to climate change. Practice and research indicate that open spaces and parks can manage rainfall flooding in a way that mimics nature or stores excess water for later use.

1.1 Problem Statement

Inland Flood

Flooding is the most frequently occurring natural disaster globally and contributed to 43% of natural disasters from 1995 to 2015 (Centre for Research on the Epidemiology of Disasters). Inland flooding is the result of stormwater runoff that causes stream flow (discharge) to spill out of the channel and into the floodplain. The Third National Climate Assessment reports that the risk of inland flooding has increased as extreme precipitation events have increased across the United States over the last three to five decades (Schwarz, et al, 2014). Changes in land use also contribute to the increased inland flooding (Watson and Adams, 2010). Thus, cities with heavily modified landscapes are vulnerable to flood hazards.

Macon, GA

Macon, Georgia, located near the fall line along the Ocmulgee River, experiences large flood events. It has a humid, subtropical climate with an average annual precipitation of 45.7 inches (1,160 mm). Recorded flood events in Macon date back to 1910 (Carter and Geological Survey, 1951). The following table provides a list of major floods of record, based on flood crests, recorded for Macon, GA (National Weather Service N.D.). The worst flood in Macon's recorded history occurred in July, 1994 with Tropical Storm Alberto. The Macon levee was breached at 34 feet, flooding the Georgia State Fairgrounds area. Portions of Interstate 16 and 75 in Macon were flooded and closed. Figure 1.1 illustrates the historic crests of the Ocmulgee river in Macon from 1880 to 2018. It shows a increase in frequency of moderate to large floods. Figure 1.2 shows the historic flood frequency of the Ocmulgee River in Macon. Figure 1.3 shows the annual peak streamflow of the Ocmulgee River in Macon (U.S. Geological Survey, 2018).

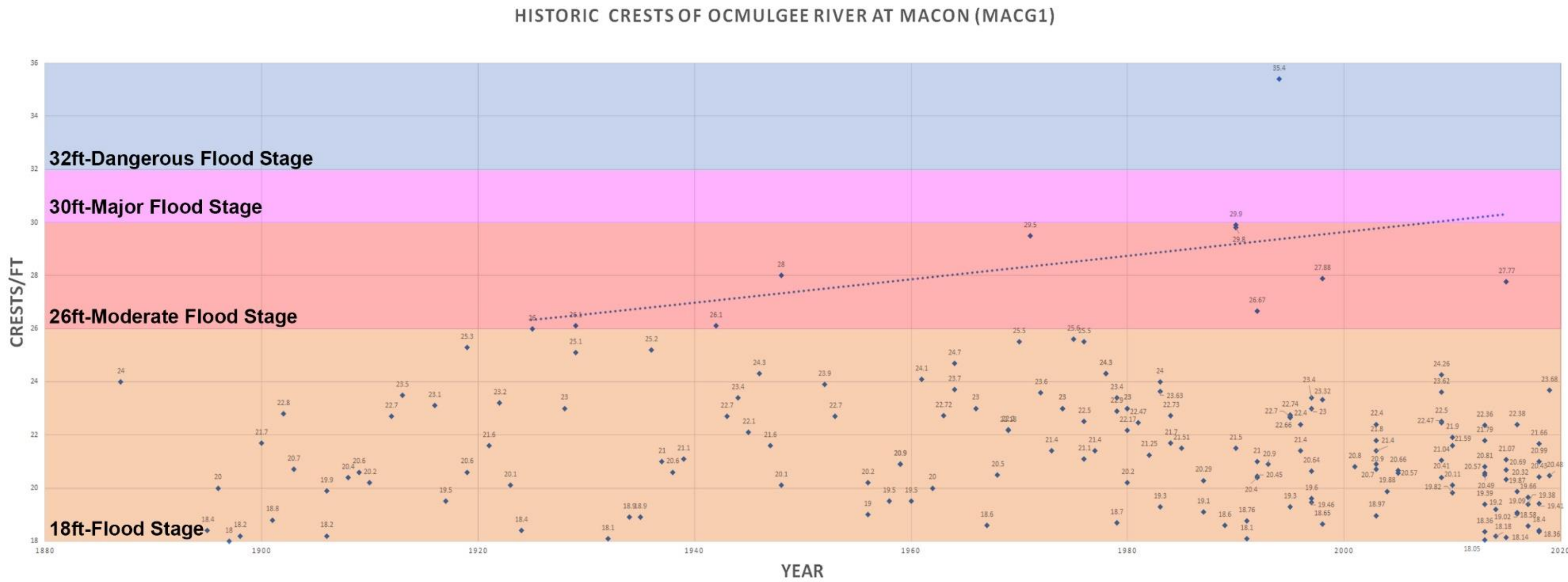


Figure 1.1: Historic Crests of Ocmulgee River in Macon showing an increase in frequency of large floods (made by author, Source: National Weather Service Peachtree City/Atlanta Weather Forecast Office)

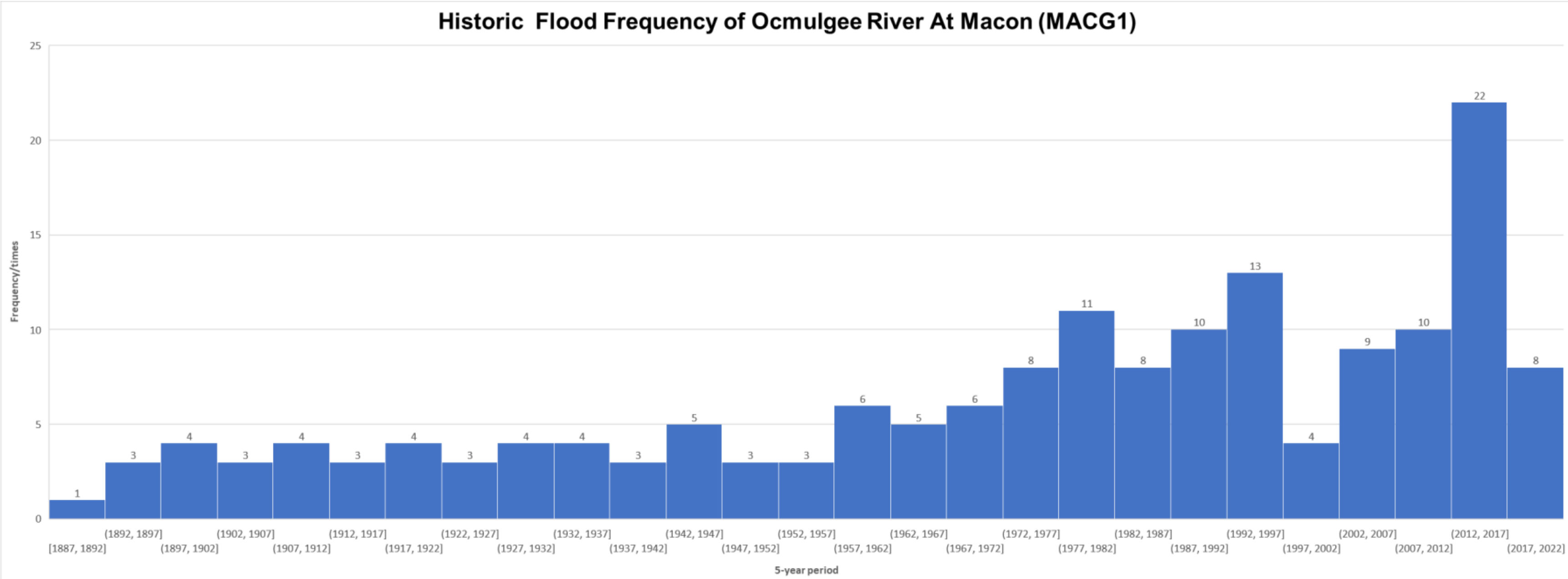


Figure 1.2: Historic Flood Frequency of Ocmulgee River in Macon (made by author, Source: National Weather Service Peachtree City/Atlanta Weather Forecast Office)

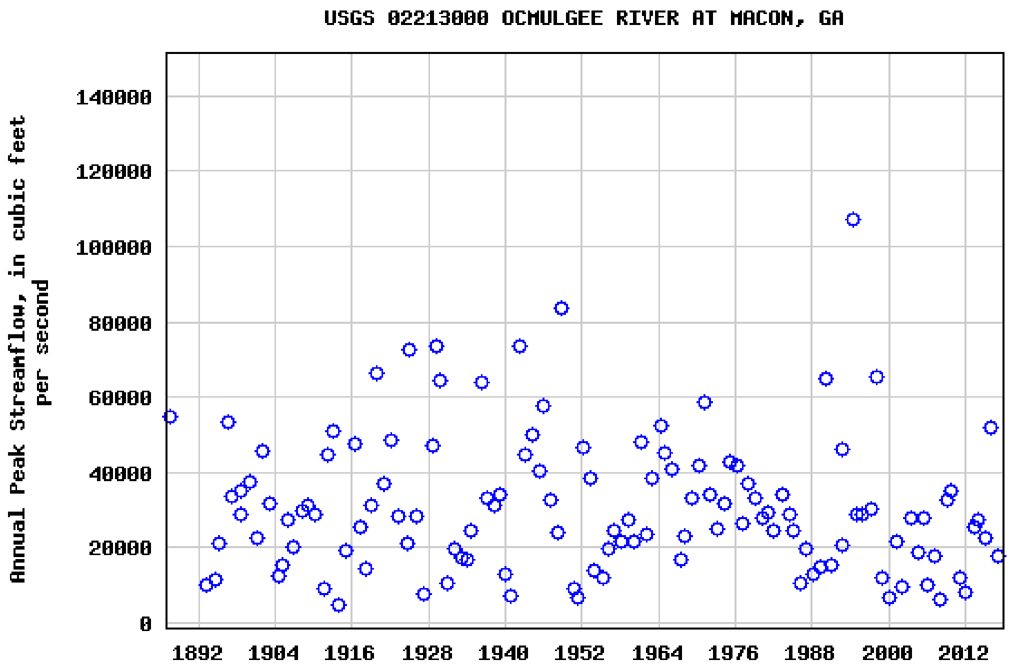


Figure 1.3: Annual Peak Streamflow of the Ocmulgee River in Macon (U.S. Geological Survey, 2018)

Ocmulgee National Monument

The Ocmulgee National Monument (OCMU) in Macon, Georgia, lies in the floodplain of the Ocmulgee River, preserving traces of over ten millennia of Southeastern Native American culture. This invaluable heritage site includes a burial mound and other ceremonial mounds, and also defensive trenches, representing highly skilled engineering techniques and flood knowledge. Partially on the 100-year flood zone, OCMU experiences periodic flooding and has to close its boardwalk over the River Trail during flooding (National Park Service, 2019). With the recent construction of the Ocmulgee Heritage Trail extension and the approval of funding to triple the size of the park, there are more opportunities for OCMU's future development. This thesis explores how to increase the resilience of the site to flooding.

1.2 Research Questions, Significance, and Methodology

The thesis attempts to answer these functional goals:

- How does the floodplain in OCMU accommodate large flooding?
- How can trails and other infrastructure in the OCMU remain usable during the flooding?
- How can the OCMU reveal the flood dynamics to the public and educate them?

To date, there is little research related to flood inundation of the OCMU. The findings of this study will benefit the OCMU, the local economy, and the residents of Macon, as well as preserve and protect local cultural and natural resources. In addition, a floodable park that is designed to accommodate periodic flooding can function both for flood hazard mitigation and recreation (Tuan Anh Le, Kien V. Nguyen, 2016).

This study uses a literature review, two case studies, and a projective design as the main research methods. The two case studies are discussed, compared, and evaluated. In addition, a projective design for the OCMU is developed and evaluated.

1.3 Limitations and Delimitations

The study has potential limitations. While the thesis only applies flood-resilient strategies within the limited boundary—the Ocmulgee National Monument, flood-resilient design can achieve best results when implemented for the whole watershed. Although funding has recently been approved to enlarge the park, this thesis is limited to the current (as of 2018) boundary. Lastly, the design for the Ocmulgee National Monument is limited since it is a preserved national park. The priority of the park management is to preserve rather than to develop. So, drastic modifications to encourage flood-resilient are not suitable for the site. Although flood-resilient design usually comprises protection of people, buildings and facilities in vulnerable settlements, and planning to encourage new development in safer areas (EPA, 2014), my research is more focused on the overall strategies to enhance flood resilience, such as the conservation of land, the discouragement of development in river corridors, and the implementation of stormwater management techniques. Additionally, this projective design will take into consideration only site-specific factors in the OCMU; however, the framework will be useful to a wider audience.

1.4 Thesis Structure

Chapter one explores background information about the thesis and the design site. Chapter two contains an overview of the literature related to the thesis question and defines the difference between flood-resilient design and flood-resistant design. A framework is developed from previous studies and evaluates flood-resilient design according to five aspects: soil health, water health, plant communities and animal habitats, infrastructure and management, and environmental education. Chapter three investigates two case studies chosen for their resilient design features: the first one is Mill Race Park, Columbus, Indiana; the second one is Yanweizhou Park, China. Chapter four contains the analysis of the site and some inventories. Chapter five explores the proposed applications of a flood-resilient system in the OCMU. As a design thesis, the chapter includes a site-specific flood-resilient design for the Ocmulgee National Monument and an evaluation of the design through a framework created by the author. Chapter six concludes with major findings and suggestions for improvements for flood-resilient design at the site and offers suggestions for further research. This process will help address the focal question of the study: how to encourage flood resilience in the OCMU and mitigate flood damage in downtown Macon.

CHAPTER 2

LITERATURE REVIEW

2.1 Interpretations of Resilience

Resilience is defined as “the act of rebounding or springing back and elasticity” in the Oxford English Dictionary. It originated from the Latin word “*resilio,*” which means to jump back (Klein, 2003, 35-45). Ever since ecologist Crawford Stanley (Buzz) Holling introduced the concept of resilience into ecology in the 1960s, it expanded its connotation and was applied to various fields of study like ecology, social ecology and aquatic ecosystem, etc. Holling defined resilience as “a measure of the ability of these systems to absorb changes and still persist” for an ecosystem (Holling, 1973). This concept later developed into *ecological resilience*, which means “the amount of disturbance that an ecosystem could withstand without changing self-organized processes and structures” (Gunderson, 2000).

Other scholars defined resilience from other perspectives, such as how long it takes for a system to recover from a disturbance, which later formed the concept of “*Engineering Resilience*” (Fiering,1982; Hashimoto, at,1982). The twofold definitions of resilience are related to the system’s condition and disturbance: *Engineering Resilience* refers to the time needed for the system to become balanced again after the disturbances; *Ecological Resilience* suggests the amount of perturbations a system can absorb before it changes its structure (Holling et al. 1995). *Ecological Resilience* reflects the idea that an ecosystem has multiple stable conditions, while engineering resilience implies that an ecosystem has only one stable condition (see Fig. 1).

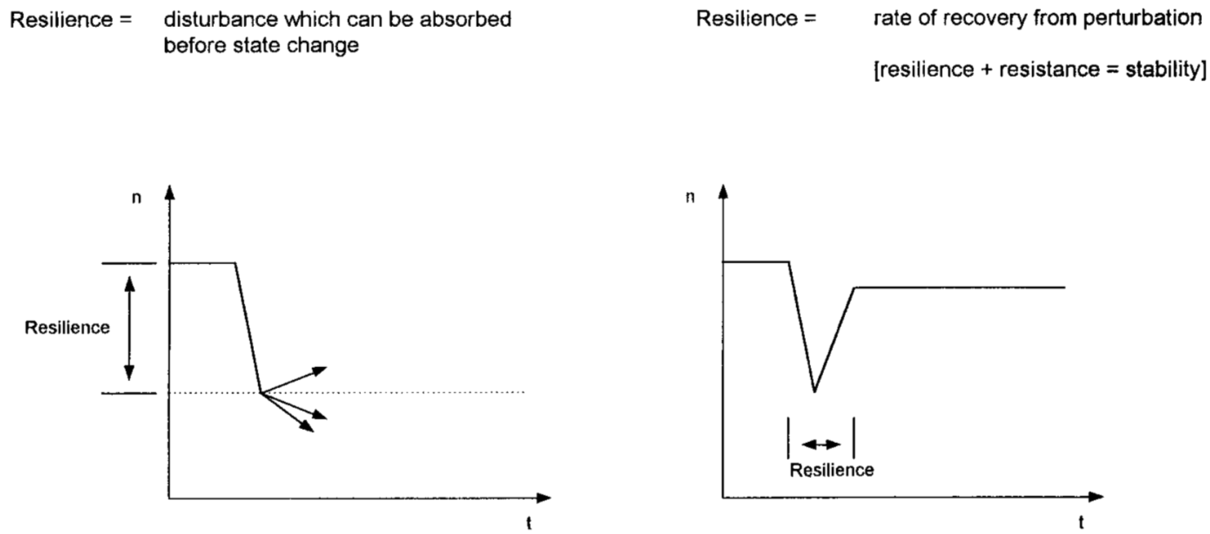


Figure 2.1: Ecological Resilience (left) and Engineering Resilience (right) (Adger, 2000).
Source: https://journals.sagepub.com/doi/pdf/10.1191/030913200701540465

The concept of *Social Resilience* derives from ecological resilience thinking. Adger notes that social resilience is "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change" (Adger, 2000; Adger et al. 2000). The Resilience Alliance (2007) defines resilience as the extent of "change or disturbance" that a system can suffer without turning into an alternative condition that has various structural and functional properties and provides diverse ecosystem services that benefit people. These services are defined as "the benefits derived from ecosystems, including provisioning, regulating, cultural functions, and supporting services" (Resilience Alliance, 2007). Other definitions that also include social resilience focus on the ability of a system to absorb perturbations (Holling et al. 1995), the speed of recovery from a disturbance (Adger, 2000), and the ability of a system to self-organize, learn, and adapt.

There are three essential key words and concepts corresponding to the three aspects of resilience: (1) Ecological resilience-- against regime change; (2) Engineering resilience-- response and recovery after disaster; (3) Social resilience-- adaptive capacity and management. Table 1 illustrates and compared these three aspects (Wang, Blackmore, 2009).

Table 1: Comparison Of Three Aspects of Resilience Connotation (Folke, 2006; Wang, Blackmore, 2009)

Aspects of resilience	Ecological resilience	Engineering resilience	Social–ecological resilience
Connotation	Resilience against regime change	Resilience for response/recovery	Resilience for adaptive capacity/management
Definition	Magnitude of disturbance that can be absorbed by an ecosystem without flipping into an alternative state	Speed or rate of system recovery after disturbances	Ability to preempt and avoid major disasters in institutions
Objectives	Positioning the system in a favorable state (original or alternative)	Returning the system to an operational status in the original regime	Reducing incident and accident occurrences, and impact if occurred
Emphasis	Persistence, change, unpredictability	Efficiency, constancy, predictability	Proactively monitoring the effects of existing management and operational approaches
Controls and factors of Concern	Slow and fast variables	Slow and fast variables	Management and operational variables
Focus on disturbance	The magnitude of disturbance	Low-frequency, high-impact disturbance	Disturbance from organization and operation
Assessment	Mainly qualitative	Mainly quantitative	Rules and operational procedures

Based on the analysis of the concept development of resilience with its different aspects and connotations, it is easy to identify the characteristics of the three aspects of resilience: (1) similarity: all assume the system is in a stable state prior to the disturbance; (2) difference: ecological resilience highlights the resistance (the ability to absorb disturbance) and restoring ability (the speed for a system to recovery into a stable state), while social–ecological resilience covers a system's ability to self-organize, learn, and adapt. Also, a system's stable state develops into multiple ones, and the stable states are variable (Yu, 2005).

2.2 Related Concepts

Resilience is often confused with vulnerability and adaptability. To avoid confusion, the definitions used for these concepts in this thesis are explained and the relationships between those concepts and resilience are discussed. According to Engle (2010), the framework of vulnerability and resilience are linked through the concept of adaptive capacity. His claim was developed from Cutter and his associates (2008), where the authors present a similar overlapping framework. The relationship of these three concepts are shown on the Figure 2.2.

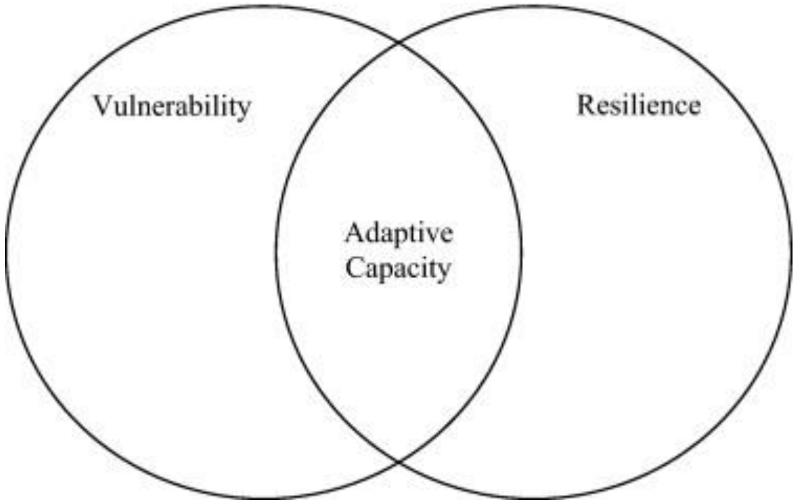


Figure 2.2: Relationship between Resilience, Adaptability and Vulnerability (Engle, 2011)
Source: https://ars-els-cdn-com.proxy-remote.galib.uga.edu/content/image/1-s2.0-S0959378011000203-gr3.jpg

2.2.1 Vulnerability

According to Eakin and Luers (2006), *vulnerability* can be broadly defined as "susceptibility to damage or harm," and its development is affected by risk-hazard research, food safety, and political ecology. It is defined as the opposite of resilience, where resilience is the capacity of a system to endure interruption and retain its functions and controls (Carpenter et al. 2001). Although the concepts of resilience and vulnerability have something in common, Bruijn notes that they are applied separately in the urban water source system: resilience and resistance describe how the system responds to the interruption or disturbance, while vulnerability frequency is applied to social systems but also applied to a natural ecological system. In addition, these two concepts originate differently: resilience is derived from stability theories and theories on system dynamics, while vulnerability is mostly used in social science (De Bruijn, 2005). Table 2 illustrates the links and distinctions between them.

Table 2: Links and Distinctions between Resilience and Vulnerability (De Bruijn, 2005; Nelson et al. 2007; Cutter et al. 2008; Engle, 2011)

Links and Distinctions		**Resilience**	**Vulnerability**
Links	Both have a relationship with *resistance*--adaptability is the bridge that links these two concepts		
Distinctions	Origin	Stability theories and theories on system dynamics	Social science
	Reflection on system	How to respond to a disturbance	Why respond in a certain way
	Connotation	Resistance, recovery	Resistance
		Emphasis on social-economic system interaction, feedback and process	Policy
	Major Applications (social-economic system)	Ecology/ environment	Society

2.2.2 Adaptability

A good example of the concept of adaptive capacity arose from the context of climate change and can be seen as an umbrella concept (a term used to cover a broad category of things rather than a single, specific item), while resilience is a factor affecting adaptive capacity (Klein et, al., 2003). The Intergovernmental Panel on Climate Change (IPCC, 2001) defines *adaptation* as natural or artificial adjustment process in response to actual or expected climate stimuli and their effects or impacts. In the study of an urban water source system, *adaptive capacity* is described as *adaptability*, which is the capacity of actors in a system to manage and affect resilience (Walker et al. 2009). When facing the stress brought by climate change, a system with higher adaptability tends to have more resilience. The study of resilience also defines *adaptive capacity* as the features of system that helps it transform, which means a system transforms into a more desirable state when the current system cannot sustain the disturbance (Folke, 2006). The links and differences between resilience and vulnerability are shown in Table 3.

Table 3: Links and Differences between Resilience and Adaptation (Vogle,1998; Klein et al. 2007; De Bruijn, 2005)

Links and differences		**Resilience**	**Adaptability**
links		When facing the stress brought by climate change, a system with higher adaptability tends to have more resilience. It's more possible for a complex adaptive system to transform into a different desirable state	
differences	Concept	One factor influences adaptability	It arose from the context of climate change and can be seen as an umbrella concept
	Disturbances	Short-term	Long-term/ continued
	System characteristics	Internal features	External expression

2.3 Flood-resilient Landscape Fundamentals

Based on the existing research, a flood-resilient landscape can be defined by five characteristics: water health, soil health, plant communities and animal habitats, infrastructure and management, and environmental education.

Water Health

The hydrology of a watershed can influence the impact of flooding and further impact the flood resilience of the watershed. For example, the relation between the duration of the storm and the size of the stream basin where the storm occurs has a direct impact on the local flood hazards. Besides, existing conditions of a watershed (like soil moisture) prior to the storm can influence the amount of stormwater runoff into the stream system (Robinson, Hazell, and Young, 1998). The concentration, runoff rate, water quality, and volume of a watershed should be analyzed prior to significant human alteration (Crabtree, 2011).

Soil Health

A floodplain near an urban center can experience soil degradation and a high frequency of flash floods. Geomorphology, the complex system of soil properties, and previous land use all contribute to accelerated soil erosion and runoff, with all its negative impacts on the area. Soil erosion caused by water and frequent extreme hydrological events, together with the soil's decreasing ability to retain water, make soil health a critical issue.

To improve soil health in the floodplain, conventional measures like soil erosion controls and flood prevention strategies in a watershed decrease the erosion rate, but are not able to restrict a surface runoff substantially (Miroslav Dumbrovsky and Svatopluk Korsuň, 2012). Institutions, including the Natural Resilient Communities, suggest several flood-resilient solutions to soil health problems, and address issues such as a change in land use, topography, geomorphology, population relocation and potential encroachments into the floodplain, upgrades to potential inundated areas that add to the efficiency of the conventional control, and strategies.

Plant Communities & Animal Habitats

Native vegetation in the floodplain represents "hydraulic roughness" and has consequential influence on the flood process. For instance, the overall roughness increases the heterogeneity of flow patterns; dense vegetation diminishes the flood wave and traps sediments during minor flooding; floodplain forests retard the release of floodwater retained on the surface by frictional effect, and therefore, strengthen the storage ability of the floodplain (Tabacchi et al. 2000, Richards and Hughes 2008). However, accelerated urbanization alters the floodplain, introduces invasive plants that can outcompete native species, affecting the resilience of river system which leads to system collapse (Poff et al. 1997, Folke 2003). Thus, river buffers and animal habitats should be designated and preserved.

Infrastructure & Management

Floodable land is able to store or convey floodwater and sediments without incurring damage locally and elsewhere (Liao, 2012). The structures in the floodable land should be flood-proof and require minimal management after flooding. Transportation infrastructure can be directly or indirectly damaged during flooding (Pregnolato et al., 2017). Most roads and trails are unaccessible during flooding, making evacuations of people and properties inconvenient and delaying the delivery of food supplies and medical aids. Sediment hazards like concentrated garbage, debris, and toxic pollutants can also cause secondary effects of health hazards. Moreover, flood waters can produce massive amounts of erosion, consequently weakening and undermining bridges, levees/dykes, and buildings. A flood resilient landscape requires improvements on accessibility of a transportation system and encourages the use of permeable pavement, sediments removal, and conduction of a management plan for critical facilities.

Environmental Education

Although the negative impact of climate change has raised the public's awareness, community flood education programs have generally not been well designed or delivered in an effective manner (Dufty, 2018). According to Dufty, the function of flood education can be conducted in a sequence of four elements: preparedness conversion, mitigation behaviors, adaptive capability, and post-flood learnings. Preparedness conversion refers to starting and maintaining preparations for flood education. Mitigation behaviors refers to education and practices before, during, and after a flood. Adaptive capability refers to learning about changing and maintaining adaptive systems and improving community competencies to mitigate the flooding. Lastly, post-flood learning helps improve preparedness levels, mitigation behaviors and adaptive capability after a flood. A new approach to flood education requires community engagement and encourages ongoing education through local plans.

The Asian Cities Climate Change Resilience Network (ACCCRN) proposed interventions in relation to four resilience framework elements which include infrastructure systems, ecosystems, agent capacities, and institutions (Fig. 2.3).

Figure 2.3: ACCCRN City Proposed Interventions in Relation to Resilience Framework Elements (made by author)
Source: Tyler, Stephen, and Marcus Moench. "A framework for urban climate resilience." Climate and development 4, no. 4 (2012): 311-326.

2.4 Flood-resistant Strategies and Flood-resilient Strategies

The concept of resilience has been applied to water source management early on, and then was introduced into flood risk management. Flood-resilient strategies refer to the approaches that enhance and consolidate the resilience of a system to react to uncertain disturbances and changes (Walker et al. 2004). Bruijn (2005) notes that flood-resistant strategies involve the construction of flood-defense infrastructure such as embankments, outlets, weirs, bypasses, and detention areas etc. In contrast, flood-resilient strategies are aimed at minimizing flood impacts and maximizing recovery rates (the speed a system returns to its former state or former development pattern). Flood resilience strategies are different from traditional strategies. Scholars like Folke (2006), Bowker (2005), Edwards (2009), Choi (2010), Walker (2004), Schelfaut (2011) and others have studied the specific measures and principles of flood-resilient strategies. Bruijn, Vis, Bowker, Zevenbergen and others compared flood-resilient measures and flood-resistant measures and claim that flood-resilient measures are more flexible and adaptable to undetermined changes than flood-resistant strategies. This is certainly advisable given the changing climate and precipitation patterns. Vis, Baldassarre, and other scholars have evaluated the performance of the flood-resilient strategies and the results show that flood-resilient strategies have better long-term effects. Flood-resilient strategies have changed the traditional solutions for flooding that depend largely on flood-resistant strategies, providing a new and systemic solution to solve urban flooding, waterlogging, and drought.

Bruijn and Klijin (2001) compared these two strategies from the perspectives of focus, volume range, and uncertainty (Table 4). Zevenbergen and his associates (2008) discussed the key elements of transitions from traditional strategies to resilient strategies (Table 5).

Table 4: Comparison between Flood-resistant Strategies and Flood-resilient Strategies (modified by author)

Source: Watson, Adams, 2011

	Flood-resistant Strategies	Flood-resilient strategies
Definition	Structural and nonstructural components are durable, resistant to flood forces (including buoyancy), and resistant to deterioration caused by inundation with floodwater	Strategies are aimed at increasing the system property "resilience" by "making space for water" and "living with floods"
Goal	1.Reduce direct impacts 2.Reduce indirect impacts 3.Provide emergency refuge and escape	1. Create structures that withstand flooding, both natural and manmade 2. Provide for rapid recovery
Strategy	Prevention 1. Relocating buildings and community infrastructure out of harm's way Mitigation 1. Raising buildings above anticipated peak flood levels 2. Engineering building structures and envelopes for severe wind and wave impacts 3. Using waterproofed building materials	Adaptation 1. Protect natural features that provide ecosystem services 2. Reduce impervious land cover 3. Control land use 4. Implement floodplain management plans 5. Implement Stormwater management 6. Conduct hazard mitigation plans Recovery 1. Create damage compensation regulations and insurances
Impact	Resist	Absorb
Advantage	System of aims and static norms and standards	Long-term effect (100 year)
Disadvantage	1. Lost chance to learn from flooding 2. Compromises the river's ability to provide ecosystem services	1. It is limited when a city is intolerant to socioeconomic fluctuation 2. It may result in a high cost in early stage (vis et al. 2003)
relationship	Complementary	

Table 5. Key Features of the Transition from a Traditional Approach to a resilient approach (Zevenbergen et,al. 2008)

Traditional	Resilient
Changes in system are stable and predictable	Changes in system are uncertain
Controlling changes (preserving status quo)	Sustaining and enhancing capacity to adapt to uncertainties
20-year planning time frame	Long-term time frame (up to 100 years)
Sequential process of planning (linear)	Continuous alignment of content and process with context
Top-down strategy making	Bottom-up initiatives and top-down strategic decisions
Focus on probability reduction	Focus on planning for less vulnerability
System of aims and static norms and standards	System of strategic alternatives
	Whole system solutions
	Full life cycle impacts for long-lived elements of the built environment

2.4.1 Flood-resilient Strategies

Many scholars have studied the measures of flood-resilient strategies and classified them differently (Table 6). Bruijn (2005) claims that these strategies are in the category of flood risk management and comprise structural and non-structural strategies. The Hamburg University of Technology (2010) classifies flood-resilient strategies into non-structural measures which are aimed at achieving four goals, called 4A's: Alleviation, Avoidance, Awareness and Assistance (Table 7). In the book *Design for Flooding* (Watson and Adams, 2010), the resilient design strategies for inland flooding are summarized accordingly: protect natural features that provide ecosystem services; reduce impervious land cover; design for very small rainfalls, moderate rainfalls, large rainfalls, and extreme events (Table 8). Natural Resilient Communities encourage strategies that "use nature to address flooding" and suggest seven measures to control riverine erosion and floods. These include setback levees, waterfront parks, floodwater detention and retention basins, flood bypasses, flood friendly culverts, open space preservation through land acquisition, and restoring floodplain elements (Table 9).

Table 6: Development of Flood-resilient Strategies (produce by author)

Year	Author	Claims
2003	Folke, et, al.	Four factors impact resilience and adaptive capacity in a social-ecological system: **learning to live with change and uncertainty; reorganizing and renewing nature diversity; combining different types of knowledge for learning; creating opportunity for self-organization**
	Vis, et, al.	Two alternative resilience strategies rely on **detention in compartment** and on **discharge via "green river"**
2005	Druijn	Flood resilient strategies are in the category of flood risk management and comprise structural and non-structural strategies
2009	Edwards	Four E's of community resilience: **engagement, education, empowerment** and **encouragement**
2010	Choi et,al.	Flood-resilient strategies are an adopted concept in flood risk management and can be classified into two groups: structural and non-structural. Structural measures are comprised of **runoff management**, **flooding adaptation**, **water transfer** and **architectural design** (Table 9)
2010	Hamburg University of Technology	It classifies flood-resilient strategies into non-structural measures which aim at four goals, called 4A's: **alleviation**, **avoidance**, **awareness,** and **assistance**
2010	Watson and Adams	They summarized the resilient design strategies for inland floods according to the following aspects: protect natural features that provide ecosystem services; reduce impervious land cover; design for very small rainfalls, moderate rainfalls, large rainfalls , and extreme events
2011	Chelfaut, et, al.	Flood-resilient strategies tie in with community awareness of and preparedness for flood and potential non-structural measures including **risk communication& perception; flood policy& institutional interplay;** and **flood management tools** (Table 10)
2011	Naturally Resilient Communities	They encourage "using nature to address flooding" and suggest these measures to control riverine erosion and floods: **setback levees, waterfront parks, floodwater detention and retention basins, flood bypasses, flood friendly culverts, open space preservation through land acquisition, and restoration of floodplain elements**

Table 7: Flood-resilient Strategies (Hamburg University of Technology, 2010)

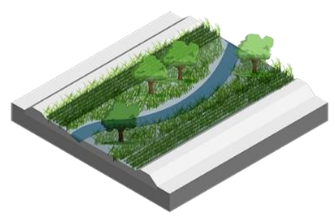
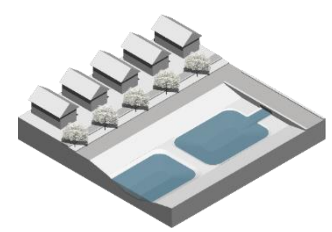
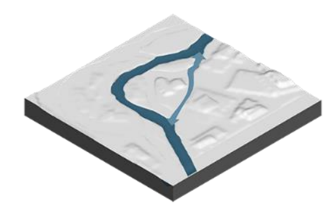
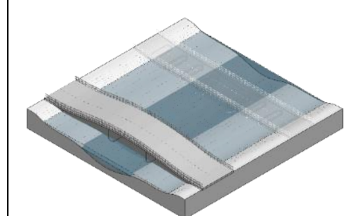
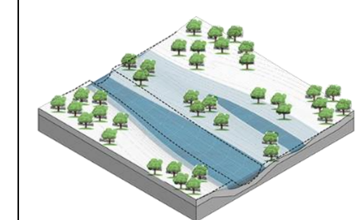
Flood-resilience measures	Type of measure	Responses	Scale
Capacity building of human resources	Information	Emergent	Intermediate
	Flood maps (Inundation and Risk)		
	Info material (brochures, public presentations, internet portals etc		
A1: Awareness of flood risk	Education - Communication	Emergent	Intermediate
	Face-to-face learning		
	Web-based learning		
	Training		
	Collaborative platforms		
Land use control	Spatial Planning	Emergent	Catchment
	Flood risk adapted land use		
A2: Avoidance of the risk where possible	Building regulations		
	Building codes		
	Zoning ordinances		
Flood preparedness	Flood Resistant buildings	Emergent	Local
	Wet-proofing		
A3: Alleviation of the effects of the flood	Dry-proofing		
	Flood action plan (local scale)	Traditional	Local
	Infrastructure maintenance		
Contingency measures	Financial Preparedness	Emergent	Catchment
	Insurance of residual risk		
A4: Assistance in the event of difficulties	Reserve funds		
	Emergency Response:	Traditional	Catchment
	Evacuation and rescue plans		
	Forecasting and warning services		
	Control Emergency Operations	Emergent	Intermediate
	Providence of emergency response staff	Traditional	Intermediate
	Emergency infrastructure	Traditional	Intermediate
	Allocation of temporary containment structures		
	Telecommunications network		
	Transportation and evacuation facilities		
	Recovery: Disaster recovery plans, pecuniary provisions of government	Emergent	Intermediate

Table 8: Resilient Design Strategies for Inland Flood (Watson and Adams, 2010)

Resilient Goal	Strategy
Protect Natural Features that Provide Ecosystem Services (PNF)	swales, depressions, and flow pathways
	wetlands, headwater streams, and stream systems
	vegetation
	geology, soils, and slopes
	Connectivity- provide corridors for native plant propagation and wildlife movement to adequate habitat
Reduce Impervious Land Cover（RILC）	porous pavement with infiltration bed
	reinforced turf systems
Design for Very Small Rainfalls (SR)	roof downspout disconnection and planter boxes
	impervious area disconnection
	green roofs
	cisterns to capture and reuse water
	rainwater harvesting
	graywater systems
	water - saving fixtures
Design for Moderate Rainfalls (MR)	urban forestry and reduction of lawn scape
	native planting
	alternatives for deicing
	rain gardens and small bioretention areas
	subsurface infiltration beds and drywells
	infiltration trench
	tree trenches and structural soil cells
	street bump - outs
Design for Large Rainfalls (LR)	retentive grading
	vegetated swale
Design for Extreme Events (EE)	green infrastructure
	riparian buffers
	wetland protection and restoration
	permaculture/community – based agriculture
	ecological wastewater treatment systems
	combined sewer overflows
	educational and interpretive features

Table 9: Natural Resilient Communities Solution to Riverine Erosion and Floods

(Source:Natresilience. "What are the nature-based solutions?" The Natural Resilience Foundation. May 23, 2018. Accessed May 23, 2019. http://natresilience.org/.)

Flood-resilience Measure	**Setback Levees**	**Waterfront Parks**	**Floodwater Detention and Retention Basins**	**Flood Bypasses**	**Flood Friendly Culverts**	**Open Space Preservation through Land Acquisition**	**Restoring Floodplain Elements**
Definition	earthen embankments that are located at a distance from a river channel in such a way to allow the river to meander in a more natural manner and occupy some or all of its natural floodplain during high water events	communal recreational spaces that are intentionally designed to be flooded with minimal damage during storm or flood events	an area that has been designed and designated for the temporary or permanent retention of floodwaters during rain or flood events	an area along a river or within a floodplain that is intentionally kept undeveloped so that it is able to receive diverted excess flood waters from a river in order to reduce the risk of flooding in a nearby specific area, such as a city or business district	infrastructure that allow water to pass underneath a bridge, road or railway without disrupting the flow of traffic	public acquisition of undeveloped land to lessen or prevent the impacts of flooding on a community’s assets	infrastructure that allow water to pass underneath a bridge, road or railway without disrupting the flow of traffic
Diagram							
Similar or Complementary Solutions	restore floodplains	Flood detention basins	Waterfront parks, Floodplains and floodplain restoration(focus on ensuring ecological health and connectivity in floodplains)	Levees	bridges, restore natural flood regimes	setback levees and horizontal levees	planning and zoning efforts that incorporate riparian buffers, setbacks, and similar protective measures
Additional Resources	USACE guidance on the design and construction of earthen levees	Guidance on *development along the waterfront* (The Waterfront Alliance); *New York City’s parks* (The New York City Department of Parks)	*Best management practices* (the State of Maine), guidance on *siting and design of floodwater detention basins* (the Santa Clara Valley Water District)	Floodwater Diversion and Storage (FEMA)	*Climate Smart Culverts Toolkit* (The Nature Conservancy); the design guidance created by Massachusetts, New York, and Washington;	*economic benefits of parks and open space* (The Trust for Public Land)	*Floodplain restoration* (FEMA), *streams and rivers restoration techniques* (The National Oceanic and Atmospheric Administration)

Continued to Table 9

Flood-resilient Measure		Setback Levees	Waterfront Parks	Floodwater Detention and Retention Basins	Flood Bypasses	Flood Friendly Culverts	Open Space Preservation through Land Acquisition	Restoring Floodplain Elements
Hazard Mitigation	1.increase conveyance in the floodway by enable floodwater to spread out and slowdown	√	√	√	√	√		
	2. Create a space to capture and store floodwater		√	√				
	3. Protect valuable habitat and remove vulnerable land from the development market						√	
	4. Identify disruption							√
Siting Considerations	1.Conduct land availability and identify and mapping the most effective place	√	√	Use low lying areas, avoid areas where seasonal groundwater levels are at or near the bottom of the basin	√	√	√	
	2. Change in land use, topography, geomorphology, population relocation and potential encroachments into the floodplain	√			√			
	3. Restoration of floodplain feature		√					
	4. Manage erosion and bank stabilization		√					√
	5. Consider inundation of infrastructure		√					
	6. Prioritize problem areas			√		√	√	
	7. Upgrade					√		
Costs	1. Land Acquisition	√	√	√	Assess vulnerable road crossings	Vary by location	√	
	2. Permits & Authorization (USACE, FEMA, Landowner)			√				
	3. Design fee		√	√				
	4. Construction & Implementation		√	√	√	Vary by circumstance		√
	5. Maintenance fee			√				
	6.Special Characteristics	Ranges significantly based on the length, size, and construction material, setback distance						

Continued to Table 9

Flood-resilient Measure		Setback Levees	Waterfront Parks	Floodwater Detention and Retention Basins	Flood Bypasses	Flood Friendly Culverts	Open Space Preservation through Land Acquisition	Restoring Floodplain Elements
Co-Benefits	1.Economic stimulus (increase population, increase commercial value)	√			√			
	2.Establish/ improve restoration potential for important commercial and game species	√		√	√	√	√	
	3.Encourage eco-tourism, active recreation (walking, jogging, cycling)and other passive recreation(birdwatching, canoeing, or hiking on nature trails)	√	√	√	√	√	√	√
	4.Improve water quality, mitigate flood intensity and losses	√						√
	5. Local environmental education (access to floodplain)	√		√				√
	6.Encourage community engagement		√	√				
	7. Improve the resilience of transportation infrastructure					√		
Maintenance Considerations	1.Clean and remove sediments	√	√	√	√	√		√
	2.Infrasttructure maintenance	√	√	Regular inspection of the inlet and outlet pipes		√		√
	3. Mowing, vegetation management			√	Control invasive species if intended to create natural habitat			
	4. Erosion repair after a flood event			√				
	5. Good planning and ongoing biological research and evaluation						√	
	6. Prevention of fragmentation						√	
	7. Ongoing attention to state and federal permitting activities							√

Structural Measures

Structural measures cover the construction materials in the urban water system, such as "green rivers," pervious pavements, and so on. Vis introduces two measures: flood retention and green rivers (Fig. 2.4). Detention in compartments means designating areas along the river for temporary water storage and dividing the existing large, continuous dike-rings into smaller compartments with different flood probabilities. Green rivers are wide discharge compartments that experience a high frequency of flooding but result in limited economic damages (Vis, et, al., 2003). Green rivers in the graphic are green – not blue – because they are dry most of the year. Choi classifies structural measures into four types: run-off management, food adaptation, flood dispatch and architecture (Choi, et, at., 2010) (Table 10).

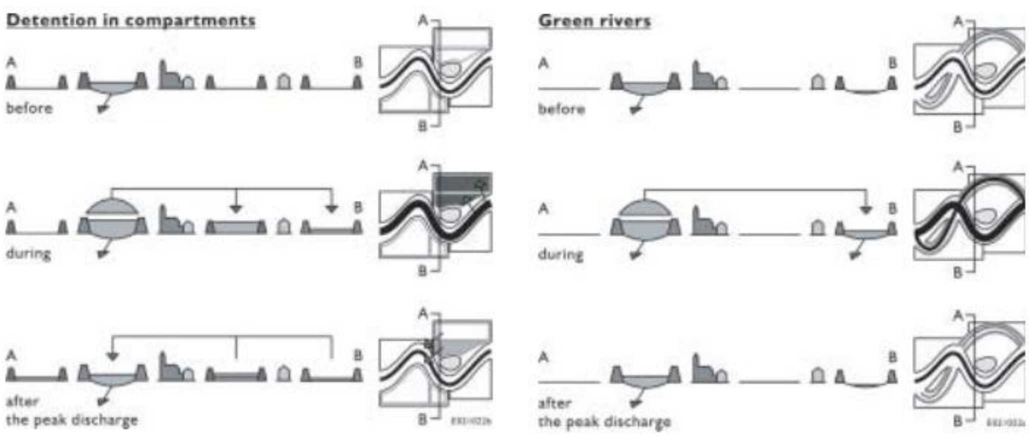


Figure 2.4: Flood Retention (left) and Green Rivers (right) (Source: Vis, et, al., 2003)

Table 10: Structural Resilience Measures (Choi, et, at., 2010)

Resilient strategies	Approach	Specific measures
Run-off management	Increase infiltration	Increase the permeability of urban surfaces
	retention	Green roof, rainwater harvest, retention pond
Flood adaptation	Increase discharge capacity	Create green Rivers, lower the floodplain
	Flood dispatch	Flood zoning, flood detention, relocation, demolition of levees and floodwalls
Dispatch	Culvert	Water diversion channel/transport channel, road system design
	Drainage network	Create double drainage system, sustainable drainage system (SUDS)
	Pump	Alleviate flood pressures in urban groundwater channels, pumping groundwater and reducing groundwater levels during floods
Architecture	Materials	Use permeable/pervious materials
	Flexibility	Should be moveable, detachable, Inflatable defense
	Design	Use green Buildings, reinforcement, central heating, control of circuits and expensive equipment

Non-structural Measures

Non-structural measures cover new management practices or improved management, including Disaster warning, Run-off management, Stormwater management, Public education and so on (Table 11).

Table 11: Non-structural Measures (Schelfaut, et, al., 2011)

Domain	Measures
Risk communication & perception	**Residents**: risk communication strategies, e.g. flyers, targeted campaigns to vulnerable groups, self-organization and informal ways of communication and collaboration **Authorities**: risk communication, e.g. training., capacity building on proper communication, guidance documents, actively involve stakeholders, community or business owners
Flood policy & institutional interplay	Residents: permits, house owner rights, financial incentives (e.g. insurance) Authorities: enforcement of legislation, participatory cooperation, more effective planning, guidance documents, actively involve stakeholders, allocate proper resources, political commitment, legal base (e.g. WFD)
Flood management tools	Residents: promote community action (stewardship), prepare home for flooding (sandbag) Authorities: plan dikes, levees, dams, retention basins, technical development of tools (e.g. Leadtime), increased utilization of tools, capacity building on warnings and tools, guidance documents, integration of technical knowledge with contingency plans, provide guidance on flood resilient constructions

2.5 Assessment on Flood Resilience

Hashimoto (1982), Moy (1982), Fiering (1982) and others are among the first scholars who evaluated resilience strategies performance in water resource systems, and they assessed the performance from the perspective of engineering resilience. Hashimoto defined the resilience of a system as its average recovery rate (average possibility of a rehabilitation from the failure set in a single time step) (Hashimoto et al., 1982). Moy claims that the longer it takes a system to recover to a stable state, the less resilient the system is (Moy et al., 1982). Based on the various definitions of resilience, Hashimoto's and Moy's assessments are focused on the system's response and recovery after disturbances, while Fiering's interpretation emphasizes the resilience in the system's transition to a resistant state.

Based on the previous studies and elements of flood-resilient landscape fundamentals, an evaluation framework (Fig. 2.5) was developed to evaluate the case studies and the projective design in later chapters. The sources of the framework are listed in Table 12.

Table 12: Source of Framework (made by author)

Goals	Measures	Edwards	Choi et al.	Hamburg University of Technology	Watson and Adams	Scheltaut, et al.	Naturally Resilient Communities	Crabtree, Paul.	EPA
Water	1. Does the project introduce hydrological analysis (concentration, run off rate, water quality, volume) to improve the water health?		✓	✓			✓	✓	✓
	2. Does the project restore wetlands and waterways?		✓		✓		✓		✓
	3. Does the project implement stormwater management & green infrastructure?		✓		✓	✓	✓	✓	✓
	4. Does the project combine the sewer overflow to alleviate flood pressures?		✓	✓	✓			✓	
Soil	5. Does the project manage soil erosion & bank stabilization?						✓		✓
	6. Does the project limit disturbance of existing health soil?			✓	✓		✓	✓	
	7. Does the project minimize impervious area?		✓	✓	✓		✓	✓	✓
Plants& Animal	8. Does the project conduct ongoing biological research and evaluation?						✓	✓	
	9. Does the project prevent fragmentation and provide sustainable buffer for fauna?				✓		✓		✓
	10. Does the project control and manage invasive species?				✓		✓		✓
	11. Does the project enhance or enlarge the habitat?				✓		✓		
Infrastructure	12. Does the project improve accessibility of road and trail systems?			✓			✓		
	13. Does the project acquire land and discourage development in river corridors?			✓			✓		
	14. Does the project introduce permeable pavements?		✓				✓	✓	✓
	15. Does the project conduct hazard mapping, hazard identification, and land use mapping ?			✓			✓	✓	✓
	16. Does the project have a maintenance plan for infrastructure ?		✓	✓	✓			✓	✓
Environmental education	17. Does the project encourage eco-tourism, active recreation (walking, jogging, cycling) and other passive recreation (birdwatching, canoeing, or hiking on nature trails)?						✓		
	18. Does the project promote local environmental education (access to floodplain, flood circle) ?	✓		✓		✓	✓		
	19. Does the project promote community engagement and actions for flood management? Does the project have adequate resources located in a region or community to conduct maintenance needs or has it taken flood-resilient strategies?	✓	✓			✓			

WATER HEALTH	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
1. Does the project introduce hydrological analysis (concentration, run off rate, water quality, volume)?			
2. Does the project restore wetlands and waterways?			
3. Does the project implement stormwater management & green infrastructure?			
4. Does the project combine sewer overflows to alleviate flood pressures?			
SOIL HEALTH	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
5. Does the project manage soil erosion and bank stabilization?			
6. Does the project limit disturbance of existing health soil?			
7. Does the project minimize impervious area?			
PLANT COMMUNITIES & ANIMAL HABITAT	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
8. Does the project conduct ongoing biological research and evaluation?			
9. Does the project prevent fragmentation and provide sustainable buffers for fauna ?			
10. Does the project control and manage invasive species?			
11. Does the project enhance or enlarge the habitat?			
INFRASTRUCTURE & MANAGEMENT	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
12. Does the project improve accessibility of road and trail systems?			
13. Does the project accquire land and discourage development in river corridors?			
14. Does the project introduce permeable pavements?			
15. Does the project conduct hazard mapping, hazard identification, and land use mapping?			
16. Does the project have a maintenance plan for infrastructure?			
ENVIRONMENTAL EDUCATION	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
17. Does the project encourage eco-tourism, active recreation (walking, jogging, cycling) and other passive recreation (birdwatching, canoeing, or hiking on nature trails)?			
18. Does the project promote local environmental education (access to floodplain, flood circle) ?			
19. Does the project promote community engagement and actions for flood management? Does the project have adequate resources located in a region or community to conduct maintenance needs or has it undertaken flood-resilient strategies?			

Figure 2.5: Evaluation Framework (made by author)

This framework will be used to evaluate the performance of two case studies in chapter three and the projective design in chapter six.

CHAPTER 3
CASE STUDY

In this chapter, two specific cases are examined in depth. An earlier example of a floodable park - the Mill Race Park, Columbus, Indiana (1993) by Michael Van Valkenburgh and a more recent award-winning resilient landscape - Yanweizhou Park in Jinhua City, China (2014) by Turenscape. The general selection criteria for each project included: water health, soil health, plant communities and animal habitats, infrastructure maintenance and environmental education.

3.1 Mill Race Park in Columbus, Indiana

Mill Race Park is an 85-acre city park located in a flood plain where the Flat Rock and the Driftwood rivers join (forming the east fork of the White River) in downtown Columbus (Fig. 3.1).

3.1.1 Layout Analysis

As a successful civic park that gives residents a sense of place and a nod to local history, Mill Race Park shares similarities with OCNM in their relationship with downtown and regional history. They are both located at the outskirts of downtown and isolated by a railroad constructed after the park itself. Mill Race park is at the “threshold space” (Pia, 2014) between the high-density city of Columbus to the east and the open space to the west (Fig.3.1). In order to situate it well with its surroundings, the design firm, Michael Van Valkenburgh Associates (MVVA) created a geometric layout that mimics the city grid and forms a clear pattern. In this way, MVVA created “a bridge between the geometry of the town and the irregular contours of the river bank” (Beardsley,1993). As Meyer (2000) notes, “its forms and spaces are the result of the designer’s reading of the site from the dual perspective of perceiver and conceptualizer.” The master plan of Mill Race Park is shown in Figure 3.2 (page 28).

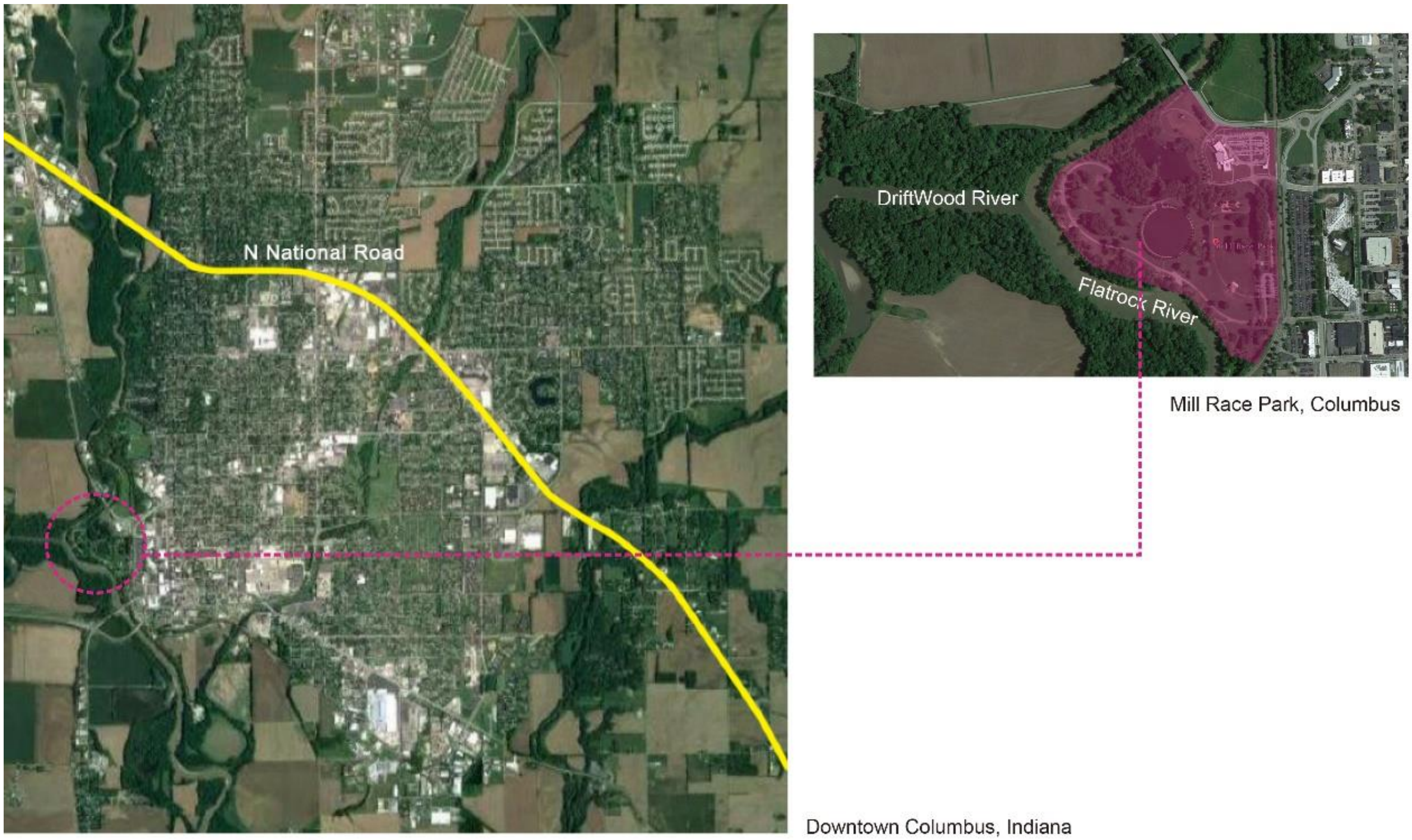


Figure 3.1: Location of Mill Race Park (Source: Google Earth)

Figure 3.2: Master Plan of Mill Race Park (Modified by author) Source: Reconstructing Urban Landscapes: Michael Van Valkenburgh Associates, 2009

3.1.2 Water Health

Mill Race Park addressed the negative elements of the original site by placing them into its unique identification. As a brownfield with contamination, shifting riverbank and periodical flooding, the park was transformed from a "vague" terrain to a cusp landscape by integrating the cyclical process of regional hydrology. The flood stage begins at 9 feet above average levels, at which point 60% of park ground is submerged, and a 100-year event begins when water tops 16 feet (Berrizbeitia, 2009). Aimed at not only observing the hydrological circulation but also participating in it, wet and dry programs were designed to guide the circulation of water and accommodate people (Fig. 3.2). A 450-feet diameter round lake (Fig. 3.3) was excavated on the site of the previous gravel pits and linked to the pre-existing irregular lake. The immense circular lake, encompassed by the Common Bald Cypress (*Taxodium distichum*) and a retaining edge, was the last structure to be submerged and the first to reemerge during the flood. To enhance the water system's operative efficiency, a pair of chutes and sluices were placed to link Round Lake and Flatrock River. Overflow of the lakes was conducted via pipes and sent back to the river. As a visible infrastructure, the sluice recharges the water from Round Lake to Flatrock River (Fig. 3.4). These topographic tactics were applied in the irregular pond (North Lake) and later influenced the park's configuration.

Figure 3.3: Round Lake (Source: Michael Van Valkenburgh Associates, 2019)

Figure 3.4: The sluice in Mill Race Park (Source: Michael Van Valkenburgh Associates, 2019)

After the park was constructed in 1993, it experienced periodical flooding and helped mitigate the hazards to downtown Columbus. Today, when the river gets to the flood stage, only the elevated amphitheater, cross bridges, and some parking lots remain visible (Fig. 3.5).

Figure 3.5: Aerial view of Mill Race Park at Flood Stage（Source：Michael Van Valkenburgh Associates, 2019）

The nearest USGS stream gage around Mill Race Park is East Fork White River in Columbus (BAKI3). The water rose to 7.86 feet on Jan 21, 2017, and a local resident recorded the flooded Mill Race Park using a video camera (Fig. 3.6). From the uploaded video in YouTube, it is safe to say that the majority of river walks in the park remained functional and only several low-lying areas were inundated. The two lakes and the permeable wildflower meadows helped retain the floodwater and mitigated the flooding. The design included a detailed drainage plan (Fig. 3.7) which added new inlets and utilities in the site.

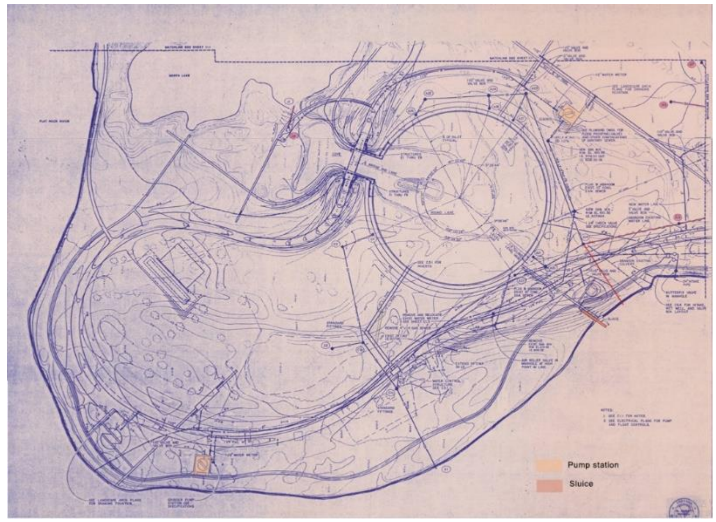


Figure 3.7: A Detailed Drainage Plan (Source: Columbus Indiana Architect Archives, 2008)

Figure 3.6: **Top**: Aerial View of Mill Race Park; **Middle**: River Trail at Flood Stage; **Bottom**: Cover Bridge above the Flood Level on Jan 21,2017 (Source：https://www.youtube.com/watch?v=d-BDvb9AX0s）

Assessment

The design team conducted a hydrological analysis and was a pioneer in proposing remedial strategies about water pollution. The project restored the floodplain features, as well as developed appropriate land use planning. During the flooding, only the highest elevated constructions are visible.

STRATEGIES	MINIMALLY	FULLY	EXCEEDED
1. Does the project introduce hydrological analysis (concentration, run off rate, water quality, volume)?		√	
2. Does the project restore wetlands and waterways?		√	
3. Does the project implement stormwater management & green infrastructure?		√	
4. Does the project combine sewer overflows to alleviate flood pressures?		√	

Figure 3.8: Assessment of Water Health (produced by author)

3.1.3 Soil Health

Designers of MVVA used several topographical tactics to create a chain of water features. Two abandoned gravel pits were transformed into two lakes: one irregular lake (North Lake) and one circular lake (Round Lake). Spoils from Round Lake were reused for the construction of a basketball court surrounded by a low berm (Fig. 3.9) and an amphitheater sited in a crescent landform (Fig. 3.10). During the flooding, “temporal measures, such as the crest of a flood stage” and “the consequent swing of territorial limits, such as the expanding and receding wetland floor” (Amidon, 2009) fully express the designe

rs’ thoughts of geometry beauty and land formation. Water-resilient plants like Pussy Willow (*Salix discolor*), Black Pussy Willow (*Salix gracilistyla 'Melanostachys'*), Northern Catalpa (*Catalpa speciosa*), and Sycamore (*Platanus occidentalis*) were planted in the riverbank for bank stabilization.

Figure 3.9: A Basketball Court (Source: Google Earth)

Figure 3.10: An Amphitheater (Source: Courtesy of MVVA)

<u>Assessment</u>

The design team upgraded several potential inundated areas and covered the land with ground cover. Soil erosion and bank stabilization were minimally considered. The designer did a detailed inventory of the site and designated eleven pieces of land for preservation and special management. Topographical measures were applied to limit disturbance of exiting healthy soils. Spoils from lake excavation were reused to build other structures in the park.The design balanced the cut and fill along with minimizing earthwork.

SOIL HEALTH	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
5. Does the project manage soil erosion and bank stabilization?	√		
6. Does the project limit disturbance of existing health soil?	√		
7. Does the project minimize impervious area?		√	

Figure 3.11: Assessment of Soil Health (made by author)

3.1.4 Plant Communities and Animal Habitats

MVVA did an onsite research and evaluation of plant communities. It removed some existing trees along the irregular lake (North Lake) and riverbank, and preserved other valuable trees on the site. There were eleven pieces of land designated to be managed before planting and later planted with various plants according to the site conditions. The general work for planting preparation involved removing the dead and fallen vegetation on the site. Three types of planting methods were used: woodland planting, wildflower meadow planting and hatched area planting.

Selective trees were planted according to their tolerance to wet soil and biological characteristics. Water-tolerant trees like Bald Cypress (*Taxodium distichum*) were planted at the perimeter Round Lake, and flowering trees like Eastern Redbud (*Cercis canadansis*) were planted along the eastern bank of North Lake. Figure 3.12 shows the inundated forest on the site.

Figure 3.12 : The Inundated Forest (Courtesy of MVVA)

Assessment

The design team did good ongoing research and an evaluation of existing plants and designed eleven pieces of land for management and later planting. Water-resilient trees and wetland bushes along the river walk established a riparian buffer for small mammals and fish, but systemic strategies for the creation of refuges and prevention of fragmentation were not provided. The team also used plants with flood adaptive native plants to stabilize the eroded riverbank, but there were no detailed plans for invasive species management. Consideration of animal survival during the flooding was not mentioned in the design.

PLANT COMMUNITIES & ANIMAL HABITAT	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
8. Does the project conduct ongoing biological research and evaluation?		√	
9. Does the project prevent fragmentation and provide sustainable buffers for fauna ?	√		
10. Does the project control and manage invasive species?	√		
11. Does the project enhance or enlarge the habitat?	√		

Figure 3.13: Assessment of Plant Communities and Animal Habitats (made by author)

3.1.5 Infrastructure and Maintenance

The infrastructure in the park was designed by Stanley Saitowitz & Natoma Architects Inc (Fig. 3.14). This infrastructure includes a boathouse at the north bank of North Lake, a stage in front of the amphitheater, a viewing tower, an arbor and three picnic shelters, a river vista near the eastern bank of White River and two elevated restrooms (Fig. 3.15). All the structures were designed to adapt to accommodate flooding, enabling several critical positions to be visible during the flooding (Berrizbeitia and Goldberger, 2009).

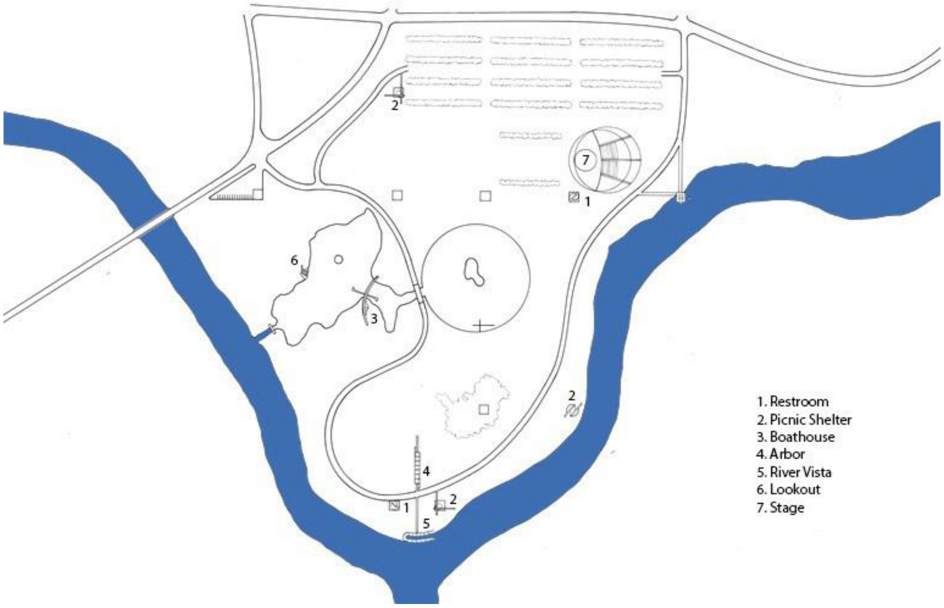


Figure 3.14: Infrastructure Map of Mill Race Park (Source: courtesy of Stanley Saitowitz & Natoma Architects Inc, 2019, http://www.saitowitz.com/work/miller-race-park/)

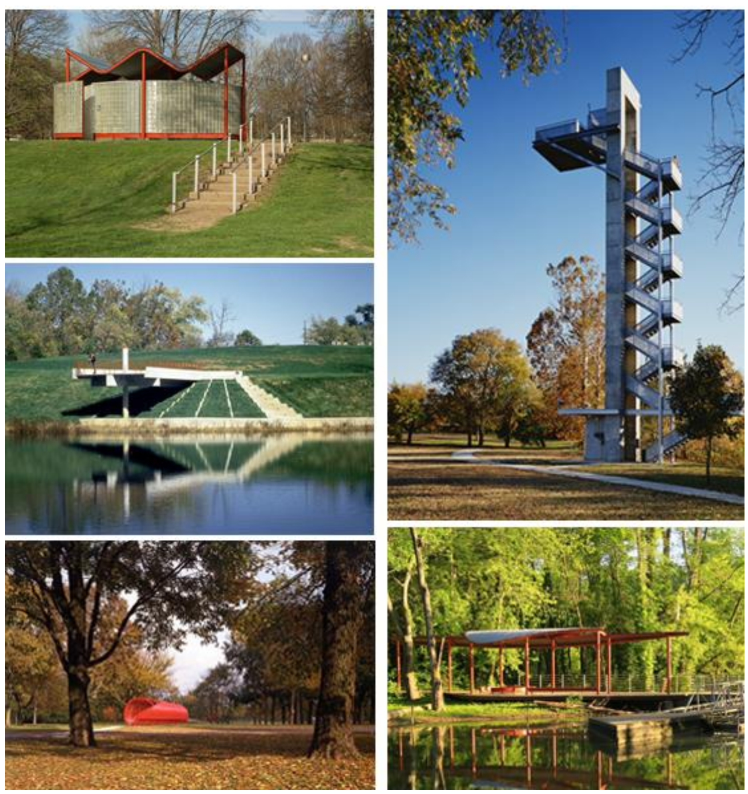


Figure 3.15 : Infrastructure in Mill Race Park (Source: courtesy of Stanley Saitowitz & Natoma Architects Inc.)

Assessment

The park was designed in 1993 when permeable pavement was not widely used. The river walk is covered by impermeable concrete and the bike trials are covered by impermeable bituminous concrete. The elevated restrooms and stage, the terraced amphitheater and lookout platform, and the high-rise tower were designed to remain visible during a flood. The steel roofs of the structures like picnic shelters and the interlocking-glass-block wall of restrooms are waterproof and low-maintenance. The lookout platform is above the flood level, and the stairs around the lookout can help mitigate the bank erosion.

INFRASTRUCTURE & MANAGEMENT	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
12. Does the project improve accessibility of road and trail systems?		√	
13. Does the project accquire land and discourage development in river corridors?		√	
14. Does the project introduce permeable pavements?	√		
15. Does the project conduct hazard mapping, hazard identification, and land use mapping?	√		
16. Does the project have a maintenance plan for infrastructure?	√		

Figure 3.16 : Assessment of Infrastructure and Management (made by author)

3.1.6 Environmental Education

The park provides various outdoor activities for local residents and at the same time promotes environmental education. People walk, run, and cycle in the park and they can enjoy concerts, canoeing, and other community activities here (Fig. 3.17). Waterfront structures like the lookout platform, the tower, and the river vista provide people with intimate connections to the water, which will improve their awareness to flooding and natural resource protection in the long term. The lookout takes the form of a chaise lounge and people can enjoy sunbathing here. The design changes two previous gravel pits into two linked lakes and provides a pathway around them. The transportation system of the park can be classified into three types: driveway, river walk, and secondary pathway (Fig. 3.18). The park provides a place for people to explore nature in an urban environment in Columbus, Indiana.

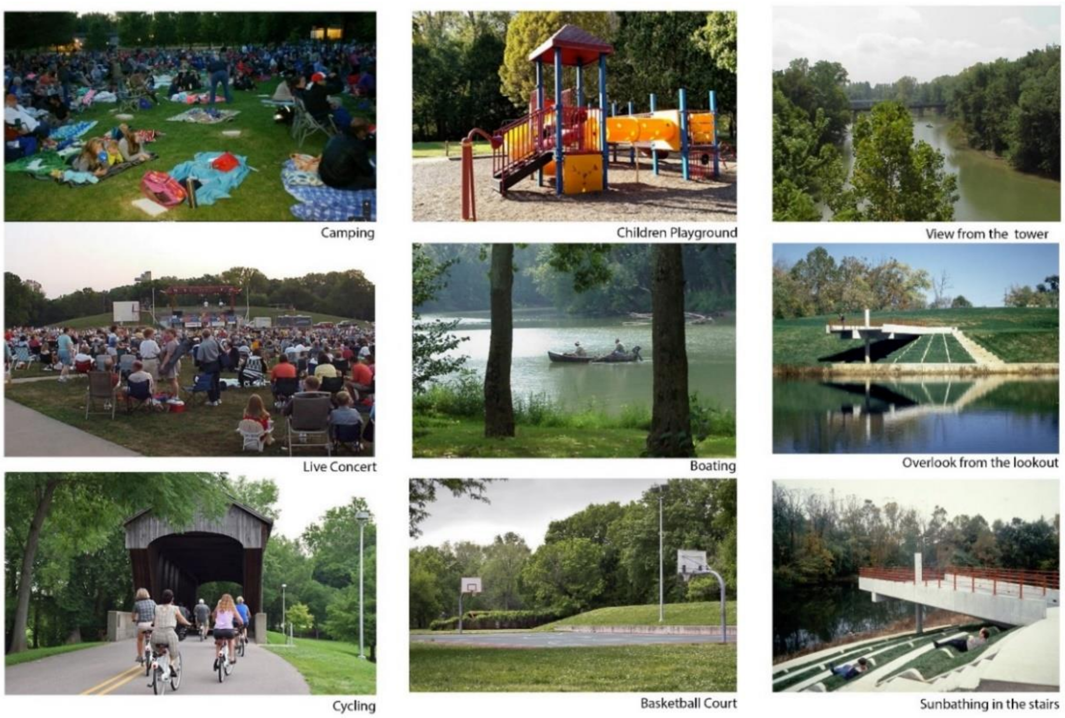


Figure 3.17: Recreation of Mill Race Park (Source: Google map and courtesy of Stanley Saitowitz & Natoma Architects Inc.)

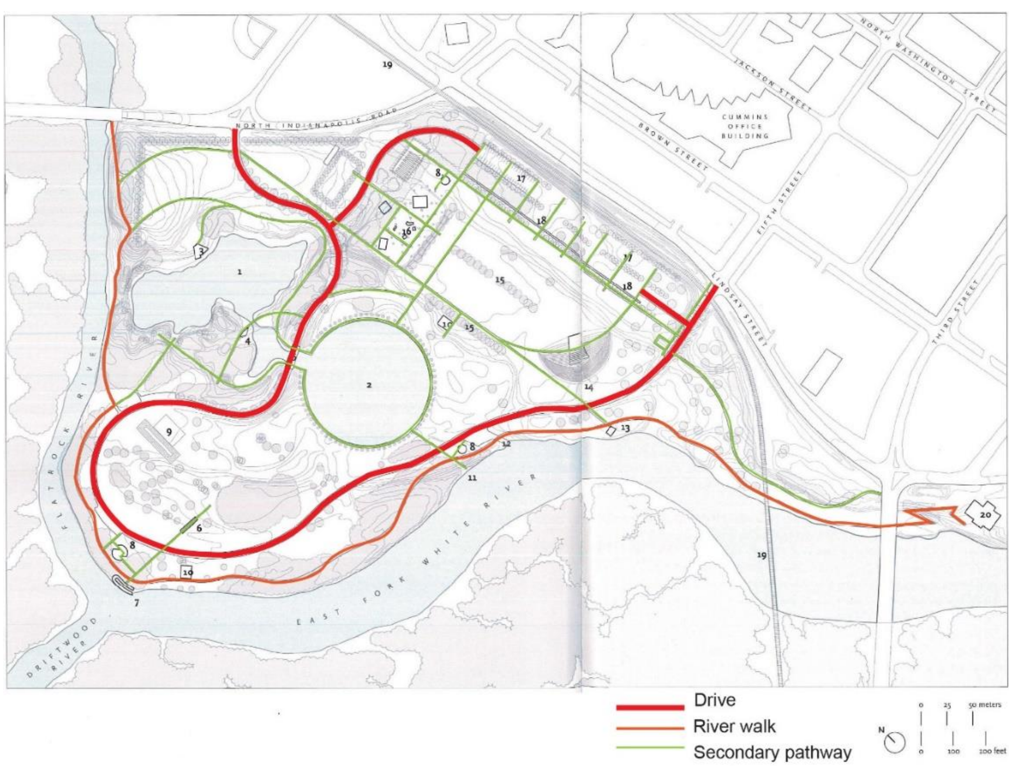


Figure 3.18: Transportation System of Mill Race Park (modified by the author, Source: http://www.kid-at-art.com/htdoc/millrace.html)

Assessment

The park provides various outdoor activities for local residents and promotes environmental education at the same time. It allows people to explore nature in an urban environment in Columbus, Indiana. People celebrate festivals and hold community activities here.

ENVIRONMENTAL EDUCATION	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
17. Does the project encourage eco-tourism, active recreation (walking, jogging, cycling) and other passive recreation (birdwatching, canoeing, or hiking on nature trails)?		√	
18. Does the project promote local environmental education (access to floodplain, flood circle) ?		√	
19. Does the project promote community engagement and actions for flood management? Does the project have adequate resources located in a region or community to conduct maintenance needs or has it undertaken flood-resilient strategies?	√		

Figure 3.19: Assessment of Environmental Education (made by author)

3.2 Yanweizhou Park in Jinhua City, China

Yanweizhou Park is located in the urban heart of Jinhua city, Zhejiang Province, China. Yanweizhou, literally meaning “the sparrow tail,” comes from the shape of the riparian wetland where the Wuyi River and Yiwu River converge to form the Jinhua River (Fig. 3.20). The three rivers divide the land into three parcels; the over 100-meter-wide surface water makes the Yanweizhou wetland inaccessible. As the last natural wetland in the city, Yanweizhou covers 64 acres (26 ha) of undeveloped land. Some cultural facilities including an opera house are under construction in the park.

The Yanweizhou wetland experiences periodic flooding due to three major factors. First, Jinhua city is in the subtropical region of eastern China. Because of its monsoon climate, Jinhua suffers from annual flooding in the rainy season. Second, although the city controls floods by constructing stronger and taller concrete floodwalls, they ultimately ruin the intimate relationship between the people, the vegetation, and the water. Consequently, this resistant construction exacerbates the destructive force of the annual floods. Finally, the existing wetland was damaged or fragmented by sand quarries, which have reduced the adaptability of the lush and dynamic wetland ecosystem to accommodate flooding.

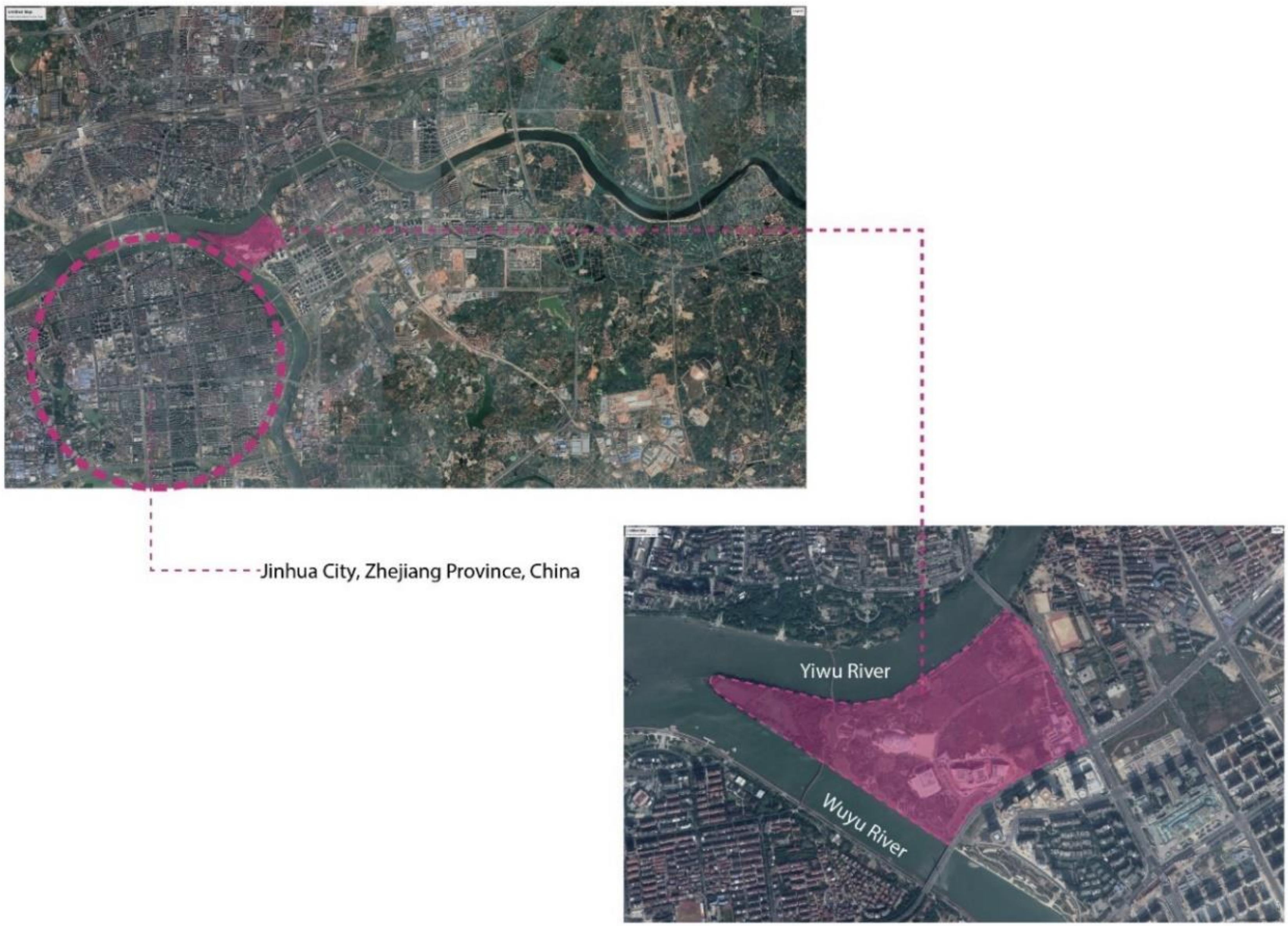


Figure 3.20: Location of Yanweizhou Park (made by author)

Confronting these issues, landscape architects from Turenscape have designated the site an experimental project, exploring how a city can live with flooding. The design goals consist of preserving a patch of riparian habitat while providing urban residents with amenities; controlling flooding; and integrating the existing organically shaped opera house into the surrounding environment. In addition, the ultimate goal is to connect the separated city to the natural riparian landscape and to strengthen the community and cultural identity of the city of Jinhua.

3.2.1 Land Use Analysis

The site can be classified into four types in terms of land use: preserved wetland zone, fitness & recreation zone, central water features zone and business & office zone (Fig. 3.21). Figure 3.22 illustrates the site condition before and after design.

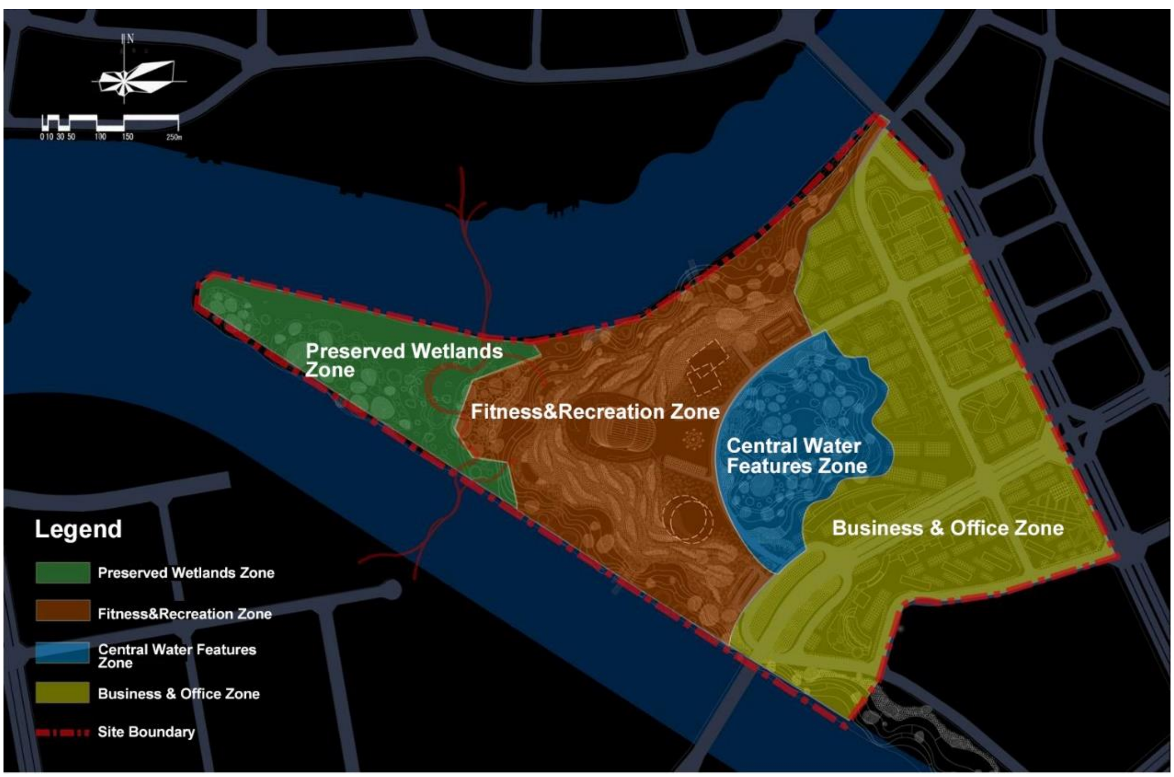


Figure 3.21: Land use of Yanweizhou Park (Source: courtesy of Turenscape)

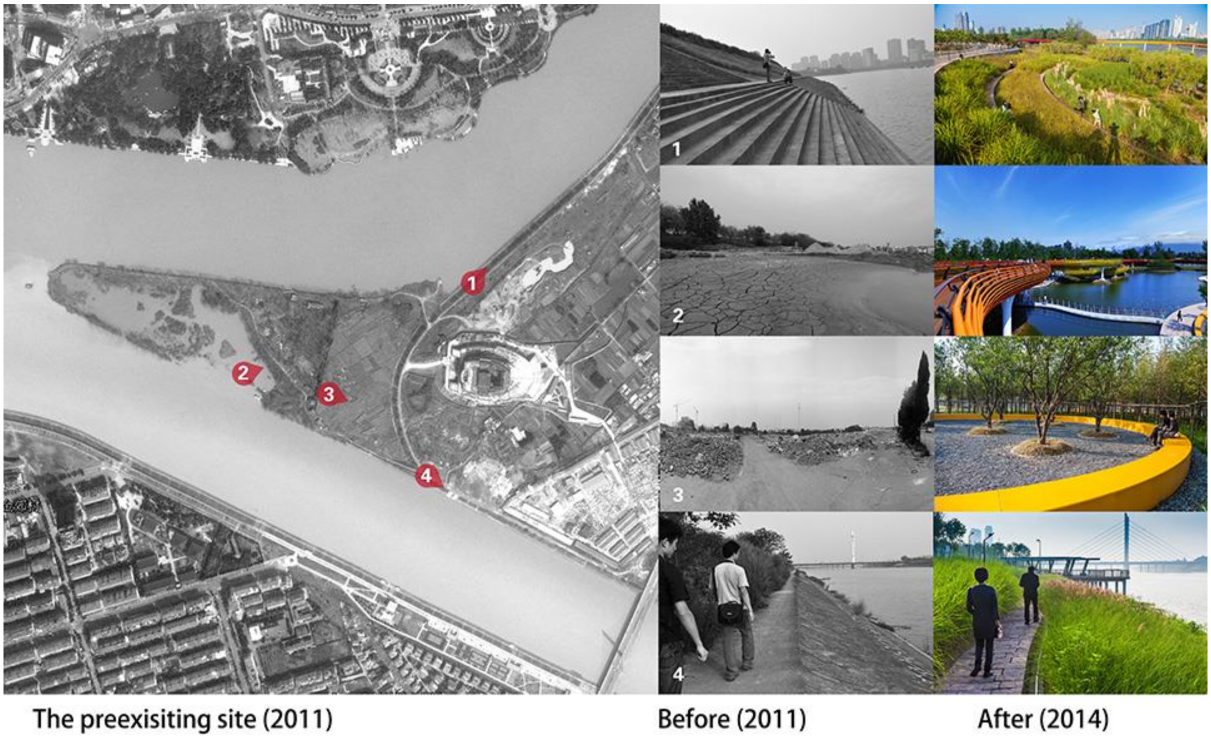


Figure 3.22: Before and After Design Comparison of Yanweizhou Park (Source: courtesy of Turenscape)

Preserved wetland zone-- the original site is a secondary-growth wetland covered with vegetation. It is a resource bank of native plants, as well as a natural habitat for animals and a transportation hub for migratory birds. Nevertheless, this area is impacted by human disturbances and pollution. There is only a single plant community and it lacks biodiversity. Thus, the natural landscape should be preserved and artificial constructions should be avoided for the protection of natural content. Ecological remediation should be applied to the damaged ecosystem to help sustain and recycle the system.

Fitness & recreation zone-- this zone is comprised of important cultural infrastructure including the Opera House and is adjacent to the riverside and preserved wetlands. Based on the site condition and multi-use of the land, the Opera House should accommodate a large audience during the show times. Advanced technologies should be used for floodwalls and to limit human contact with the wetlands.

Central water features zone-- the site has a large area of farmland and is a little flat. It is integrated land facing the Opera House and has the possibility to be developed into a focal point for gatherings and art shows. The Aquatic Theater and artificial wetlands are located here.

Business & office zone-- this zone is adjacent to the city and crowded roadways; thus, it is not suitable for recreation. However, it is a suitable place for developing business if the people and vehicles are controlled. The city and the park have a mutualistic relationship: the high-rise buildings separate the park from the noisy city and bring it popularity, while the tranquil, multi-use park attracts more people to work there.

3.2.2 Water Health

Grading

The original site has a flat topography and lacks variation in elevation. The Turenscape design team made the park more vertical and more functional. The site was divided into three sections according to its topography: wetland zone, terrace zone and water feature zone (Fig.3.23).

Figure 3.23: Topography of Yanweizhou Park (Source: courtesy of Turenscape)

Wetland Zone--the perennial inundated area of the wetland is at the normal water level of the river (34.62 meters, 113.58 feet). The island is 0.5 meters (1.64 feet) above the river surface, and the seasonal inundated area in the wetland is 35.5 meters (116.47 feet) high and will be completely submerged during a 20-year flood event.

Terrace Zone--this zone has four tiers from the bottom (36 meters, 20-year flood level) to the top (40 meters, 50-year flood level) of the water-resilient terraced river embankment: 36 meters (118.11 feet) to 37 meters (121.39 feet); 37 meters to 38 meters (124.67 feet); 38 meters to 39 meters (127.95 feet); 39 meters to 40 meters (131.23 feet).

Water Feature Zone--the elevation of this hollow pond decreases from 37/38 meters at the edge to the river level (same as the normal water level) of 34.62 meters (113.58 feet).

Terraced River Embankment

The site has two concrete floodwalls designed for 20-year and 50-year flood events, and these structures break up the integrity and consistency of the natural riparian ecosystem. Turenscape's new design replaces the floodwalls with a water-resilient terraced river embankment (Fig. 3.24) that is covered with flood adapted native vegetation (Landzine, 2015), challenging the traditional thought that concrete floodwalls can control flooding.

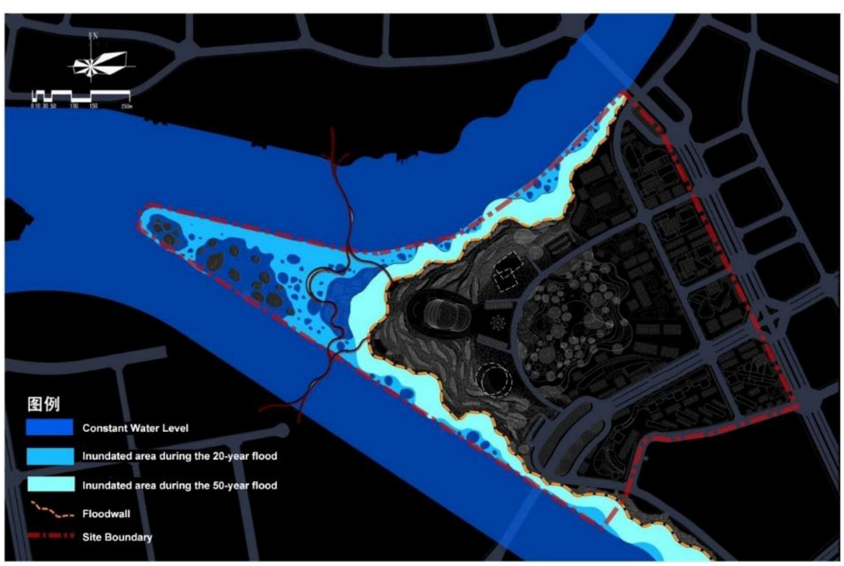


Figure 3.24 : Inundation map of Yanweizhou Park (Source: courtesy of Turenscape)

The bottom of this terraced embankment is 35.5 meters (116.47 feet) high and will be inundated during a 20-year flood. The top of the terraced embankment is 40 meters (131.23 feet) high and the complete embankment will be submerged, while the inner site will remain functional.

Stormwater Management

Runoff flows through a large area of impermeable pavements in the urban city and then is pumped into the watercourse via the sewer system with pollutants. Consequently, it causes a loss of groundwater, as well as aggregating the pollution of the urban river. The design limits the use of impermeable pavements and places several permeable green patches and ponds in the park (Fig. 3.25). In this way, the directed runoff can recharge the groundwater.

The ponds of the Central Water Feature are the main rainwater harvest area. This area is adjacent to the Business & Office Zone, which has the largest area covered by impermeable pavements and is encompassed by roadways. It also has the largest volume of runoff and the worst water quality. Hollow ponds are created by grading and excavation, and artificial wetlands with aquatic plants harvest rainwater within the ponds. This vegetation filters and purifies rainwater, as well as irrigates the lawns without harming the visual value of the landscape. This strategy saves precious water resources and follows the principle of sustainable ecological development.

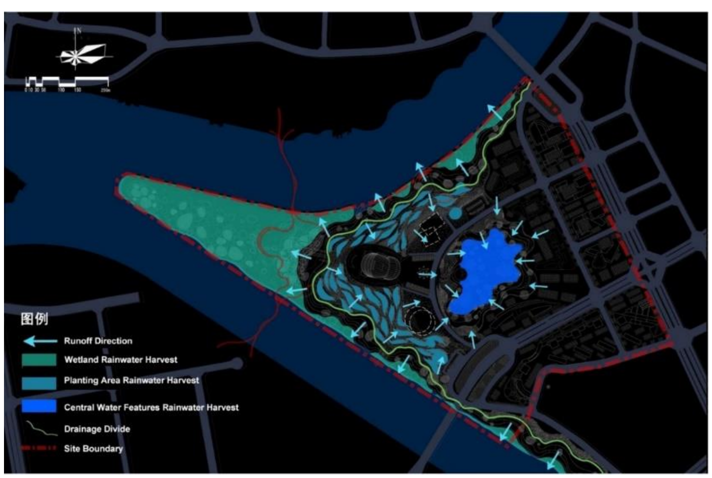


Figure 3.25 : Stormwater Management of Yanweizhou Park (Source: courtesy of Turenscape)

<u>Assessment</u>

Flooding causes are identified and flood inundation maps are analyzed. The design emphasizes the restoration of floodplain features. Stormwater management and green infrastructure are fully implemented on the site, but the project doesn't combine stormwater into sewer overflow.

WATER HEALTH	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
1. Does the project introduce hydrological analysis (concentration, run off rate, water quality, volume)?		√	
2. Does the project restore wetlands and waterways?			√
3. Does the project implement stormwater management and green infrastructure?		√	
4. Does the project combine sewer overflows to alleviate flood pressures?	√		

Figure 3.26 : Assessment of Water Health (made by author)

3.2.3 Soil Health

The riverbank is highly impacted by erosion and accumulation effects. Based on different locations and water flow features, the riverbank is classified into four types: eroded riverbank, river inlet, riverbank impacted by accumulation effect, and marginal wetland accumulation (Fig. 3.27). To protect the inner environment of wetland and keep floating pollutants from entering the wetland, the design uses ecological solutions like ripraps and water-resilient vegetation or a combination of both.

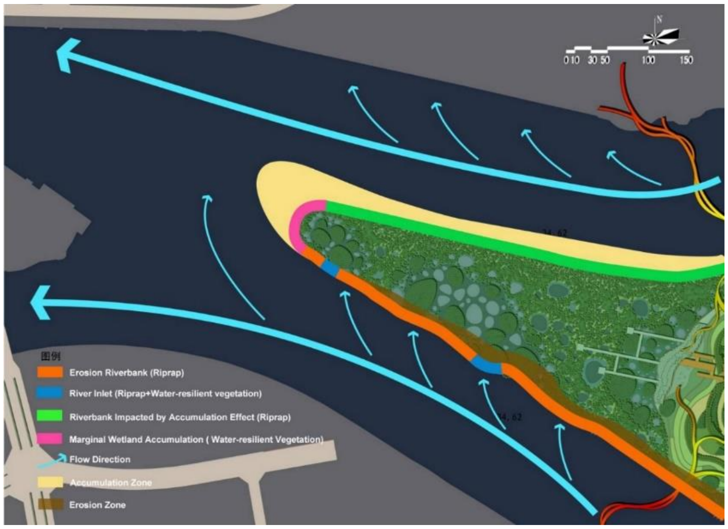


Figure 3.27: Riverbank of Yanweizhou Park (Source: courtesy of Turenscape)

Eroded Riverbank--if the natural riverbank is restored completely, the total area of wetland will shrink due to the erosion; thus, riprap is a better alternative. It protects the riverbank from erosion, and keeps the floating pollutants out of the inner wetland at the same time. In addition, it will not obstruct the material and energy exchange between river and wetland, and it provides a habitat and a foraging place for small animals and fish (Fig. 3. 28).

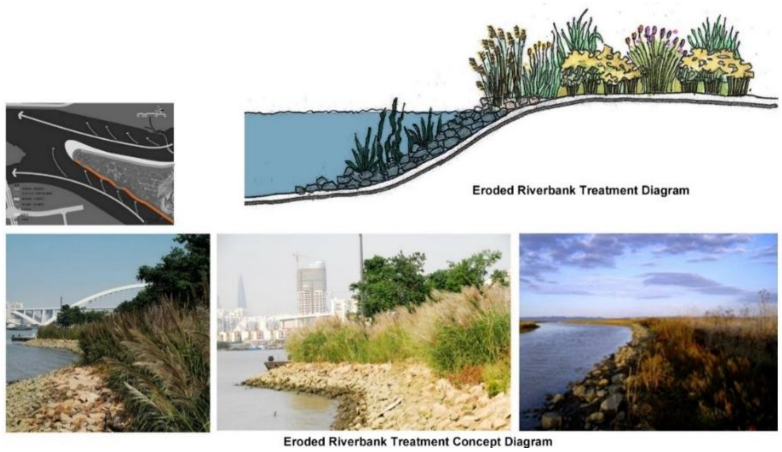


Figure 3.28: Treatment of Eroded Riverbank of Yanweizhou Park (Source: courtesy of Turenscape)

River Inlet--this area is a vulnerable geological zone where the river flows directly into the inner wetland and may expand its fragmentation by erosion. Thus, riprap is required to stabilize the bank. Meanwhile, due to the limited height for constructing riprap, Common Reed (*Phragmites australis*) and other tall growing plants are densely planted to keep the floating pollutants out of the wetland (Fig. 3.29).

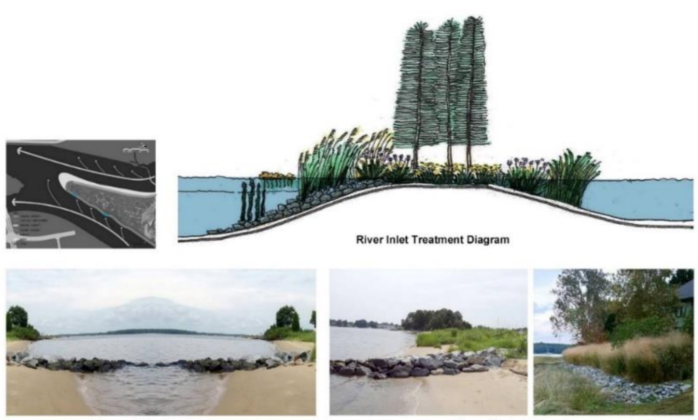


Figure 3.29: Treatment of River Inlet of Yanweizhou Park (Source: courtesy of Turenscape)

Riverbank Impacted by Accumulation Effect--this type of riverbank will develop into a shallow alluvial plain created by depositing sediment over a long period of time. Riprap is an ideal solution to block the floating pollutants and to reduce the construction height. Maintenance, removing the silt and sediment, is needed (Fig. 3.30).

Figure 3.30 Treatment of Riverbank Impacted by Accumulation Effect of Yanweizhou Park (Source: courtesy of Turenscape)

Marginal Wetland Accumulation--this marginal area is in the accumulation zone most influenced by the accumulation effect and will expand its boundary. Since the current low-lying topography is unsuitable for riprap construction, dense growing plants should be planted here (Fig. 3.31).

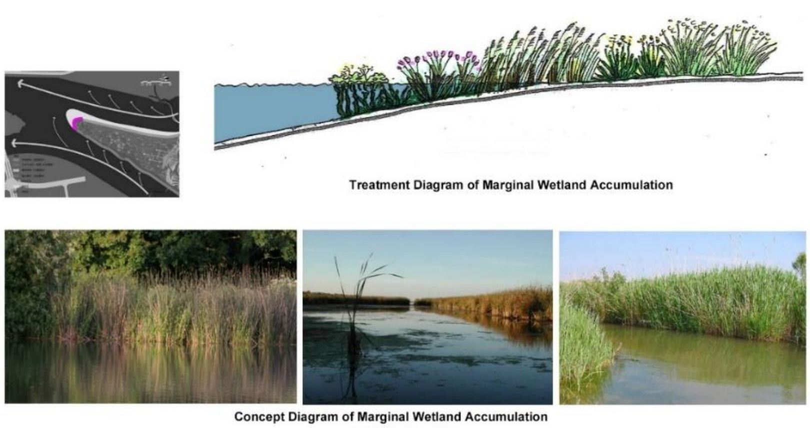


Figure 3.31: Treatment of Marginal Wetland of Yanweizhou Park (Source: courtesy of Turenscape)

Assessment

The riverbanks are designed according to their different locations and features. Riprap and water-resilient vegetation and a combination of both solutions are applied to the site. In this way, the project limits the disturbance of existing health soil and minimizes impervious areas sufficiently.

SOIL HEALTH	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
5. Does the project manage soil erosion and bank stabilization?	√		
6. Does the project limit disturbance of existing health soil?		√	
7. Does the project minimize impervious area?			√

Figure 3.32: Assessment of Soil Health (made by author)

3.2.4 Plant Communities & Animal Habitat

According to different natural contexts, surrounding environments, and demands, the planting plan categorizes the site into five sections: natural wetland planting zone, water-resilient terraced embankment planting zone, green canopy plaza planting zone, artificial wetland planting zone, and commercial building planting zone (Fig. 3.33). The plan makes full use of native plants and encourages sustainable development by considering plant communities.

Figure 3.33 : Planting plan of Yanweizhou Park (Source: courtesy of Turenscape)

Natural Wetland Planting Zone--this zone covers the front riparian wetland and the wetlands on both sides of the Yanweizhou wetland. There are wetland plant communities currently on the site; therefore, the design preserves valuable trees, shrubs, understory plants, and aquatic plants, and adds more aquatic vegetation for aesthetic and ecological purposes.

Water-resilient Terraced Embankment Planting Zone--this zone is designed as a flood-resilient terraced river embankment and planting beds because the original site has low aesthetic value and there are no vegetation resources for preservation and utilization. High-yield crops like Chinese Cabbage (*Brassica campestris L.)* and Sunflower (*Helianthus Annuus Linn*) are planted in the terraced planting beds as ornamental plants, accompanied with perennial ornamental grass to create rustic, tranquil scenery.

Green Canopy Plaza Planting Zone-- this zone covers the Opera House and the surrounding plaza and activity areas. The original condition is the same as the Water-resilient Terraced Embankment Planting Zone which is aesthetically unpleasant. Therefore, canopy trees like the Chinese Sweet Gum (*Liquidambar formosana Hance*), Chinese Wingnut (*Pterocarya stenoptera*) and Magnolia (*Magnolia grandiflora Linn),* and flowering trees like the East Asian Cherry (*Prunus serrulata*), and Yulan Magnolia (Magnolia denudata) are planted to make an area with seasonal blooming flowers.

Artificial Wetland Planting Zone--this zone includes the central water and surrounding terrain, theater, and water plaza. The current condition is not satisfactory and needs improvement. Trees like Dawn Redwood (*Metasequoia glyptostroboides*), Chinese Tallow (*Sapium sebiferum*), and aquatic plants like Chinese Silver Grass (*Miscanthus sinensis*) and Cogon Grass (*Imperata cylindrica*) are planted here.

Commercial Building Planting Zone--the dense architecture complex needs to be shaded and the planting plan needs to meet the ecological demands. The canopy trees like Chinese Privet (*Ligustrum lucidum*) and Yulan Magnolia (*Magnolia denudate*) provide shaded areas for walking, seating, and resting in front of the buildings.

<u>Restoration of Wetland</u>

Yanweizhou Wetland is a precious riparian wetland in the urban city, and the design follows the minimum intervention principles and prohibits people from getting into the wetland in order to protect the habitat and vegetation (Fig. 3. 34). Moreover, biological recovery engineering strategies are implemented on the site to enrich the food chain, to improve the biodiversity, and to help form a healthy and self-sustaining ecosystem.

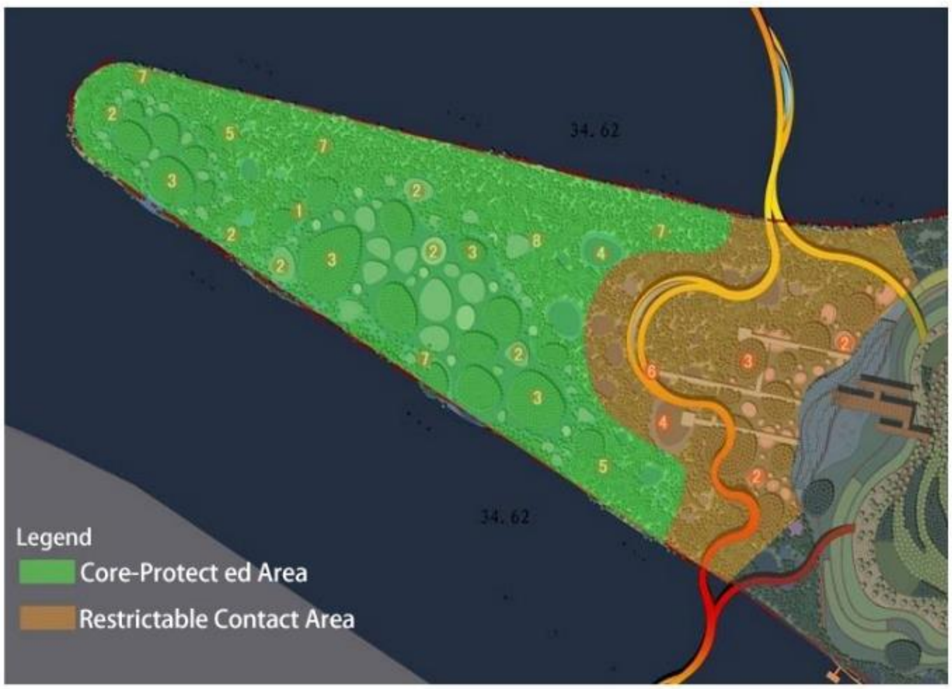


Figure 3.34: Preserved wetland in Yanweizhou Park (Source: courtesy of Turenscape)

Create Diverse Habitats to Promote Biodiversity

The habitats of a marginal wetland can be classified into three types: Occasional Inundated Area, Seasonal Inundated Area, and Perennial Inundated Area (Fig. 3.35). To promote biodiversity, two strategies are implemented here: improving the functions of the three various habitats and creating diverse habitats to meet the needs of more species. Table 13 illustrates strategies for creation of habitats.

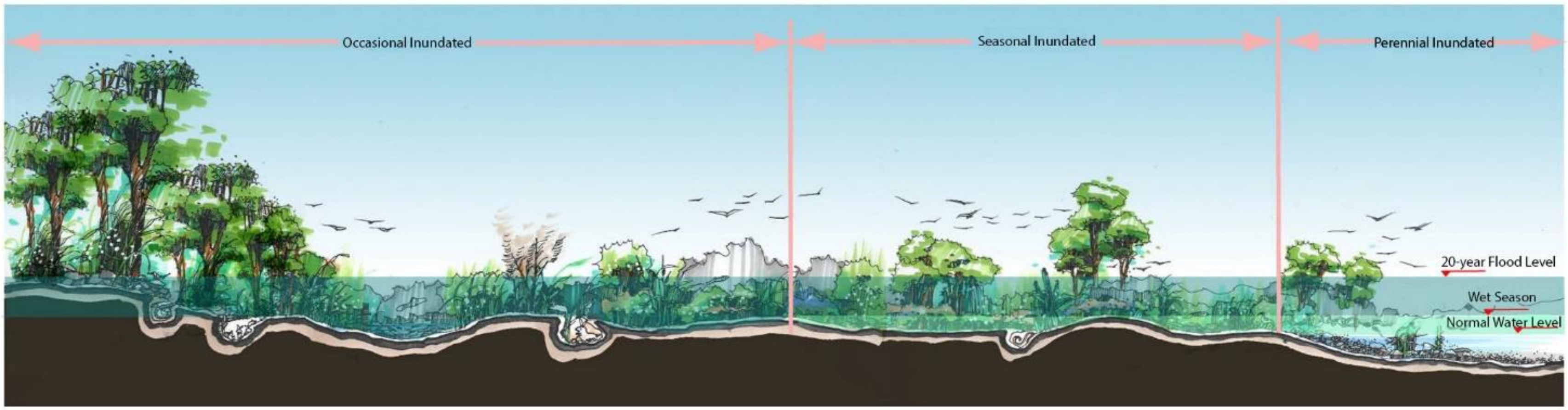


Illustration Diagram of Marginal Wetland Biodiversity

Figure 3.35: Three Types of Marginal Habitats in Yanweizhou Park (Source: courtesy of Turenscape)

The creation of habitats can be classified into three types: Aquatic habitats, Seasonal Inundated Area, and Terrestrial Habitats. Table 14 shows the summary of strategies used in the creation of the habitats.

Table 13: Strategies for Creation of Habitats (made by author)

Source: Courtesy of Turenscape

Classification	Habitat	Features	Ecological Value	Strategies
Aquatic Habitats	Bog	gentle slope, shallow water and lots of gravel	places for wading birds to forage: the boundary habitat between water and land allows for greater biodiversity according to ***Edge Effect***	**Mudflats**: filling sand and earth and lowering the water, creating foraging and resting places for wading and shore birds
				Riprap (a human-made pile or stack of stones): piling up submerged materials like rocks to reduce vertical depth and increase porosity
	Pond	closed and comparatively stable ecosystem	provide a stable habitat and forage space for fish and amphibians	**Riprap and sand**: piling up large stones to simulate reef and sand in the riverbed to provide shelter for benthonic animals and fish spawning
				Wood structure: floating and submerged materials like twigs and logs to provide habitats for waterfowl and amphibians
Seasonal Inundated Wetland	Swamp	inundated seasonally and characterized by periodic or permanent shallow water	rich in species, and functions as an ideal place for settlement and foraging	**Depressions**: creating the water kept by the depressions to provide a moist habitat for aquatic plants and small animals
				Land cover: piling up different sizes of stone and logs according to the topography, providing habitats both in wet and dry conditions
Terrestrial Environment	A shallow islet in a stream	small piece of land by the water	habitats for small mammals and rich in plant communities	**Land cover change**: applying soil replenishment partially to get soils with different nutrient levels and piling up the gravel, sands, and landfill sequentially
				Refuge: piling up bundles of twigs and logs, along with riprap, to provide refuge for small mammals and hibernating animals
	Island	land in the water	habitats for birds and amphibians, a stepping stone corridor for migratory animals	**Sandy habitat**:creating a cover of 10 to 20 cm (3.93 inches to 7.86 inches) of sandy soil
				Loam habitat: creating a thick layer of soil applicable to large areas of islands

Aquatic Habitats

An aquatic habitat is usually located on a flushed riverbank where the slope is gentle. It is an unstable area that experiences tidal shifts and changes between wet and dry seasons. It is a transfer zone between land and water where *Edge Effect* happens --the occurrence of greater species diversity and biological density in this ecotone (Wikipedia, 2019). Aquatic Habitats consist of a bog and a pond.

Bog

The shallow and gentle slope in a bog is a perfect shelter and forage space for wading birds, amphibians, reptiles, and shellfish. The shallow bog is stabilized by floodwalls, and the design restores it with riverbank environmental planning (Fig. 3.36-37).

Figure 3.362: Illustration of Habitat Creation of Aquatic Habitats (bog) (Source: courtesy of Turenscape)

Figure 3.37: Concept Imageof Habitat Creation of Aquatic Habitats (bog) (Source: courtesy of Turenscape)

Pond

A pond is a comparatively closed aquatic system with water all year around. It is surrounded by swamp or land, and its relatively stable environment is an ideal habitat for fish and small aquatic animals, as well as a place for food and water. The design approach is to simulate the natural pond by creating wood and bedrock (Fig. 3.38-39).

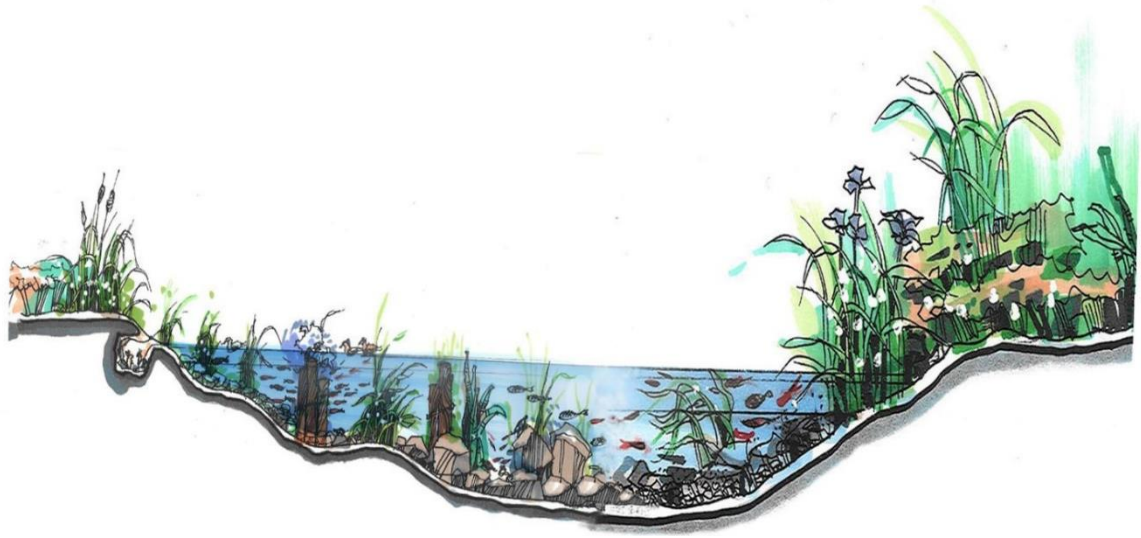


Figure 3.38: Illustration of Habitat Creation of Aquatic Habitats (pond)(Source: courtesy of Turenscape)

Figure 3.39: Concept Image of Habitat Creation of Aquatic Habitats (pond) (Source: courtesy of Turenscape)

Seasonal Inundated Area (Swamp)

Seasonal Inundated Wetland (swamp)

Flooding is an important force in shaping the natural process. Periodic floods carry sediments rich in nutrients and cover the surface of the floodplain to ensure nutrient recharge and energy input of the natural ecosystem in the floodplain area (Fig. 3.40-41). Thus, flooding makes the floodplain a region where rivers and land interact frequently with diverse species.

Figure 3.40 Illustration of Habitat Creation of Seasonal Inundated Wetland (swamp) (Source: courtesy of Turenscape)

Figure 3.41: Concept Image of Habitat Creation of Seasonal Inundated Wetland (swamp) (Source: courtesy of Turenscape)

Terrestrial Environment

The terrestrial environment has the most diverse plant communities and is the main habitat for tall trees and bushes. The creation of a terrestrial environment consists of a shallow islet of stream and island.

<u>A shallow islet in a stream</u>

Its vertical structure is more diverse than aquatic environments and inundated areas. In addition, the tall trees in this environment provide shelters for birds. The focus on creating habitats in the terrestrial environment provides varying slope and humidity to increase topographic diversity.

Beyond changing topography and land cover, “*Plant Nodes*” are built by sowing, cutting, transplanting and developing the Soil Seed Bank (all viable seeds existing on or in the soil or associated litter) (Li and Ming, 2003). Terrestrial and aquatic plant communities are established to promote their self-development in the process of natural succession. To attract more birds and small mammals and advance the refuges, strategies such as placing nests and piling up bundles of twigs and logs are adopted (Fig. 3.42-43).

Figure 3.42 : Illustration of Habitat Creation of Terrestrial Environment (a shallow islet of a stream) (Source: courtesy of Turenscape)

Figure 3.43 : Concept Image of Habitat Creation of Terrestrial Environment (a shallow islet of a stream) (Source: courtesy of Turenscape)

Island

Small islands in the water provide resting and nesting places for amphibians and birds. The design creates diverse environments of different sizes and land coverage (Fig. 3. 44-45).

Figure 3.44: Illustration of Habitat Creation of Terrestrial Environment (island) (Source: courtesy of Turenscape)

Figure 3.45 : Concept Image of Habitat Creation of Terrestrial Environment (island) Source: courtesy of Turenscape

<u>Assessment</u>

The design conducted thorough ongoing research and assessed the existing plants and designated eleven pieces of land for management and later planting. Water-resilience trees and wetland brushes along the river walk established a riparian buffer for small mammals and fish, but systemic strategies for the creation of refuges and prevention of fragmentation were not provided. It also planted flood adaptive native plants to stabilize the eroded riverbank. However, there was no detail plan for invasive species management. Consideration of animal survival during the flooding was not mentioned in the design.

PLANT COMMUNITIES & ANIMAL HABITAT	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
8. Does the project conduct ongoing biological research and evaluation?		√	
9. Does the project prevent fragmentation and provide sustainable buffers for fauna ?		√	
10.Does the project control and manage invasive species?		√	
11.Does the project enhance or enlarge the habitat?		√	

Figure 3.46 : Assessment of Plant Communities and Animal Habitats (made by author)

3.2.5 Infrastructure Design & Maintenance

The design aimed at creating a resilient space for a dynamic experience and reducing the infrastructure maintenance. The design team considered the situation when some of the infrastructure may be submerged during flooding and created a water resilient landscape through the extensive application of re-used materials and permeable pavements. Circulation, pavement, and water-resilient infrastructure will be discussed in order.

<u>Circulation</u>

The design created a safe, convenient, and systematic circulation and ensured the accessibility of a pedestrian bridge during the flooding. The circulation can be divided into two systems: external and internal circulation (Fig. 3.47).

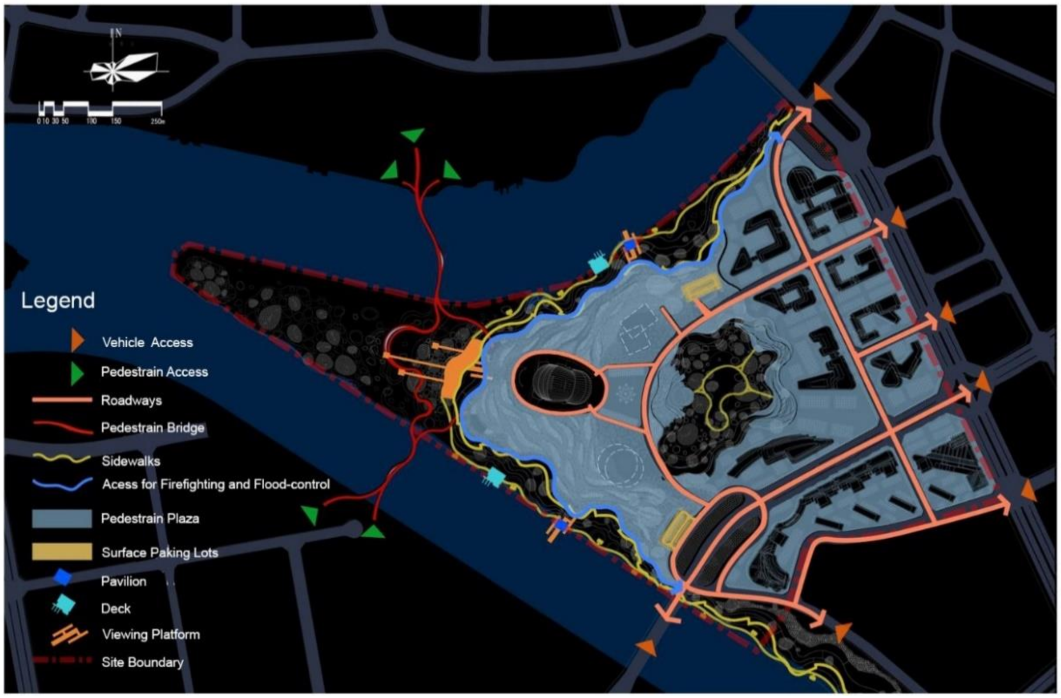


Figure 3.47: Circulation of Yanweizhou Park (Source: courtesy of Turenscape)

External circulation is comprised of a pedestrian bridge and roadways for firefighting and flood control. The original site was an abandoned sand quarry that was inaccessible and separated from Jinhua city. The design improved the accessibility of the park by building a pedestrian bridge snaking across the two rivers and connecting the southern and northern city districts. The design team took inspiration from a local tradition of dragon dancing during the Spring Festival. People dance with the wooden Bench Dragon to simulate a long and colorful dragon during the celebration. Thus, a "Bench Dragon Bridge" symbolized a bond of local cultural and social identity. According to Early Morning Scene (2014), "it recovers the vernacular cultural identity of the city" (Fig. 3.48). More importantly, as a flood-resilient infrastructure, the five-meter (16.40 feet) wide bridge is above the 200-year flood level with many four-meter (13.12 feet) wide ramps which give visitors an easy access from various locations. Visitors can overlook the riparian wetland and experience the dynamic river currents from the bridge (Fig. 3.48-49).

Figure 3.48: Yanweizhou Park during flooding (Source: courtesy of Turenscape)

Figure 3.49: Yanweizhou Park at Normal Water Level (Source: courtesy of Turenscape)

Internal circulation is comprised of roadways and sidewalks. The roadways run through the Business and Office Zone and Opera House, providing access to this area and meeting the requirements for firefighting. Sidewalks can be classified into two types: a river walk along the Terraced River Embankment (Fig. 3.50) and boardwalks in the wetland (Fig. 3. 51). The permeable gravel that is collected from the site covers all the sidewalks.

Figure 3.50: The Terraced River Embankment in Yanweizhou Park (Source: courtesy of Turenscape)

Figure 3.51 : Boardwalk in Yanweizhou Park (Source: courtesy of Turenscape)

Pavements

In order to direct the runoff into the bio-swale and planting beds, all the sidewalks are graded higher than the planting beds alongside them. In this way, even if the large volume of rainwater is not absorbed into the ground in a short time, it will flow into the green space to ensure the access of roadways.

The pavements are reused from the previous sand quarry and are one hundred percent permeable in the inner land of the park. To create a dynamic pattern with rhythm and sequence, gravel surfaces, permeable concrete, and unit pavements are placed alternatively (Fig. 3.52).

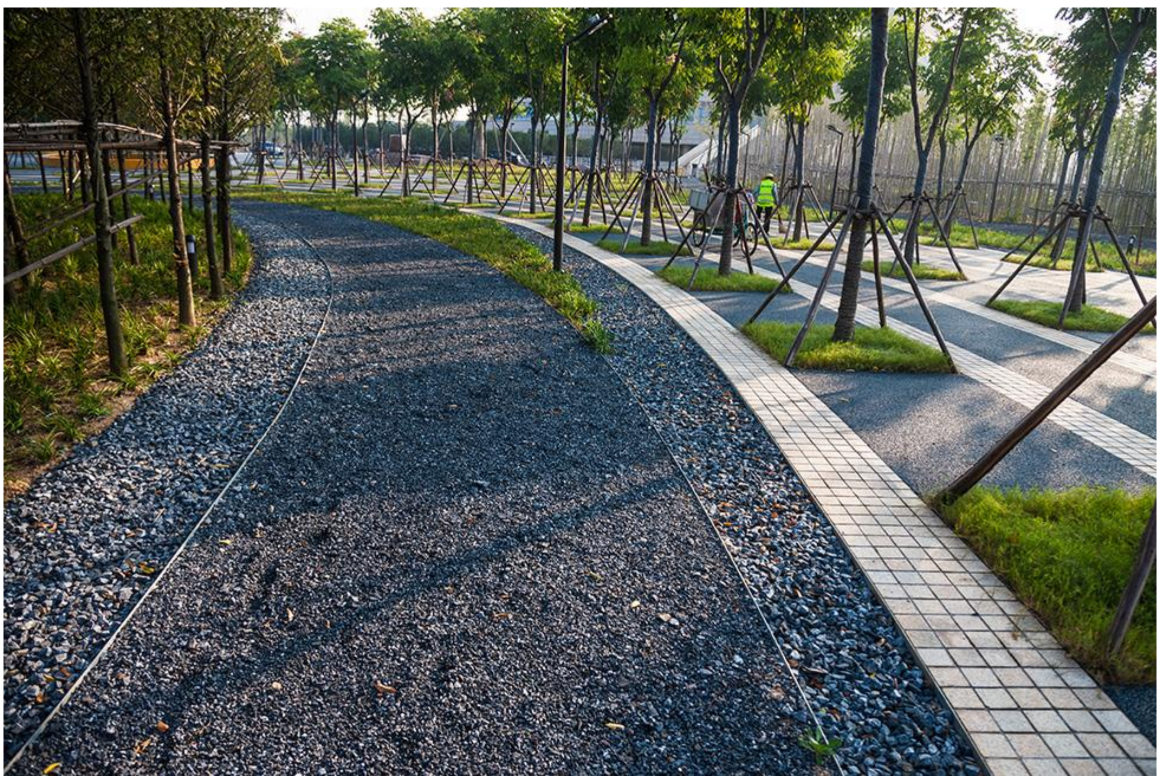


Figure 3.52: Pavements in Yanweizhou Park (Source: courtesy of Turenscape)

Flood Resilient Infrastructures

Sitting at the convergence of two rivers, the infrastructures in the park are designed to be flood-resilient. Accessibility and minimum maintenance after flooding are the priorities to be addressed.

Flood-resilient infrastructures function well and provide ecological functions at the same time. For example, long fiberglass benches encircle the bio-swale planted with water adaptive plants like Chinese Redwood (*Metasequoia glyptostroboides*) (Fig. 3.53).

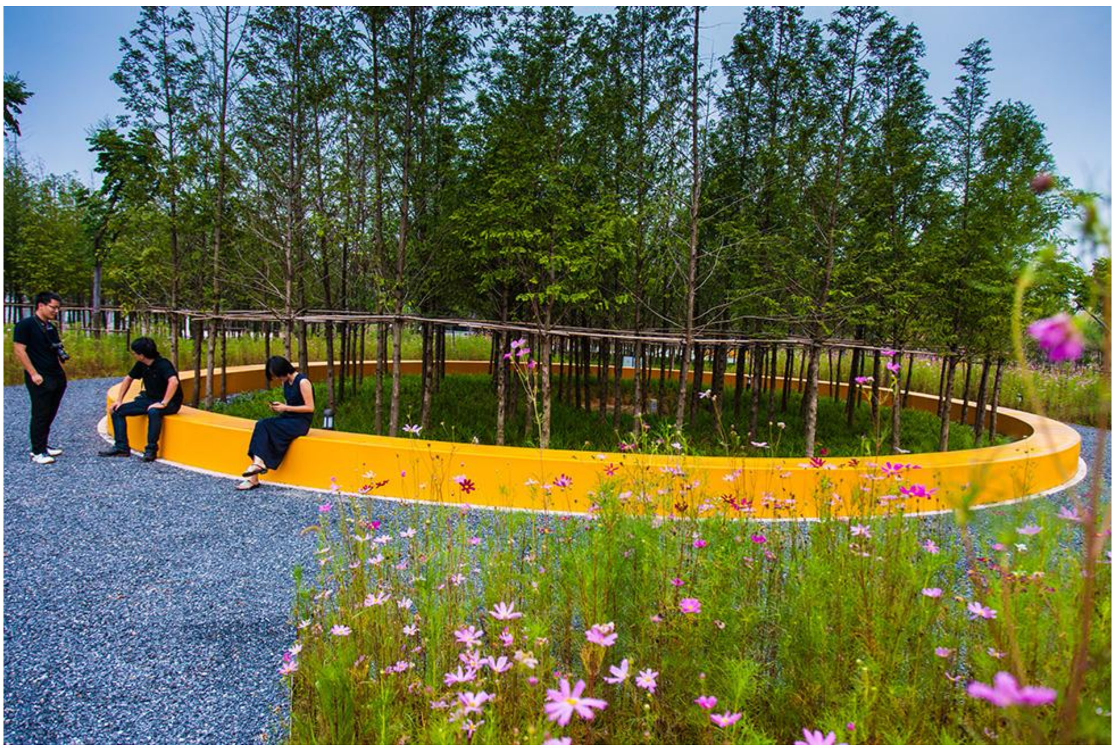


Figure 3.53: Bio-swale in Yanweizhou Park (Source: courtesy of Turenscape)

The pavilion with an extended platform is designed above the 200-year flood level and people can have a close look at the pond, the river, the city, and the Bayong Qiao Bridge from it (Fig. 3.54).

Figure 3.54: The pavilion in Yanweizhou Park (Source: courtesy of Turenscape)

Another example is the terraced embankment where people can have an intimate connection to the riparian wetland. The native flood adapted plants, along with the permeable stairs and paths, help mitigate the bank erosion and flood sediment hazards. The tall grasses are periodically fertilized from the silt brought by the flood (Landzine, 2015) (Fig. 3.55).

Figure 3.55: The terraced river embankment in Yanweizhou Park (Source: http://www.sohu.com/a/126328403_4781939)

Assessment

The design did improve the accessibility of pedestrian circulation, but the sediment after flooding is still a problem. It will take a lot of labor and time to clean and remove it. Some of the flood-resilient infrastructures performed well while others were not satisfactory as the design proposed. The future design should consider better ways to address the maintenance management.

During the 2014 flood in Jinhua city, the pedestrian bridge functioned well as usual, but all the landscape lights in the park were off for two nights and the park was a mess after the storm-- garbage and silt brought by flooding covered everything. The infrastructural maintenance was not satisfactory as the design proposed. The action stage of the river was at 34.67 meters (113.75 feet) and the total distribution box was placed at the level of 39 meters (127.95 feet). However, the water stage rose to 38 meters (124.67 feet) at 7:00 pm on June 23, 2014. As stated by the park manager Huiqun Hu, “The electricity distribution box is fine but several sub distribution boxes were submerged and we have to cut off the power. Finally, we reduced losses to some extent after unplugging the electricity distribution box." Another thorny problem was cleaning and removing the sediment after flooding. One of the workers said ,"We only cleaned 50-meters of road in three hours, and it gets harder to clean when the silt becomes dry." Another worker who deals with the garbage in the artificial pond told a reporter that he had filled up sixty garbage carts since seven clock in the morning and there was still a lot to do (Zhejiang News, 2015).

INFRASTRUCTURE & MANAGEMENT	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
12. Does the project improve accessibility of road and trail systems?		√	
13. Does the project accquire land and discourage development in river corridors?		√	
14. Does the project introduce permeable pavements?		√	
15. Does the project conduct hazard mapping, hazard identification, and land use mapping?		√	
16. Does the project have a maintenance plan for infrastructure?		√	

Figure 3.56: Assessment of Infrastructure and Management (made by author)

5.2.6 Environment Education

The design changed a brown field into a recreation place both for active and passive recreation, as well as into a place for local environmental education. In the Yanweizhou Park, people have access to the floodplain.

After replacing the concrete floodwalls with terraced embankments, the water was filtered by layers of gravel and flowed into the inner pond of the Center Water Feature Zone. Children now play and swim in the inner pond which previously was a sand quarry (Fig. 3.57).

Figure 3.57: The Inner Pond of the Center Water Feature Zone, Yanweizhou Park (Source: courtesy of Turenscape)

The flood adaptive boardwalks were designed above the five-year flood level and blend with the path system and with the terraces. They connect people with the previously inaccessible riparian wetland and improve people's awareness of flooding and natural resource protection (Fig. 3.58). The pedestrian bridge flies above the natural riparian wetland and artificial wetland, allowing people to have a close look at the floodplain and wetlands (Fig. 3.59).

Figure 3.58: A Platform in the wetland, Yanweizhou Park (Source: courtesy of Turenscape)

Figure 3.59: A Pedestrain Bridge in Yanweizhou Park (Source: courtesy of Turenscape)

Assessment

The design changes a brownfield into a recreation place both for active and passive recreation, as well as a place for local environmental education. The inner pond provides a place for children to connect intimately with water. The pedestrian bridge flies above the wetlands and allows people to have a close look at the floodplain and wetlands. The park promotes communitiy engagement and after the park opened in May 2014, an average of 40,000 visitors used the park and the bridge each day. It has becomes a focal place in Jinhua city.

ENVIRONMENTAL EDUCATION	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
17. Does the project encourage eco-tourism, active recreation (walking, jogging, cycling) and other passive recreation (birdwatching, canoeing, or hiking on nature trails)?		√	
18. Does the project promote local environmental education (access to floodplain, flood circle) ?		√	
19. Does the project promote community engagement and actions for flood management? Does the project have adequate resources located in a region or community to conduct maintenance needs or has it undertaken flood-resilient strategies?	√		

Figure 3.60: Assessment of Environmental Education (made by author)

3.3 Conclusion

<u>Assessment &Rating</u>

The two case studies are rated by the percentage of strategies achieved (Fig. 3.61). If it achieved minimally, it is ranked as OK. If it achieved the goal fully, it is ranked as Good. If it exceeded the goal, it is ranked as Excellent. Figure 3.60 illustrates the detailed achievements of the case studies.

ASPECTS	STRATEGIES	Mill Race Park	Yanweizhou Park
WATER HEALTH	1. Does the project introduce hydrological analysis (concentration, run off rate, water quality, volume)?	Good	Good
	2. Does the project restore wetlands and waterways?	Good	Excellent
	3. Does the project implement stormwater management & green infrastructure?	Good	Good
	4. Does the project combine sewer overflows to alleviate flood pressures?	Good	OK
SOIL HEALTH	5. Does the project manage soil erosion and bank stabilization?	OK	OK
	6. Does the project limit disturbance of existing health soil?	OK	Good
	7. Does the project minimize impervious area?	Good	Excellent
PLANT COMMUNITIES & ANIMAL HABITATS	8. Does the project conduct ongoing biological research and evaluation?	Good	Good
	9. Does the project prevent fragmentation and provide sustainable buffers for fauna ?	OK	Good
	10. Does the project control and manage invasive species?	OK	Good
	11. Does the project enhance or enlarge the habitat?	OK	OK
INFRASTRUCTURE & MANAGEMENT	12. Does the project improve accessibility of road and trail systems?	Good	Good
	13. Does the project accquire land and discourage development in river corridors?	Good	Good
	14. Does the project introduce permeable pavements?	OK	Good
	15. Does the project conduct hazard mapping, hazard identification, and land use mapping?	OK	Good
	16. Does the project have a maintenance plan for infrastructure?	OK	Good
ENVIRONMENTAL EDUCATION	17. Does the project encourage eco-tourism, active recreation (walking, jogging, cycling) and other passive recreation (birdwatching, canoeing, or hiking on nature trails)?	Good	Good
	18. Does the project promote local environmental education (access to floodplain, flood circle) ?	Good	Good
	19. Does the project promote community engagement and actions for flood management? Does the project have adequate resources located in a region or community to conduct maintenance needs or has it undertaken flood-resilient strategies?	OK	OK

Figure 3.61: Rating of two case studies (made by author)

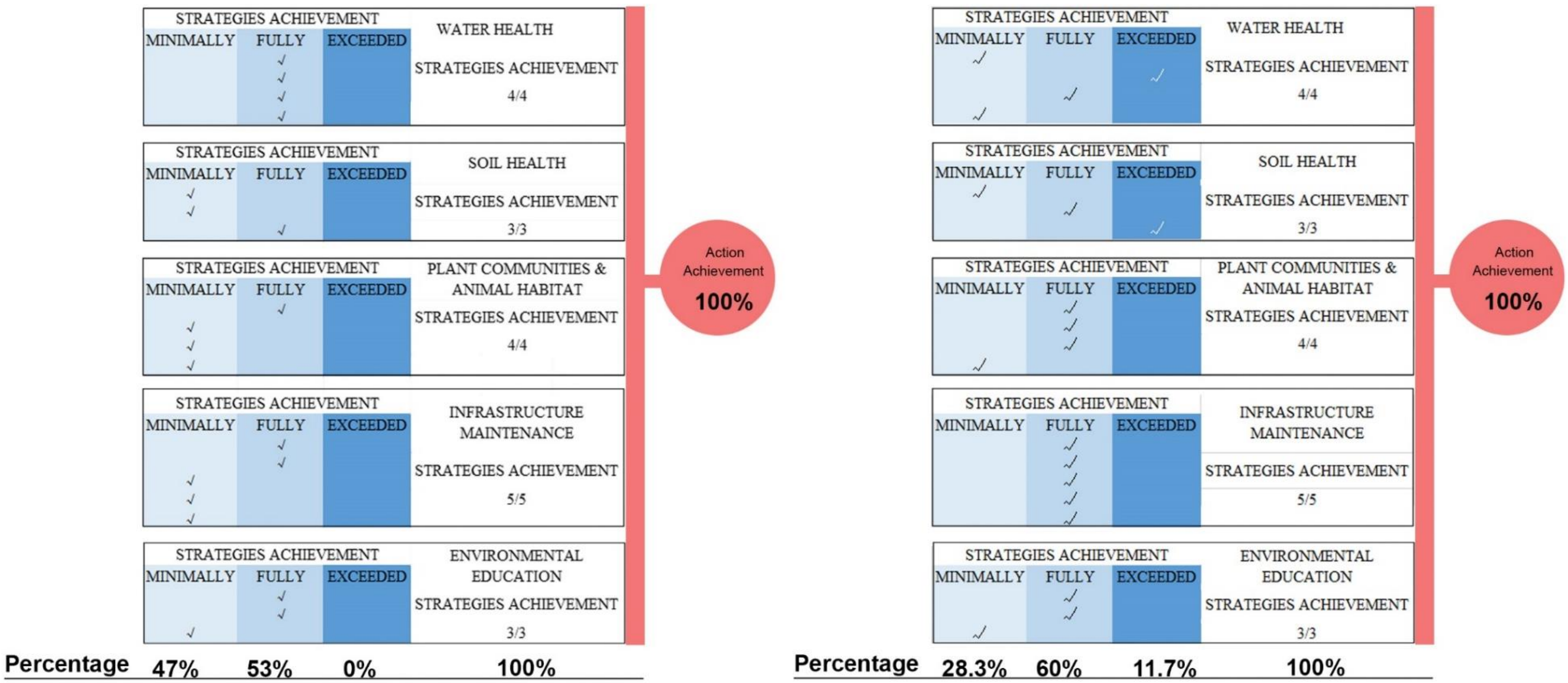


Figure 3.62: Action Achievements of two case studies (made by author)

Comparison

Mill Race Park is an early model of flood-resilient design and it achieved 100% of the criteria in the framework of flood-resilient design discussed in chapter two. This precedent of floodable park design focuses on the topographic tactics. It also provides a series of wet and dry programs to address the flooding and it meets the residents' needs. While Yanweizhou Park was built eleven years later, it also achieved 100% of its goals. However, the Turenscape design team made a great effort to improve the pavement permeability and made the park an experimental place for environmental education. Ecological design, like the terraced river embankment, bio-swale, and the inner pond in the Central Water Feature Zone, make the park unique and attractive. Yanweizhou Park is a successful model for floodable parks worldwide.

Five criteria, water health, soil health, plant communities and animal habitats, infrastructure and maintenance, and environmental education, were used to evaluate the flood resilience of the parks. The design team did a good job in conducting hydrological analysis and pre-design inventory, preserving the floodplain features and reducing infrastructure maintenance, encouraging eco-tourism and providing places for recreation and environment education, etc. However, both design teams did not consider conducting specific hazard identification for infrastructure and utilities, and developing remediation for flood hazards. Future design should take infrastructure maintenance after flooding and invasive species control into consideration.

CHAPTER 4

INVENTORY

4.1 Study Area

One of the distinguishing geographic characteristics of Georgia is the *fall line*, which is a 32 km (20 mi)-wide transition zone extending from Augusta southwest to Columbus (Fig. 4.1) and forming a narrow transition zone between the flat and sandy upper Coastal Plain to the south and the rocky hills of the Piedmont to the north. The city of Macon is located at the fall line of the Ocmulgee River, where the Native American Mississippian culture flourished from 800-1600 CE. *Okmulgee*, the Native American name for the river, means "where the water boils up." The river provides habitats for various flora and fauna, as well as a main watershed for much of the Piedmont and Coastal Plain of central Georgia (Fig.4.1) (Wendy B. Zomlefer et al. 2013, 453-473).

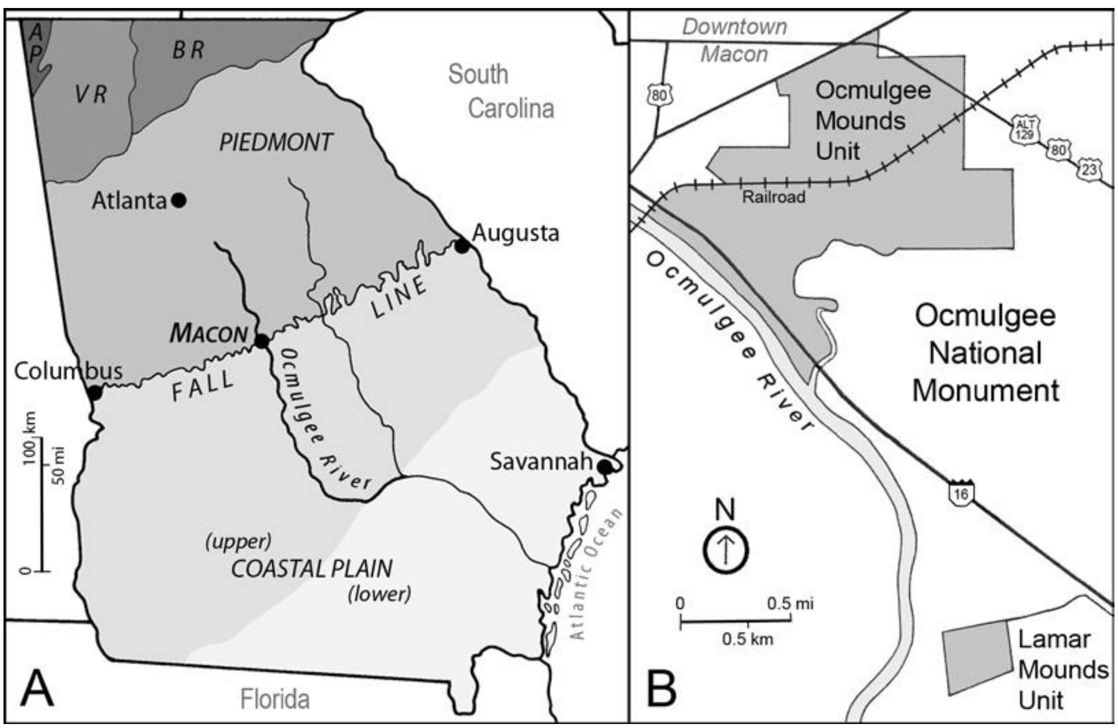


Figure 4.1 Location of Ocmulgee National Monument. A. Physiographic regions of Georgia, the fall line, and the Ocmulgee River. Abbreviations: AP = Appalachian Plateau, BR = Blue Ridge, VR = Valley and Ridge. B. Detail of eastern Macon, Georgia, showing location of the two land parcels comprising

Ocmulgee National Monument: the Ocmulgee Mounds and Lamar Mounds units. A modified by WBZ from Wharton (1978); B modified by WBZ from Wheeler (2007) and NPS (2012d). (Froeschauer, P. 1989)

The Ocmulgee National Monument (OCMU), governed by the National Park Service (NPS, U.S. Department of the Interior), is located along the Ocmulgee River in eastern Macon (Bibb County) at the fall line (NPS 2019). The 283.9 ha (701.5 acres) park has two separated parts (Figs. 1B and 2): the much larger main park unit, Ocmulgee Mound (265.7 ha, 656.5 acres), and the smaller segregated parcel ca. 3.2 km (2 mi) to the south, the Lamar Mounds unit (18 ha, 45 acres). This study only focuses on the main park unit, Ocmulgee Mound (Fig 4.2).

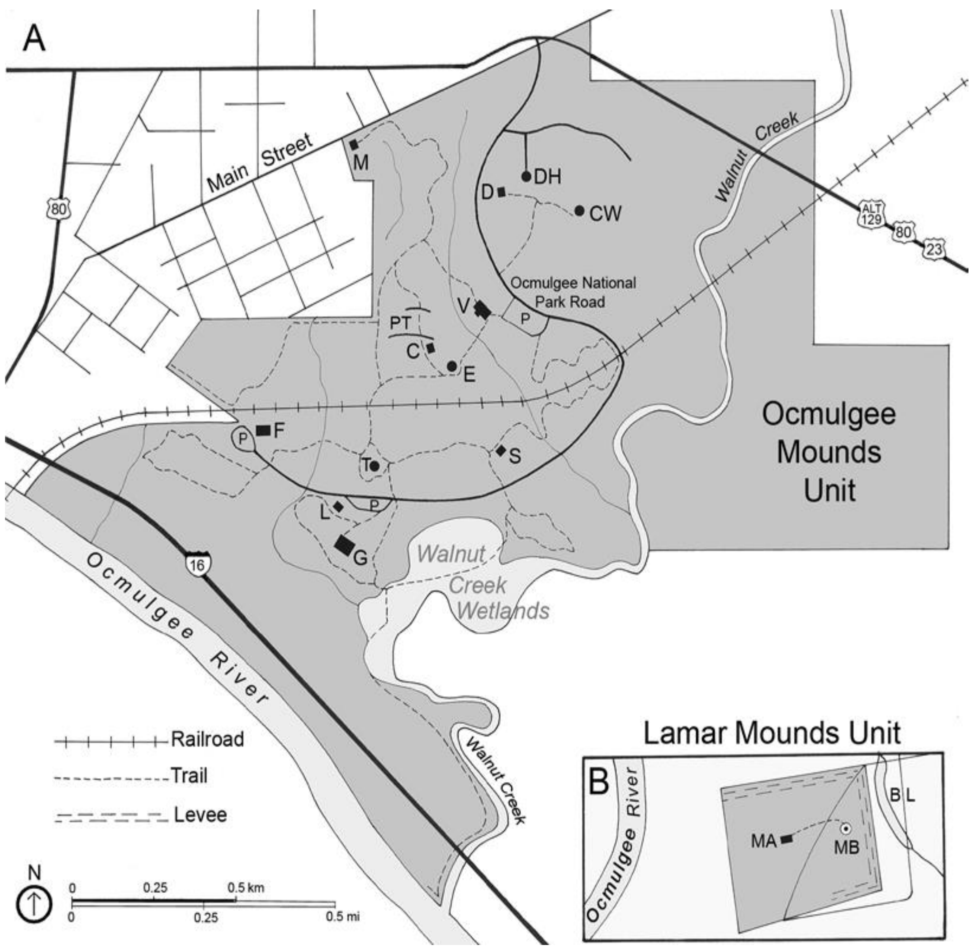


Figure 4.2 Map of Ocmulgee National Monument, showing trails and locations of major cultural features. A. Ocmulgee Mounds unit, the main park.
Abbreviations: C = Cornfield Mound, CW = Civil War earthwork, D = Dunlap Mound, DH = Dunlap House, E = Earthlodge, F = Funeral Mound, G = Great Temple Mound, L = Lesser Temple Mound, M = McDougal Mound, P = parking lot, PT = prehistoric trenches, S = Southeast Mound, T = trading post site, V = Visitor Center. (Froeschauer, P. 1989)

4.2 Topography

The topography of the Ocmulgee Mounds unit (Macon plateau site or "Ocmulgee Old Fields"; coordinates 32.838194°, -83.602124°) is dominated by a series of low hills and floodplains. The site is higher in the north and lower in the south. The highest point is the McDouga Mound at 415.5 feet, and the lowest point is the riverbed of Walnut Creek at 282 feet (Fig.4.3).

The Ocmulgee Mounds unit is juxtaposed to the eastern part of downtown Macon and is delineated to the southwest by the Ocmulgee River and to the south by Walnut Creek (Fig. 4.3). The Norfolk Northern Railroad runs through the park and divides it into two parts. Emery Highway (U.S. 80E) passes through the northeast of the park and Interstate 16 cuts through its southwestern boundary, parallel to the Ocmulgee River.

The slope of the site ranges from 2% to 76% (Fig. 4.4). Most of its land is below the 8% slope. Around the Great Temple Mound and along the driveway of the park, the slope is up to 20%. Figure 4.5 illustrates the two-foot interval contour map of the site.

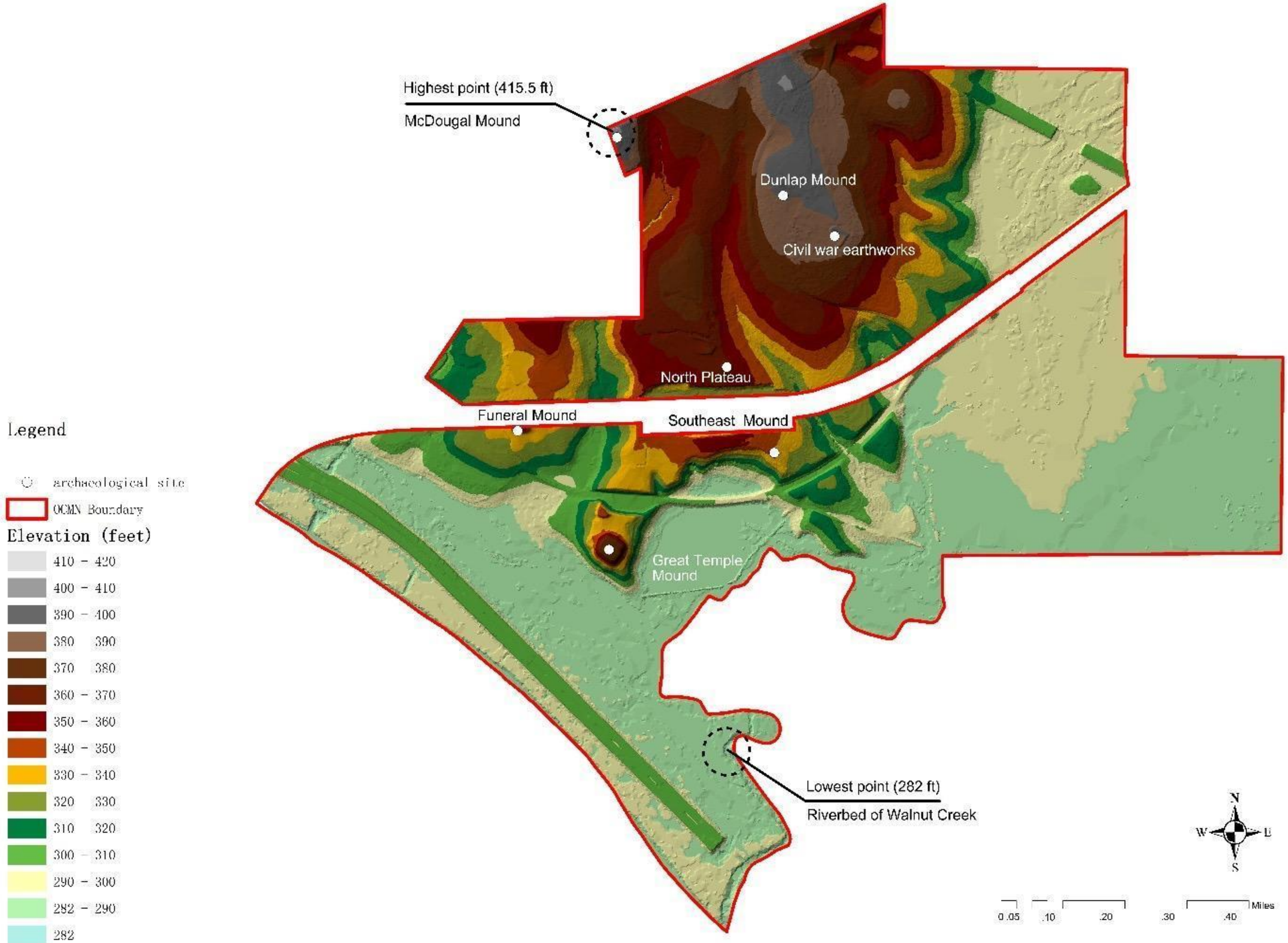


Figure 4.3: Elevation of the Ocmulgee Mounds unit (made by author)

Figure 4.4: Slope analysis of Ocmulgee Mounds unit (made by author)

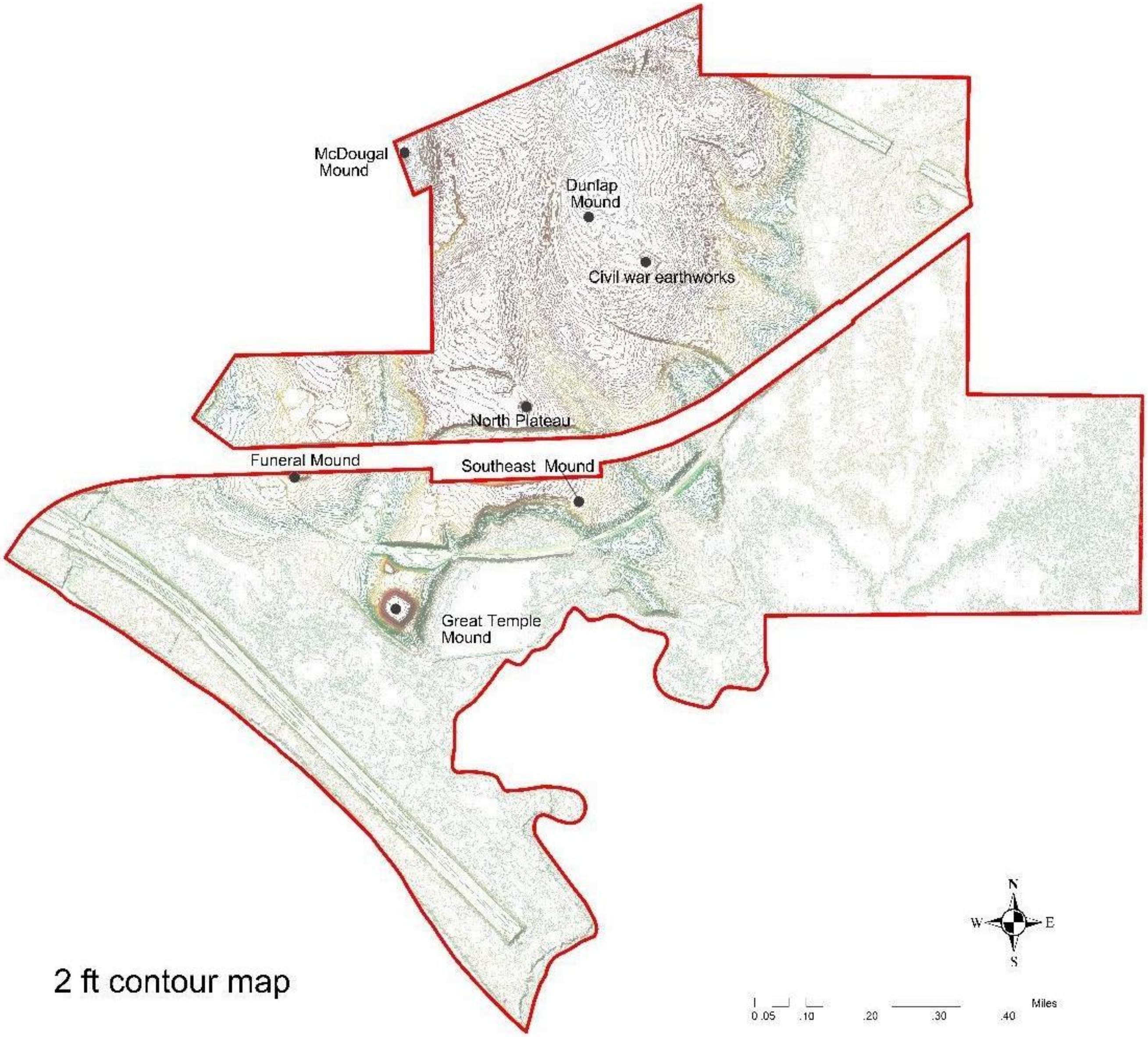


Figure 4.5: Contour map of Ocmulgee Mounds unit (made by author)

4.3 Soil type

According to the Natural Resources Conservation Service (NRCS, United States Department of Agriculture), the soil of the Ocmuglee Mounds unit can be categorized into eight types: Chewacla association, Congaree silt loam, Cowarts sandy loam, Orangeburg sandy loam (2 to 5 percent slopes and 5 to 8 percent slopes), Orangeburg-Urban land complex, Urban land, Vaucluse loamy sand (8 to 17 percent slopes), and Vaucluse-Urban land complex (2 to 8 percent slopes) (Fig. 4.6). Table 14 illustrates the soil features of the site.

Ck--Chewacla association, refers to the soil that has a somewhat poorly drained soils that formed in alluvium.

Co--Congaree silt loam, refers to the "well drained or moderately well drained soil" which usually found on flood plains near the large steams.

VeD-- Vaucluse loamy sand, 8 to 17 percent slopes.

OcC-- Orangeburg sandy loam, 5 to 8 percent slopes.

OcB-- Orangeburg sandy loam, 2 to 5 percent slopes.

W-- Water.

Vuc--Vaucluse-Urban land complex, 2 to 8 percent slopes

OcuC--Orangeburg-Urban land complex, 0 to 8 percent slopes.

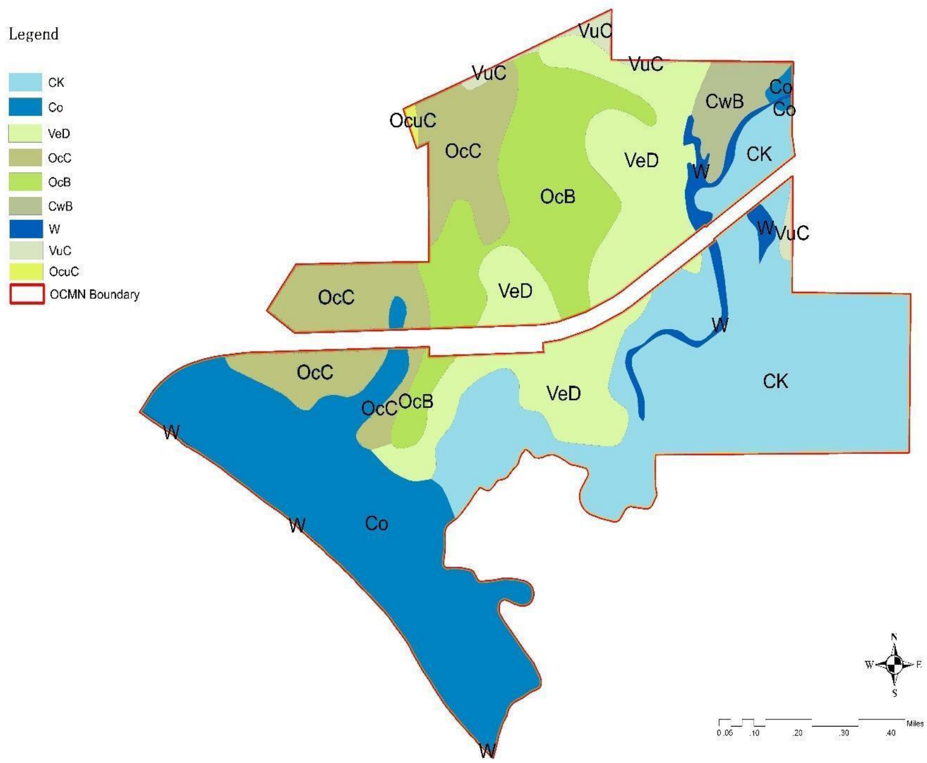


Figure 4.6: Soil types of Ocmulgee Mounds unit (made by author)

Table 14: Soil Features (made by author)
Source: Custom Soil Resource Report for Bibb County, Georgia

Map Unit Symbol	Map Unit Name	Acres	Percentage	Setting	Hydrologic Soil Group	Available water storage in profile	Capacity of the most limiting layer to transmit water (Ksat)	Ecological site
CK	Chewacla association	193.7	28.3%	Flood plains	B/D	High (about 12.0 inches)	Moderately high to high (0.57 to 1.98 in/hr)	
Co	Congaree silt loam	145.7	21.2%	Flood plains	C	High (about 9.6 inches)	High (about 9.6 inches)	
VeD	Vaucluse loamy sand, 8 to 17 percent slopes	123.7	18.0%	Hills	C	Low (about 4.6 inches)	Very low to moderately high (0.00 to 0.57 in/hr)	
OcC	Orangeburg sandy loam, 5 to 8 percent slopes	91.2	13.3%	Hills	B	Moderate (about 7.5 inches)	Moderately high to high (0.57 to 1.98 in/hr)	
OcB	Orangeburg sandy loam, 2 to 5 percent slopes	87.8	12.8%	interfluves	B	Moderate (about 7.5 inches)	Moderately high to high (0.57 to 1.98 in/hr)	
CwB	Cowarts sandy loam, 2 to 5 percent slopes	17.4	2.5%	Hills	C	Low (about 3.2 inches)	Very low to moderately high (0.00 to 0.57 in/hr)	Loamy Summit Woodland
W	Water	14.6	2.1%					
VuC	Vaucluse-Urban land complex, 2 to 8 percent slopes	10.3	1.5%	Hills	C	Low (about 4.6 inches)	Very low to moderately high (0.00 to 0.57 in/hr)	
OcuC	Orangeburg-Urban land complex, 0 to 8 percent slopes	1.2	0.2%	Hills	B	Moderate (about 7.5 inches)	Moderately high to high (0.57 to 1.98 in/hr)	
Totals		685.5	100.0%					

The available water capacity is the volume of soil that can be used for the use of plants. Another way to refer to water capacity is "the classes of available water capacity," which is classified into four categories (Fig. 4.7): very high, high, moderate and low (NRCS, 1998). Around fifty percent of the soil (Co and Ck) in the Ocmulgee Mounds unit has high ability for water storage, but is very limited for the use as a pond reservoir, and this part of the soil lies in the flood plain along the Ocmuglee River and Walnut Creek. Soil that has moderate ability of water storage covers ca. 26.3% of the unit and the remaining 22 % soil is limited to hold water. Table 1 shows the detail features of the soil in the main unit of OCMU.

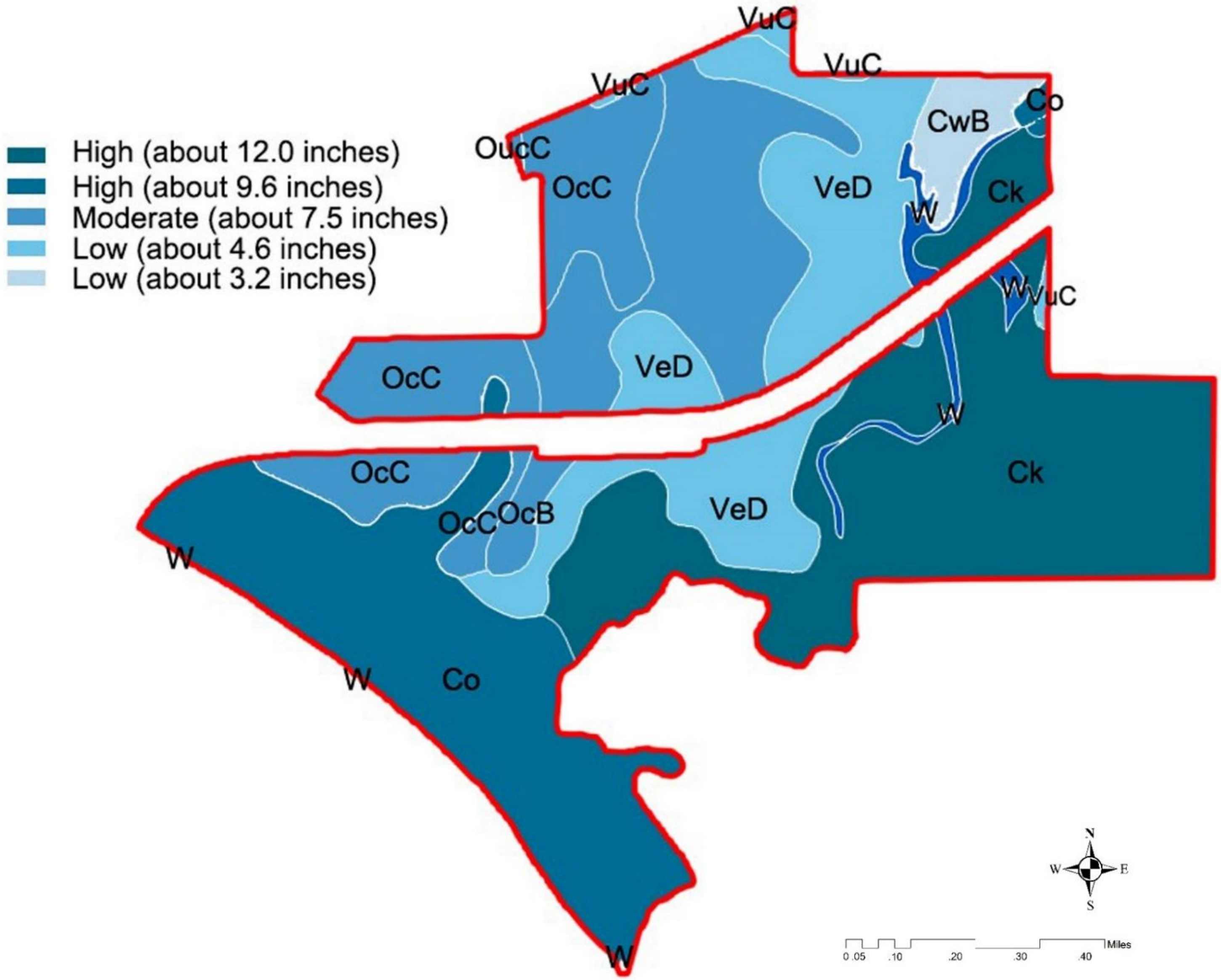


Figure 4.7: Soil Water Storage Availability of Ocmulgee Mounds unit (made by author)

4.4 Land cover and Plant community

4.4.1 Land cover

Land cover refers to the physical material at the surface of the earth (Gregorio**,** Jansen,2000). Different land use or land cover will result in various surface run-off and infiltration. Based on data from the National Oceanic and Atmospheric Administration (NOOA), Figure 4.9 illustrates a 2010 land cover map of the OCMU main unit and Figure 4.10 is a simplified version of it. The land cover of the Ocmulgee Mounds unit can be classified into fifteen types (Table 15).

Table 15: Land Cover of Ocmulgee Mounds Unit (made by author)
Source:https://coast.noaa.gov/dataviewer/#/landcover/search/9308339.897829738,3872639.1052649226,-9305000.313105939,3876614.0935386554/details/1470

Number	Land cover	Percentage
1	Developed - Low Intensity	20.4%
2	Evergreen Forest	12.9%
3	Developed - Open Space	11.9%
4	Deciduous Forest	11.2%
5	Palustrine Forested Wetland	9.4%
6	Developed - Medium Intensity	8.2%
7	Mixed Forest	7.3%
8	Developed - High Intensity	3.8%
9	Palustrine Emergent Wetland	3.2%
10	Scrub/Shrub	3.0%
11	grassland	2.9%
12	Pasture/Hay	2.6%
13	Palustrine Scrub/Shrub Wetland	1.7%
14	Water	1.4%
15	Cultivated	0.2%
	Total	**100.0%**

In the simplified land use map (Fig.4.10), the Palustrine Forested Wetland (9.4%), Palustrine Emergent Wetland (3.2%) and Palustrine Scrub/Shrub Wetland (1.7%) are combined to Wetland (14.3%). And the Evergreen Forest (12.9%), Deciduous Forest (11.2%), Mixed Forest(7.3%) are combined to Forest (31.3%). Grassland (2.9%) and Pasture/Hay (2.6%) are combined into Grassland/ Pasture/Hay (5.4%).

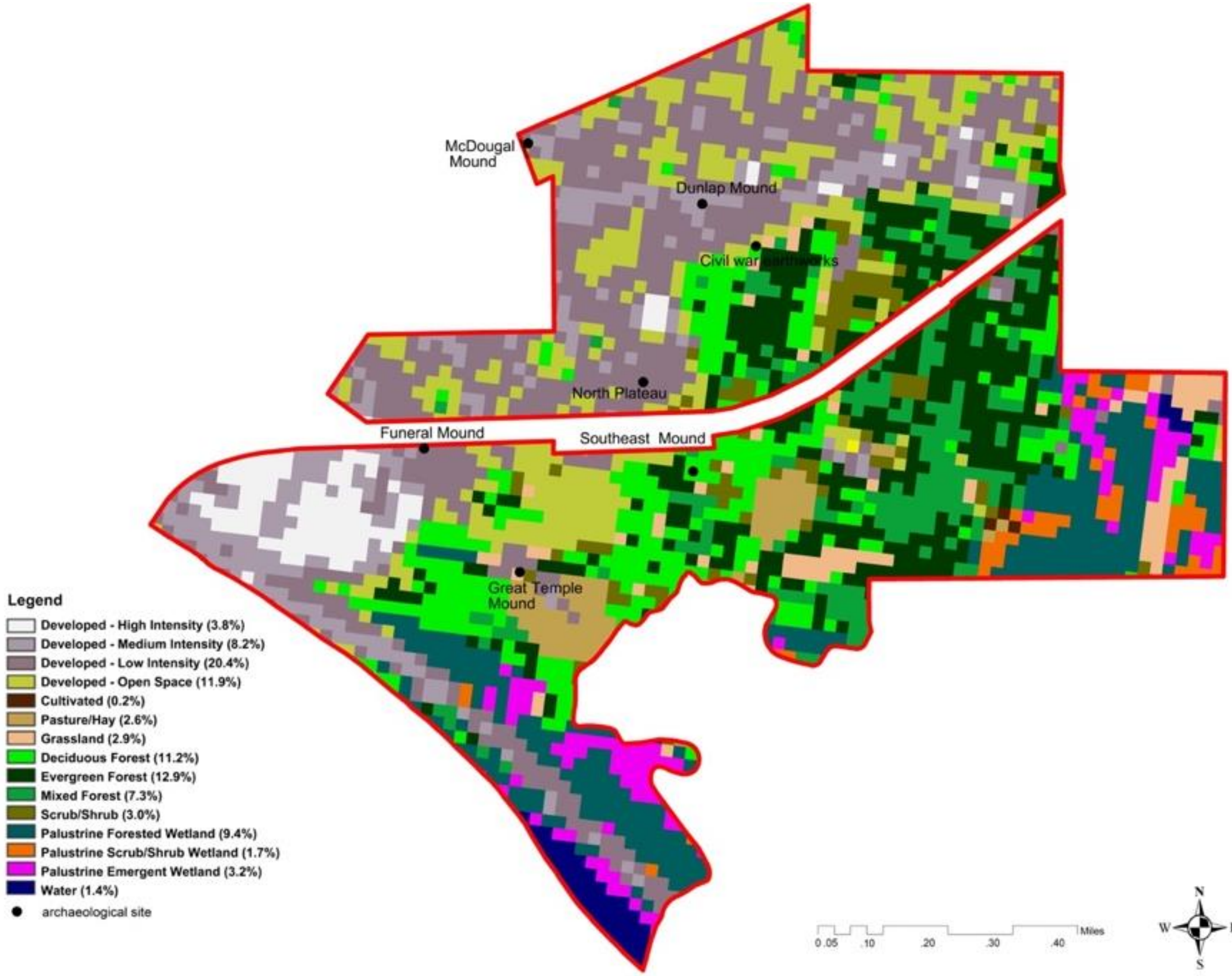


Figure 4.8：2010 Land Cover Map of Ocmulgee Mounds Unit in Detail (made by author)
Source:https://coast.noaa.gov/dataviewer/#/landcover/search/9308339.897829738,3872639.1052649226,9305000.313105939,3876614.0935386554/details/1470

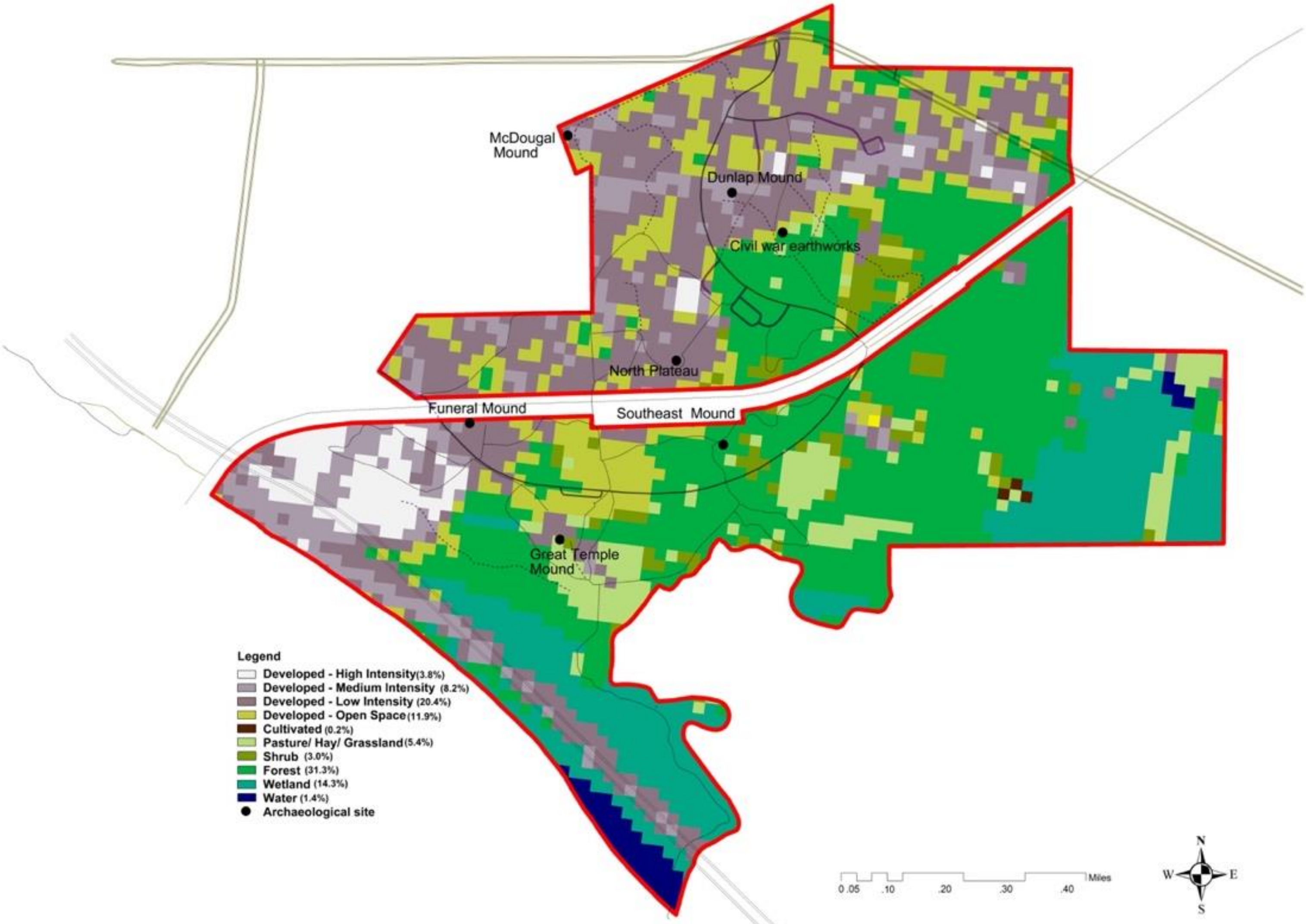


Figure 4.9：Modified 2010 Land Cover Map of Ocmulgee Mounds Unit (made by author)
Source: https://coast.noaa.gov/dataviewer/#/landcover/search/9308339.897829738,3872639.1052649226,-9305000.313105939,3876614.0935386554/details/1

Zomlefer and his associates (2013) note that the Ocmulgee National Monument has a long history of disturbances that drastically altered its land cover, especially in the last two centuries. According to the *2007 OCMU Cultural Landscape Report* (Wheeler 2007, 46), prehistorical vegetation is unavailable, but it is noted that Mississippian farmers cleared the land around the Ocmulgee mounds to use for building material, defense, and cropland. More recently, a major part of the Macon Plateau experienced significant alteration due to wide-scale excavation -- the New Deal archeology between 1933 and 1936. Currently, the Ocmulgee Mounds unit is comprised of grassy fields (around the mounds) embraced mostly by upland woods and forested or open wetland habitats (Fig.4.11) (Zomlefer et al. 2013, 460).

4.4.2 Plant communities

According to the most recent 2008-2009 Floristic surveys of OCMU made by Zomlefer and associates, there are 436 species (610 specimens) in the park and 106 species are non-native. With the exception of three cultivated exotics, the remaining 103 introduced species take up 23.6 percent of the flora and grow together with native grasses in the mound areas.

Based on the previous research of Wharton (1978), Foreschauer (1989), W.B. Zomlefer and his associates (2008), the overall plant communities of the Ocmulgee Mounds unit can be categorized into five types (Fig. 4.11): upland hardwood forest, upland mixed hardwood-pine forest, swamp forest, open wetland, and disturbed areas (Zomlefer et al. 2013, 461). The detail species are shown on Table 16.

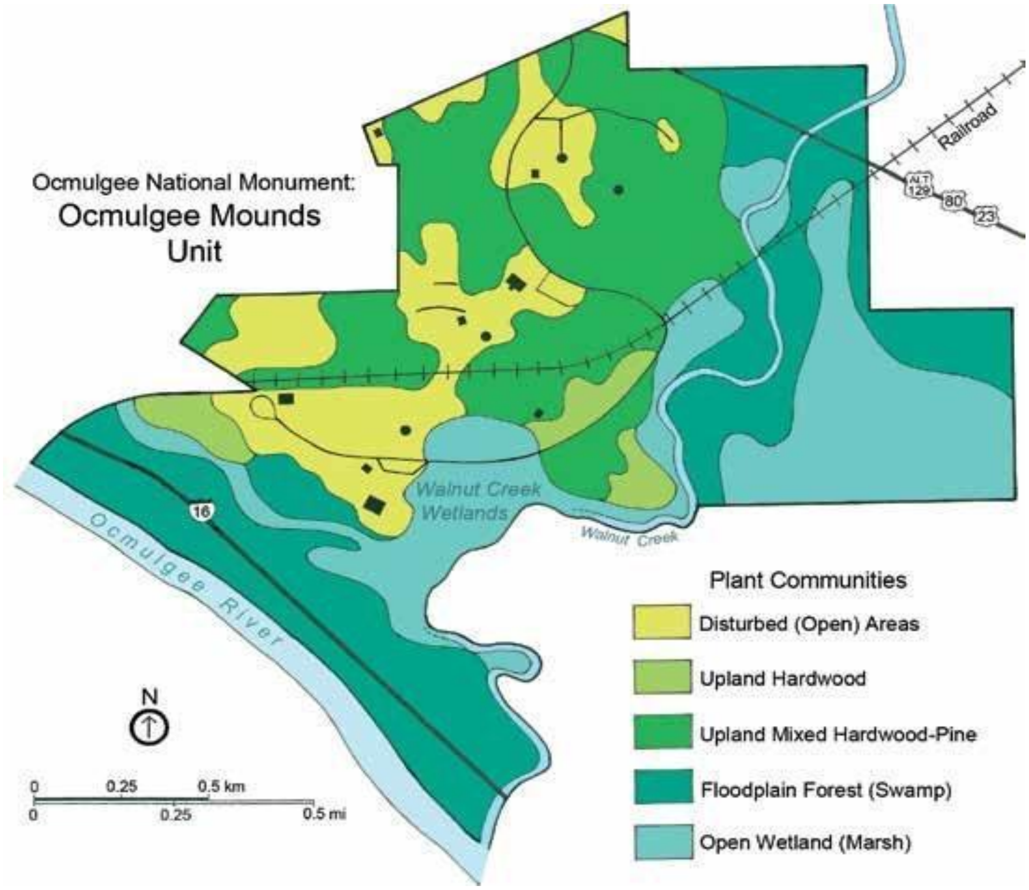


Figure 4.10： Plant Communities in Ocmulgee Mounds Unit (Zomlefer et al. 2013)

Upland Forests--It refers to the land that has a tree canopy with a combined coverage of species ranging from 50 to 100 percent (Aaseng, 2003). The plant communities in the upland hardwood forest and the upland mixed hardwood-pine forest are similar, but the understory vegetation is more varied in the mixed hardwood forest. Disturbance has altered the forested uplands into secondary growth hardwood and mixed hardwood-pine at the Ocmulgee mounds unit (Wharton 1978; Burkholder et al. 2010). They are composed of dominant hardwood canopy trees and understory shrubs and shrubby trees intertwined with vine species (Zomlefer et al. 2013, 462).

Floodplain Forest--Swamp or bottomland hardwood (floodplain, alluvial, or palustrine forest) along the Ocmulgee river and Walnut Creek, are seasonally inundated, mesic lowland. It is located in the southwestern and eastern part of the park , mainly surrounding by open marshland

(Wharton 1978).Tall trees form a closed-canopy over an impassable clump of shrubby understory with a comparably scattered fern community (Zomlefer et al. 2013, 462).

Open Wetlands– Zomlefer and associates claim that this wide-ranging definition applies to the aquatic area at the study area where there is little to no canopy and it is submerged by water at least for a while throughout the year. Walnut Creek wetland, a large marsh, emerged from hydrological changes due to the construction of Interstate 16 between 1966 and 1968 (Wheeler 2007; Burkholder et al. 2010; Macon Telegraph 2013). These open wetlands were once forested and inundated seasonally before 1994 where Interstate 16 was constructed, but now they contain "standing water" all year around. Sedges and grasses prevail in these areas with scattered woody vines and shrubs along the margins.

Disturbed or Ruderal Areas-- Cleared sections around public access areas (parking lots, roadsides, trails, railroad right-of -way) and mowed fields surrounding earthworks and other historic sites apply to this general category. These areas comprise non-native and invasive species and a dominance of graminoids and *Asteraceae* and are bordered by woody species (Zomlefer et al. 2013, 462).

According to the NPS water assessment report (Burkholder et al. 2010), the wetland and aquatic vegetation in the main mound unit has been disturbed by at least three major engineering constructions: Interstate 16, the Macon levee and the pre-existing railroad bed (Fig.4.16). First, "the bridging from the construction of I-16" cut off the flow channel of surface water towards to Ocmulgee River. Second, the intersection of the I-16 roadbed with a pre-existent railroad bed retains water on OCMU's southeastern boundary. Consequently, it transformed the previous "forested woodland with organic soil into an open aquatic wetland with emergent and floating vegetation"(Burkholder et al. 2010). Lastly, the Macon levee which parallels the Ocmulgee River, has caused "more severe flooding on the eastern shore"(Burkholder et al. 2010). As Chief Ranger G. LaChine said, "The flooding led to increased erosion and tree loss." Overall, the construction and the places mentioned above have become overpopulated with invasive plants such as Chinese privet, which contributes to the loss of native wetland tree species like swamp chestnut and river birch.

Table 16: Vegetation of Ocmulgee Mounds Unit (modified by author)
Source: A Baseline Vascular Plant Survey for Ocmulgee National Monument, Bibb County, Macon, Georgia (Zomlefer et al. 2013)

Community types	Dominant trees	Dominant understory shrubs and shrubby trees	Dominant vine/ ferns
Upland forest	oaks (e.g., *Quercus falcata, Q. nigra, Q. phellos*) hickories (e.g, *Carya glabra, C. ovata*) Loblolly pine (*Pinus taeda*)	*Aesculus pavia, Asimina parviflora, Calycanthus floridus, Carpinus caroliniana, Celtis laevigata, Cornus florida, Crataegus* spp. (e.g., *C. spathulata*), *Diospyros virginiana, Ilex* spp. (e.g., *I. decidua*), *Ligustrum sinense, Prunus serotina*, and *Vaccinium arboreum*.	*Gelsemium sempervirens, Hedera helix,* *Lonicera japonica,* Smilax spp. *(e.g., S. bonanox),* *Toxicodendron radicans,* Vitis spp. *(e.g., V. rotundifolia)*
Swamp forest	*Acer* spp. (e.g., *A. negundo, A. rubrum*), *Betula nigra, Fraxinus penn- sylvanica, Liquidambar styraciflua, Liriodendron tulipifera, Nyssa biflora, Platanus occidentalis, Quercus* spp. (e.g., *Q. nigra*), and *Ulmus americana*	*Alnus serrulata, Asimina parviflora, Bignonia capreolata, Carpinus caroliniana, Crataegus viridis, Itea virginica, Ilex* spp. (e.g., *I. vomitoria*), *Ligustrum sinense, Lonicera japonica, Ostrya virginiana, Pinus taeda, Salix caroliniana, Smilax* spp. (e.g., *S. laurifolia*), *Triadica sebifera, Toxicodendron radicans*, and *Vitis* spp. (e.g., *V. rotundifolia*)	*Onoclea sensiblis* and *Woodwardia areolata*, and angiosperm species, such as *Arundinaria gigantea, Arisaema triphyllum, Com- melina virginica, Juncus coriaceus, Justicia ovata, Leersia lenticularis, Lobelia cardinalis, Lycopus rubellus*, and *Pi lea pumila*

Community types	Predominate sedges and grasses	Common woody vines and scattered shrubs	Common herbaceous species
Open wetland	*Carex* spp. (e.g., *C. loui sianica, C. lupulina*), *Cyperus* spp. (e.g., *C. erythrorhizos, C. retrorsus*), *Leersia virginica, Panicum anceps, P. rigidu lum, Phanopyrum gymnocarpon, Rhynchospora globularis*, and *Scirpus cyperinus*	*Berchemia scandens, Brun- nichia ovata, Cephalanthus occidentalis, Cornus stricta, Forestiera acuminata, Hibiscus laevis, Rubus pensilvanicus, Sabal minor, Sambucus canadensis, Smilax* spp. (e.g., *S. glauca*), and *Vitis* spp. (e.g., *V. aestivalis*)	*Erechtites hieraciifolius, Galium triflorum, Hydrocotyle verticillata, Iris hexagona, Juncus dichotomus, Ludwigia spp. (e.g., L. decurrens), Mikania scandens, Mimulus alatus, Murdannia keisak, Packera glabella, Persicaria spp*

Community Types	Non-Native And Invasive Species And A Predominance of Graminoids	Asteraceae	Woody Species At The Borders
Disturbed/ Ruderal areas	*Andropogon* spp. (e.g., *A. glomeratus*), *Bromus racemosus*, *Cynodon dactylon*, *Dactylis glomerata*, *Danthonia spicata*, *Dichanthelium* spp. (e.g., *D. dichotomum*), *Echinochloa crusgalli*, *Eragrostis* spp. (e.g., *E. curvula*), *Festuca subverticillata*, *Lolium pe- renne*, *Panicum* spp. (e.g., *P. virgatum)*, *Paspalum* spp. (e.g., *P. dilatatum*), *Setaria parviflora*, *Sorghastrum nutans*, *Sorghum halepense*, and *Vulpia myuros*	*Ambrosia artemisiifolia*, *Erigeron strigosus*, *Eupatorium hyssopifolium*, *Gamochaeta* spp. (e.g., *G. pensylva- nica*), *Helenium amarum*, *Hypochaeris radicata*, *Krigia virginica*, *Pityopsis graminifolia*, *Solidago altissima*, *Son- chus oleraceus*, and *Youngia japonica*. *Allium canadense*, *Chaerophyllum tainturieri*, *Glandularia pulchella*, *Hous- tonia pusilla*, *Ipomoea* spp. (e.g., *I. cordatotriloba*), *Lamium amplexicaule*, *Lespedeza cuneata*, *Plantago* spp. (e.g., *P. lanceolata*), *Polypremum procumbens*, *Stellaria media*, *Trifolium arvense*, *Vicia* spp. (e.g., *V. sativa*), and *Viola ar- vensis*	*Morus rubra*, *Prunus serotina*, *Rubus trivialis*, *Toxicodendron radicans*, and *Vitis* spp. (e.g., *V. rotundifolia*).

4.5 Land Use

The land use of the OCMU main unit has undergone drastic changes from the Woodland Period (1000BCE-900 CE) to now. During the Woodland Period, people constructed semi-permanent villages, as well as stone effigy mounds and earthen burial and platform mounds. It was occupied by the Early Mississippians from 900 to 1100 CE, and it functioned as an agricultural farmland and a ceremonial land in that period. Later on, the Lamar Mississippians abandoned this land and migrated to the swamps about 3.2 km (2 miles) downstream. The main unit was not in use again until 1690 when the Creek (the descendants of the Lamar) returned to the site and re-established "Okmulgee Town." During this period, the land was used as agricultural, ceremonial, and commercial lands. Just over one century later, the site was incorporated into the new city of Macon in 1826. However, in the mid-1850s, the site was transformed into a large plantation, and construction of the Central Georgia Railroad impaired the site ecosystem and led to soil erosion. There were later impairments such as the clearing of vegetation and removal of much of the Funeral Mound. From 1933 to 1942, a massive excavation organized by the Smithsonian Institute and the Civilian Conservation Corps (CCC) took place at the site. Also, the site was designated as the Ocmulgee National Monument by Presidential Proclamation in 1936. During the 1960s, large construction projects were implemented at the site and further damaged its ecosystem. A brick factory, fertilizer plant, and dairy farm were also built at the site. The situation became worse when the construction of the Macon Levee (1950) and Interstate 16 (in the 1960s) extensively changed the hydrology of the park. However, until recently, limited funding and labor were allocated to the OCMU. This year on March 12, the White House officially signed a bill which expands the park by 2100 acres and re-designates it from the Ocmulgee National Monument to the Ocmulgee Mounds National Historical Park. Table 17 illustrates the land use history of the Ocmulgee Mounds unit.

Table 17: Land Use history of Ocmulgee Mounds Unit (made by author)
Source: National Park Service, 2019 https://www.nps.gov/ocmu/learn/historyculture/people.htm
A Baseline Vascular Plant Survey for Ocmulgee National Monument, Bibb County, Macon, Georgia (Zomlefer et al. 2013)

Periods	Main Unit of OCMU	Land Use	Note
Paleoindian Culture (17,000 BCE-9,600 BCE)	Ice Age hunters arrive in the Southeast, leaving their distinctive "Clovis" spear points on the Macon Plateau	Residential	
Archaic Period (9,600 BCE-1000 BCE)	A residential stable hunting and gathering band was located along the major water course for food resource	Residential	Early Archaic culture consisted of small mobile bands exploiting defined territories, but the increase in the number of sites and the recovery of non-local chert tended to support an increase in population resulting in larger numbers of bands that traded resources with each other
Woodland Period (1000 BCE-900 CE)	People constructed semi-permanent villages, as well as stone effigy mounds and earthen burial and platform mounds	Residential, ceremonial, agricultural	The Woodland Culture was thriving here up until 900 CE when newcomers known as the Mississippians came here and built their villages
Early Mississippians (900 CE-1100 CE)	Early Mississippians built a town along the Ocmulgee River bottomlands. The town included a ceremonial complex: a circular earth lodge with seven massive flat-topped pyramidal earthworks	Agricultural, ceremonial	An agricultural economy was the dominant economy managed by master farmers
Lamar/Late Mississippians (by 1350 CE)	Ocmulgee Fields was no longer used as a ceremonial center	Forest	
1690 Creek re-established the town	The “Creek” returned to Ocmulgee Fields and rebuilt “Okmulgee Town”	Agricultural, ceremonial, commercial	Agriculture was the dominant economic source, and people traded with the British in a trading post and fort near the sacred mounds
1826-1828	The Ocmulgee Field was incorporated into the new city of Macon	Recreational	The new state of Georgia obtained concessions to Creek tribal lands in 1826
Mid-1850s	The main park functioned as a large plantation Construction of the Central Georgia Railroad (1835-1843) cleared the vegetation and removed much of the Funeral Mound	Agricultural, industrial	Grazing removed understory vegetation in the forested areas of Walnut Creek, and intensive agricultural production around the mound eroded topsoil that accumulated downriver at the Lamar site
1933-1942 Massive excavation	Archeological studies were organized by the Smithsonian Institute and the Civilian Conservation Corps (CCC)	Recreational	Ocmulgee Field was designated as Ocmulgee National Monument by Presidential Proclamation in 1936
1960 Large construction on the site	After the Civil War (1861-1865), industrial buildings such as a brick factory, fertilizer plant, and dairy farm were built at the park The construction of the Macon Levee (1950) and Interstate 16 (in the 1960s) extensively changed the hydrology of the park	Recreational, industrial	Industrial and recreational activities further eroded the earthwork of the park and changed its hydrology
2019 Expanded and renamed	The site was expanded by 2100 acres and placed under preservation	Recreational	On March 12, 2019, the White House officially signed a bill which expands the park by 2100 acres and re-designates the park from the Ocmulgee National Monument to the Ocmulgee Mounds National Historical Park

4.6 Water System

4.6.1 Watershed

OCMU lies in the Walnut Creek watershed (50.2 square miles), a sub-watershed of the Ocmulgee River watershed (2,400 square miles) (Fig. 4.12). The Ocmulgee River delineates the southwestern boundary of OCMU, and Walnut Creek (20 miles in length), its largest tributary in the main unit, partly establishes its southeastern boundary (Fig. 4.13).

Figure 4.11: Ocmulgee River Watershed
Source:https://epd.georgia.gov/sites/epd.georgia.gov/files/related_files/site_page/Ocmulgee-Contents.pdf

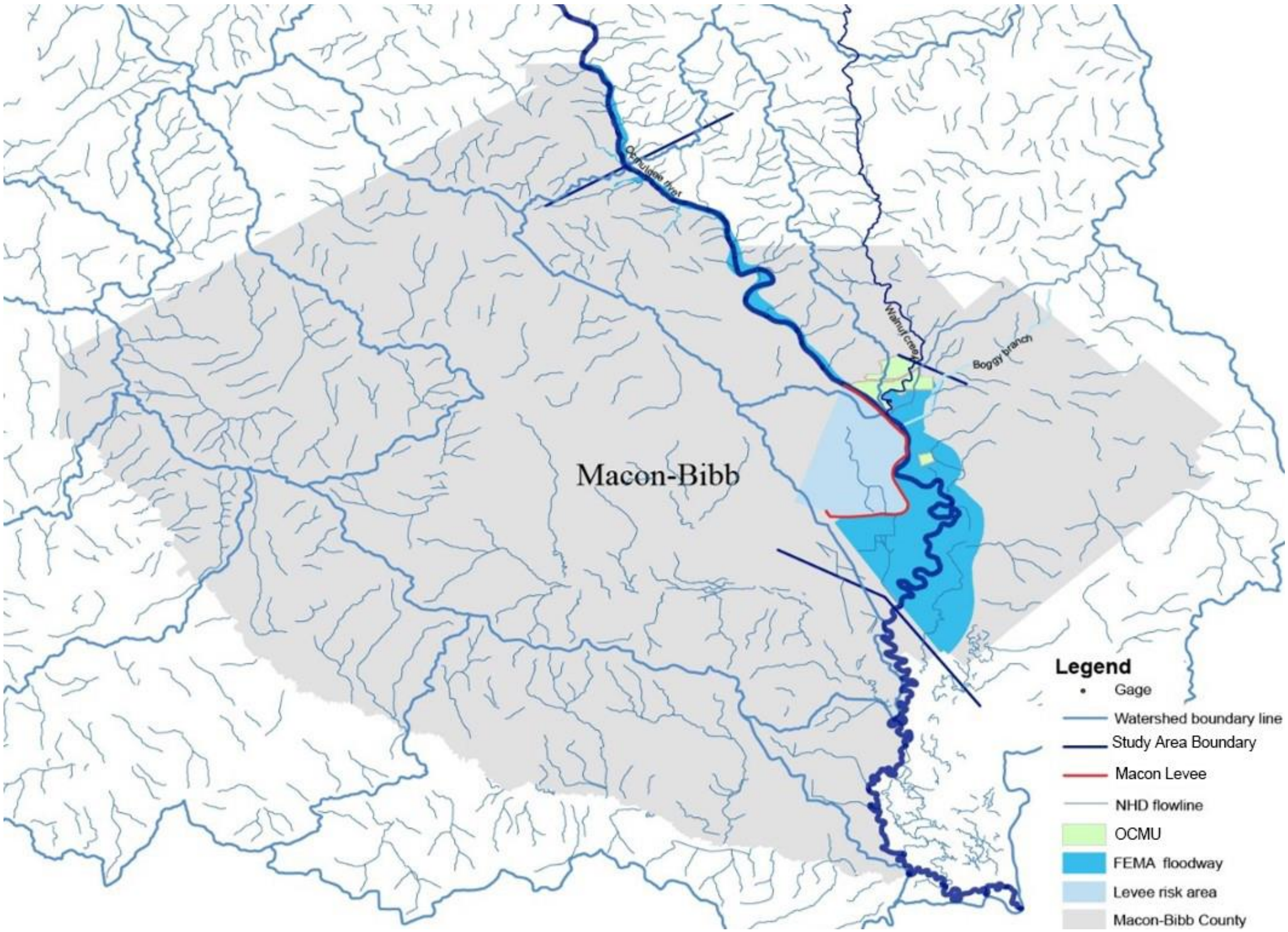


Figure 4.12: Watercourse of OCMU (made by author)

4.6.2 Hydrology of OCMU

The USGS maintains a stream gage (funded in cooperation with the City of Macon, Georgia in the Ocmulgee River just upstream from OCMU (USGS 02213000/Gauge MACG1, Bibb County, Georgia; Hydrologic Unit Code 03070103; latitude 32°50'19", longitude 83°37'14"; Horizontal Datum: NAD83; drainage area 2,240 square miles; datum of gage: 269.80 feet above sea level). This site is also upstream from the Macon levee, with monitoring of discharge and stage height. Discharge data have been recorded daily since February 1893 except for a ~15-year gap in the early 1900s; gauge height has been recorded since October 1992. Real-time data (the previous 10 days) are also available. However, data of precipitation, discharge, and gage height is provisionally subject to revision. According to Burkholder, previous data show high variation in daily discharge over the past ~15 years, ranging from ca. 200 to ca. 50,000 cfs, except for the major flood from Tropical Storm Alberto (1994) when daily discharge was ca. 100,000 cfs (Fig. 4.13, Appendix A).

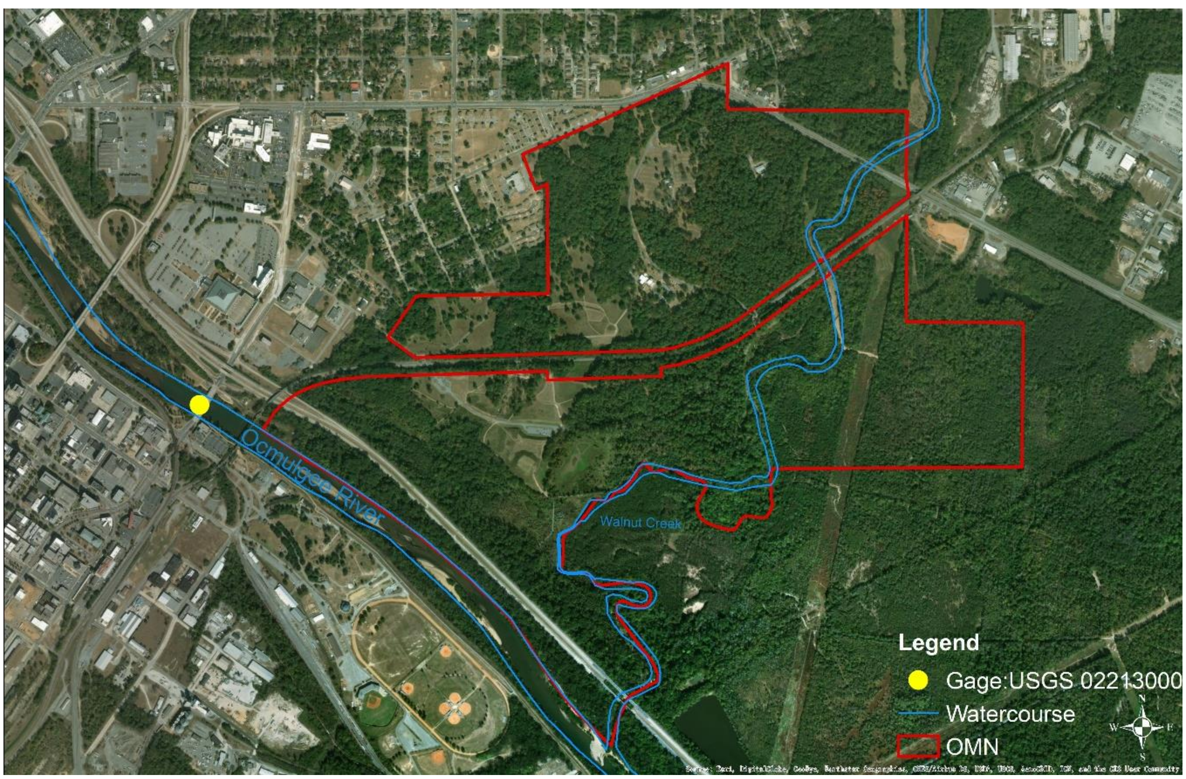


Figure 4.13：USGS Gage near OCMU (made by author)

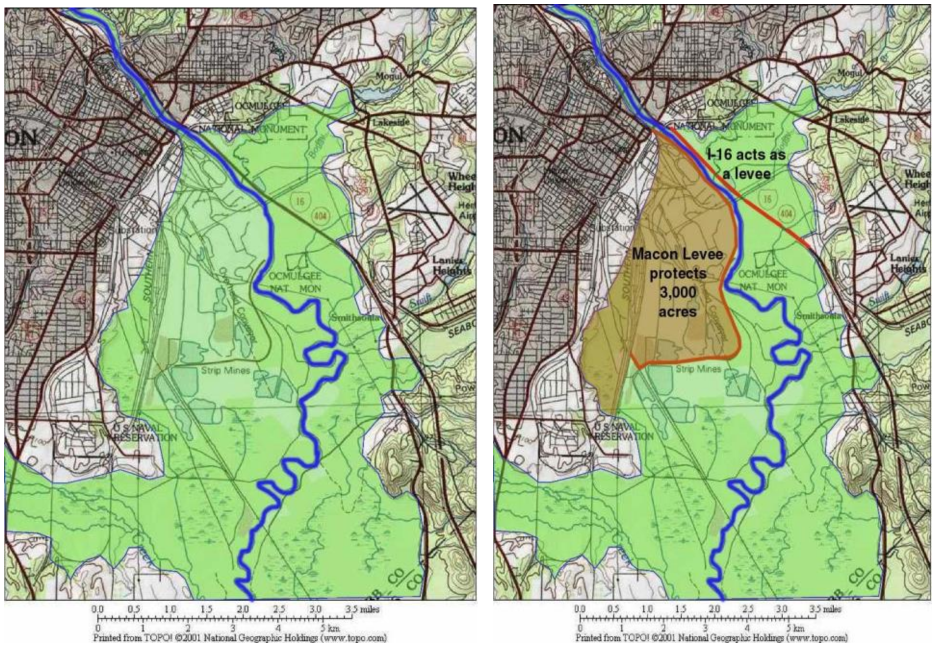


Figure 4.14: Flood Plain Maps Before (Left) and After (Right) the Construction of the Macon Levee System
Source: (left) http://www.macon-bibb.com/EPE/Slim/Floodplain/1-Floodplain.jpg
(right) http://www.macon-bibb.com/EPE/Slim/Floodplain/2-Levee_I-16.jpg

Recorded flood events occurred in Macon dating back to 1910 (Carter and Geological Survey, U.S. 1951). Figure 15 illustrates the major floods of record, based on local record crest history (National Weather Service N.D.). High variation in daily gauge height also ranges from 3.0 feet to 35.4 feet. The lowest water stage occurred in October 24th, 1954. The highest daily gauge height occurred in July 1994 with Tropical Storm Alberto, and the Macon levee was breached at 34.5 feet flooding the Georgia State Fairgrounds area. Portions of Interstates 16 and 75 in Macon were flooded and closed.

The hydrology of the OCMU, especially its largest stream, the Ocmulgee River, was drastically changed with the construction of the Macon levee and the flood wall (completed in 1950) and Interstate 16 (completed in 1968) (Fig. 4.14). About 20 years later, the levee was raised by three feet, but the outcome was not successful. The levee profoundly channelized the river, and had a negative, continued impact on water quality and aquatic communities. In an article published in the *Macon Telegraph* on February 02, 2007, the U.S. Army Corps of Engineers said that the Macon levee is the "only levee in Georgia that is in such poor condition it might not hold back floodwaters." It failed the Army Corps of Engineer's inspection in 2007. In fact, it has become harder for the levee to pass the Army Corps of Engineer's inspections because stricter standards have been established after the flooding brought about Hurricane Katrina in 2005. According to data analyzed from the National Weather Service, the Ocmulgee River experiences more flooding than it used to, and the number of flood warnings they release each year is twice as much as it was in 1970.

The watercourse of the Ocmulgee Mounds unit (segments of the Ocmulgee River and Walnut Creek) has been ranked as "impaired waters for biota and /or general recreation" on the state's 303(d) list conducted by United States Environmental Protection Agency (U.S. EPA). The water system is threatened by the "sedimentation, bank erosion, and trash accumulation." The waters are polluted by the extra sediment loading and high density of fecal coliform bacteria resulting from urbanization (Burkholder et al. 2010).

Walnut Creek and the three smaller streams in OCMU have experienced severe streambank alteration and sedimentation (Burkholder et al. 2010). *Streambank alteration* refers to a streambank that is altered or damaged by livestock grazing, recreation, logging and other land uses and has a negative impact on water quality and aquatic habitat conditions (Cowley, 2002). All the three unnamed streams originate in urban areas and two of them are discontinued or partly discontinued; they are also polluted by garbage and other wastes (Chief Ranger G. LaChine, pers. comm.) (see Fig. 4.16).

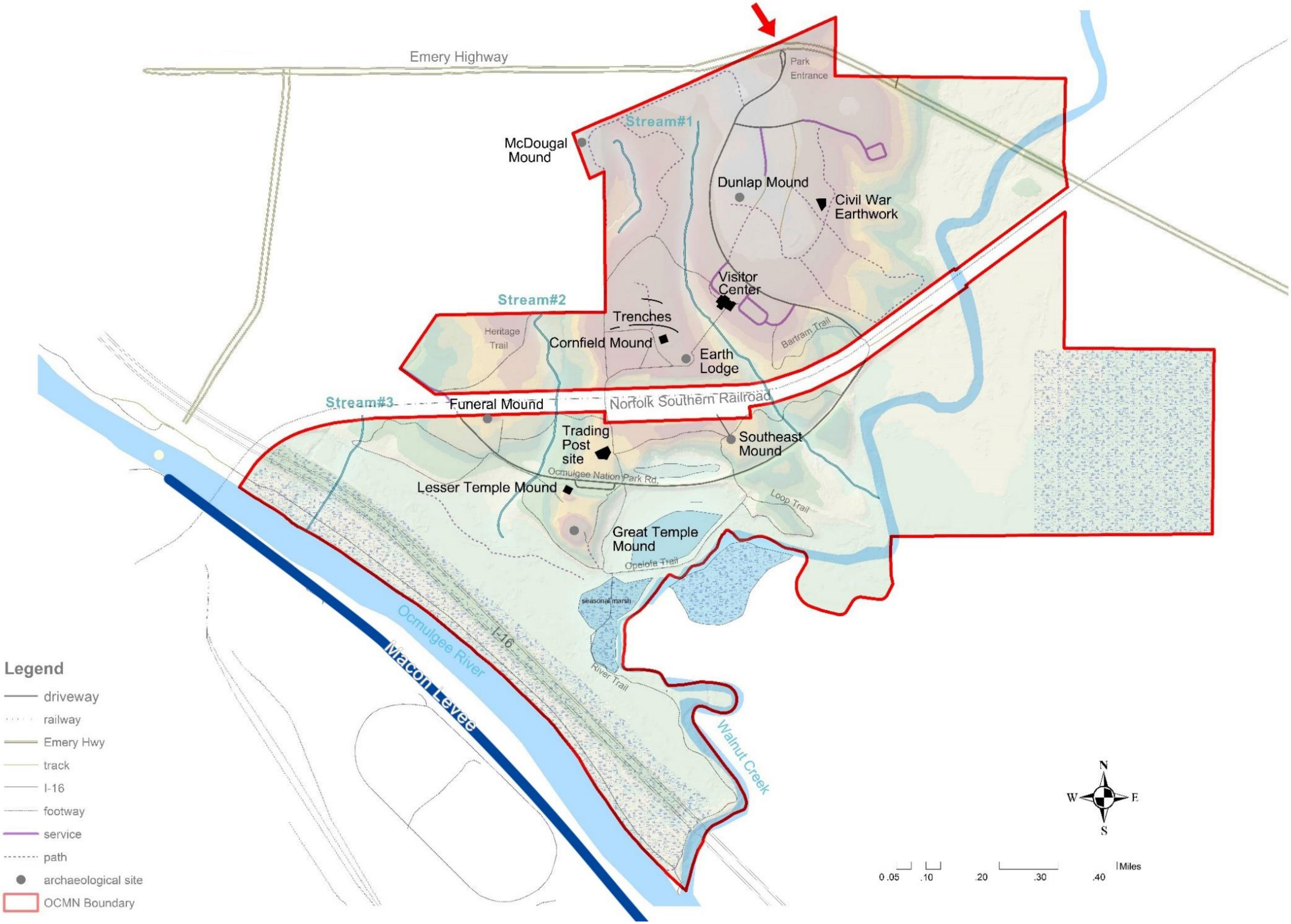


Figure 4.15: Three Streams and Circulation of the Site (made by author)

Small Stream # 1 flows between the visitor center and the Earth Lodge, and is a tributary of Walnut Creek. Originates as the outflow of a storm sewer (Chief Ranger G. LaChine, pers. comm.), it's prone to flash floods and also receives runoff form the OCMU parking lot and road. NPS maintained the channel of Stream # 2 by ditching until about a decade ago, and cessation of that practice has promoted more wetland formation. During wet periods, stream #2 originates from a paved urban culvert in east Macon, goes underground, emerges at the edge of OCMU property (*Plate 4*), flows through OCMU for a short distance, leaves OCMU and flows through an economically depressed part of Macon, re-enters OCMU, and becomes a tributary of wetlands adjacent to Walnut Creek. The stream can carry a substantial sediment load that has caused major erosion and cut a ~20-foot-deep channel. Its deposits have created a large silt plain (Chief Ranger G. LaChine, pers. comm.). Stream #3 originates in Macon and is fed by the city's storm sewer system. It flows along the OCMU periphery, flows through an inaccessible area of OCMU, and then enters the Ocmulgee River directly. This stream has been the focus of major urban debris cleanup efforts by concerned citizens (Chief Ranger G. LaChine, pers. comm.). It is heavily silted and deeply eroded. It should be noted that there also may be an additional, very small intermittent spring near the central area of the Main Unit of OCMU, which may flow under the railroad tracks during prolonged wet periods (Chief Ranger G. LaChine, pers. comm.).

(Adapted from Burkholder et al. 2010: 39-40)

Wetlands take up ca. 40% of the existing acreage of OCMU, and they are various in size and origin (Burkholder et al. 2010). For instance, during the late 1800s- early 1900s, the small Clay Hole Pond on the OCMU property was an open pit mine. Now, it's a shallow depression (usually less than a foot deep) that is bisected by the OCMU road and recharged by Walnut Creek. Another example is the largest wetland on the site, changed by the 1994 flood from a seasonal wetland to a wetland with year-round standing water (Fig. 4.17). After evaluating the surrounding environment, the NPS "constructed a boardwalk across it as a hiking trail" in 2010. Functioning to enhance wetland education, this wetland is favored by visitors (Chief Ranger G. LaChine, pers. comm.).


Figure 4.16: Wetlands on the Site (photo by author)


Figure 4.17: Boardwalk on the Site (photo by author)

4.7 Known Flood Hazard Areas

Based on the National Weather Service (NWS) and Federal Emergency Management Agency (FEMA)'s National Flood Hazard map, the south section of the Ocmulgee Mounds unit lies in Flood Zone AE, which has a one percent of annual flood probability (Fig. 4.18). The estimated 100-year flood elevation in Macon is 302.9 feet above sea level (Stamey, 1996).

Modified from the maps made by FEMA, NWS, USGS and others, a series of inundation maps were made to show where flooding may occur in the Ocmulgee Mounds unit (Fig.4.19). The water crest ranges from 14 feet to 35 feet, and the flood impacts are shown in Table 5.

According to the National Weather Service (NWS), stream stage is used to analyze the volume of water that is moving in a stream at any given moment. Based on the data analyzed by NWS, there are four important stream stages that profoundly impact the OCMU (Fig.4.20). When the surface water level reaches 16 feet (action stage), related people or agencies need to pay attention to the hydrologic situation and take action. When the surface water level reaches 18 feet (flood stage), it "begins to create a hazard to lives, property, or commerce." When the surface water level reaches 26 feet (moderate flood stage), some structures and roads near the Ocmulgee River and Walnut Creek will be inundated and a Flood Warning should be issued. When the surface water level reaches 30 feet, structures and roads near the Ocmulgee River and Walnut Creek will be inundated extensively, and "significant evacuations of people and/or transfer of property to higher elevations are necessary." And as mentioned earlier, the highest daily gauge height occurred in July 1994, with Tropical Storm Alberto, and the Macon levee was breached at 34.5 feet flooding the Georgia State Fairgrounds area. Portions of Interstate 16 and 75 in Macon were flooded and closed.

Besides the four important stream stages, Figure 4.20 illustrates other four stream stages that mark the threshold of the inundation map of OCMU. From the height of 21 feet, the River trail along the Ocmulgee River will begin to be submerged. From the height of 24 feet, Walnut Creek Connector Trail and the north part of the main mound unit will be inundated. From the height of 31 feet, the Ocmulgee National Park Road will be submerged, and from the height of 33 feet, the lower part of the Interstate 16 will be inundated. Table 18 illustrates the flood impact on OCMU.

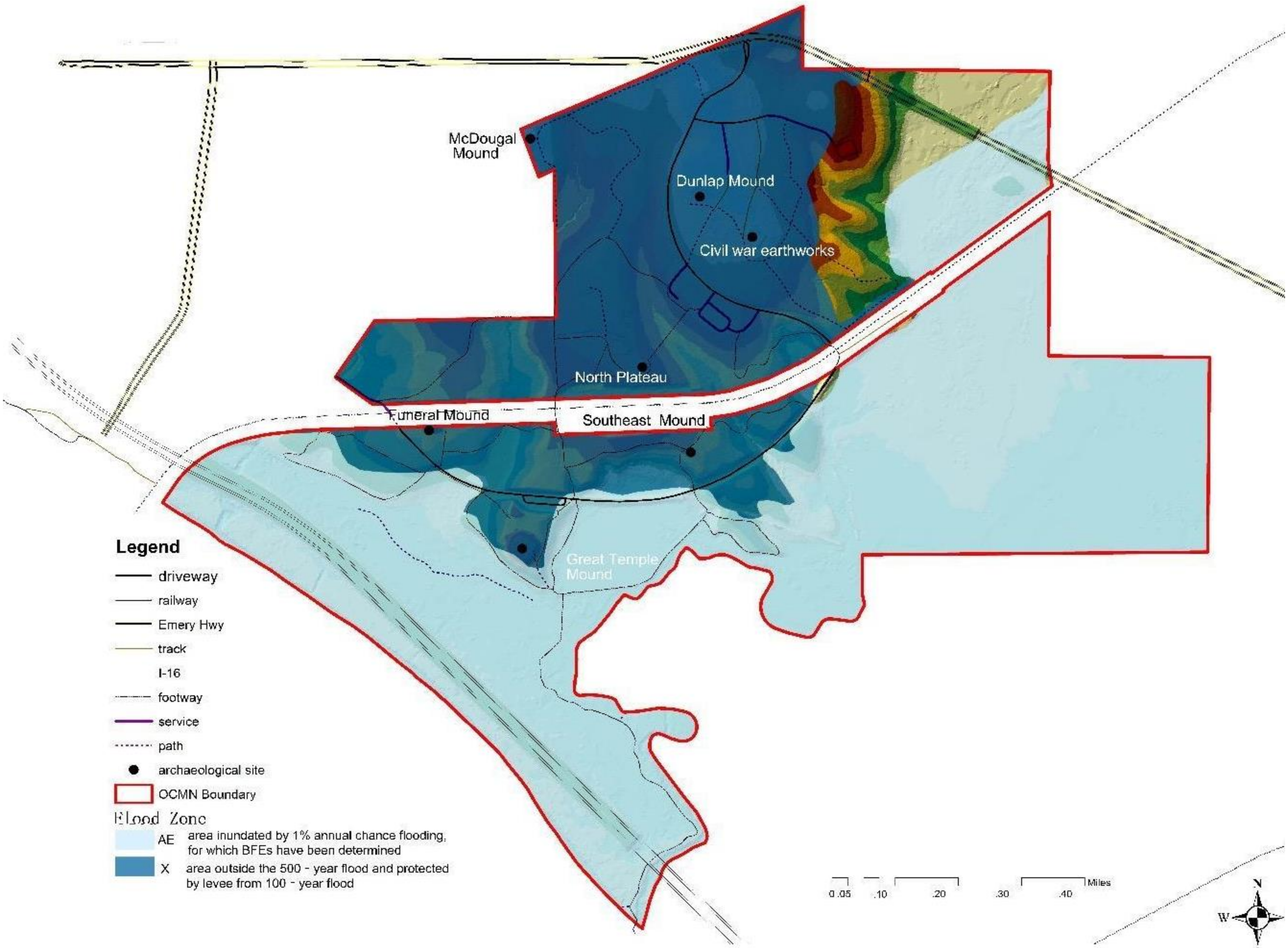


Figure 4.18: Flood Zone of Ocmulgee Mounds unit (made by author)

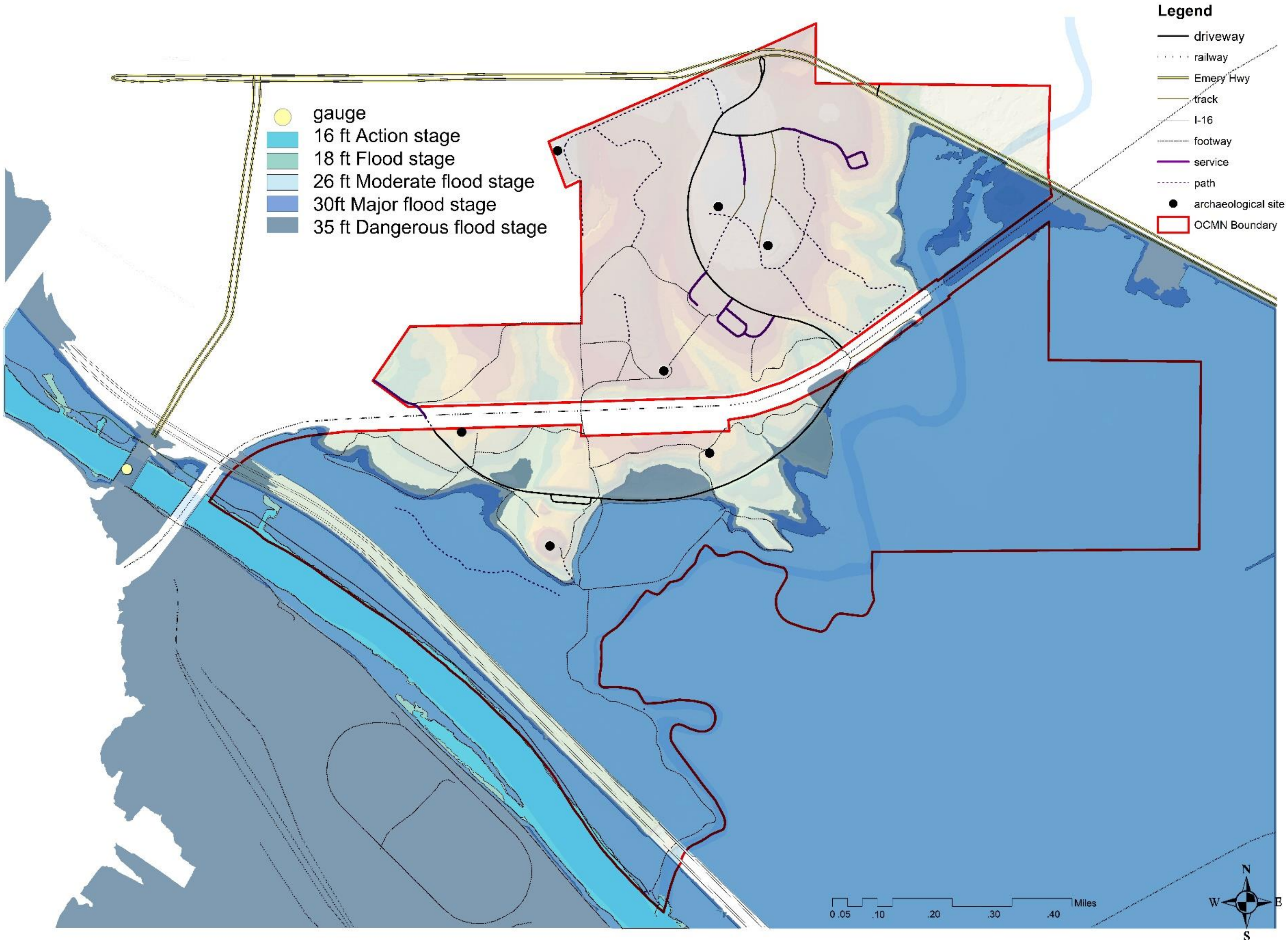


Figure 4.19: Flood Stage Map (made by author)

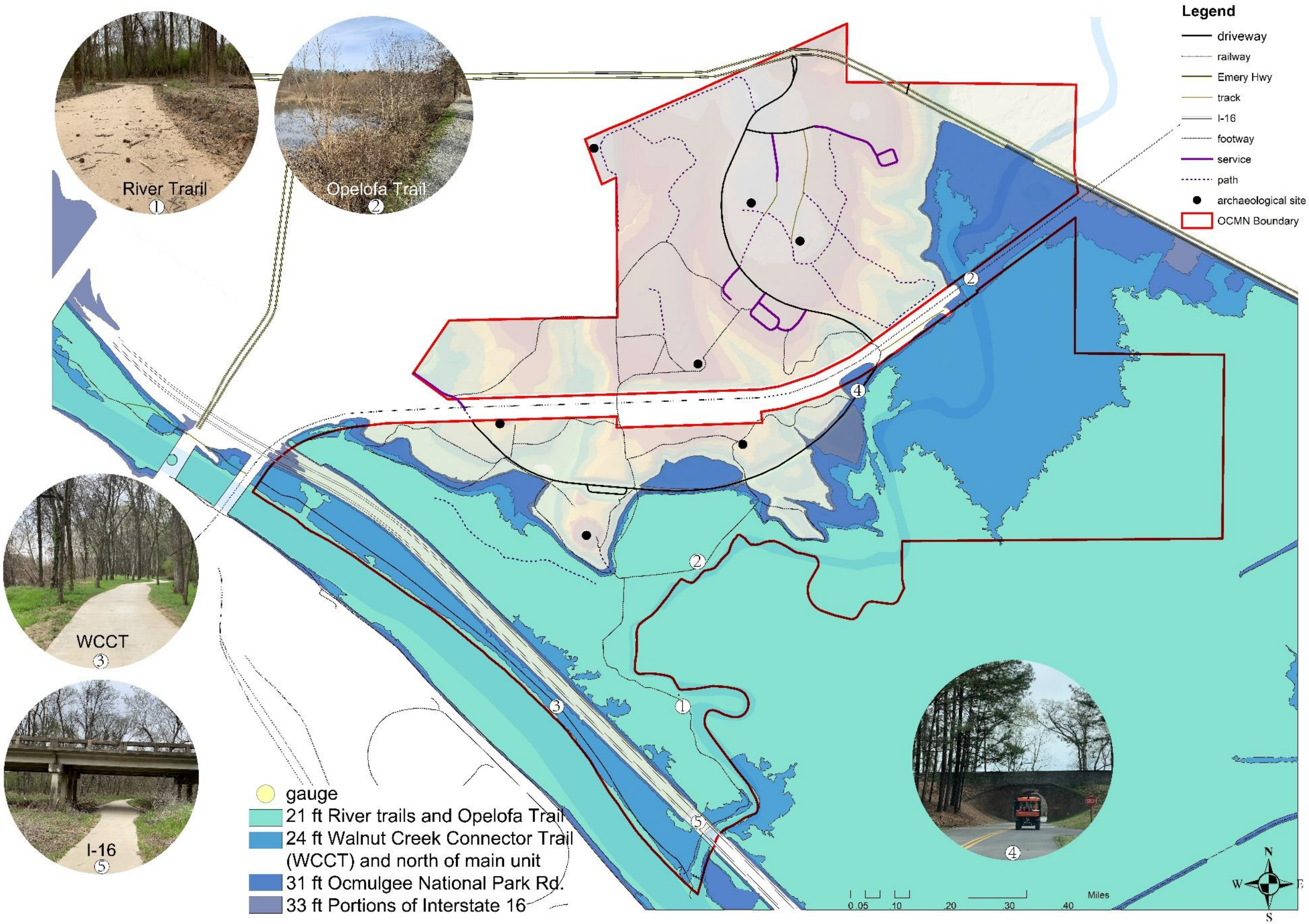


Figure 4.20: Four Important Flood Stage (made by author)

Table 18: Flood Impact on OCMU (made by author)

Crest Stage (ft)	Flood impact	Elevation (ft)
14	No impact	283.4
15	No impact	284.4
16	**Action Stage**- Bank-full conditions occur along the river upstream and downstream from the gage at U.S. Highway 80 or Martin Luther King Boulevard. Some flooding of low-lying areas begins in portions of the Ocmulgee Riverwalk	285.4
17	Some flooding of low-lying areas begins in portions of the Ocmulgee Riverwalk	286.4
18	**Flood stage is reached** -Minor flooding begins along the river upstream and downstream from the gage at U.S. Highway 80 or Martin Luther King Boulevard. Portions of the Ocmulgee Riverwalk and agricultural lands well downstream will be under a foot of water	287.4
19	**Minor flooding continues** - The Macon Greenway Ocmulgee Heritage Trail will begin to flood in areas just north of the Martin Luther King Boulevard bridge. The public should not use this portion of the trail	288.4
20	**Minor flooding expands**- An increasing amount of the Macon Greenway Ocmulgee Heritage Trail floods north of the Martin Luther King Boulevard bridge. The flood waters will be around one foot deep on portions of the trail and both banks overflow upstream from the bridge. Large portions of agricultural lands well downstream will be under one to three feet of water	289.4
21	**Inundated trail** -Part of River Trail and portions of Opelofa Trail near the Walnut Creek begin to be submerged	290.4
22	**Minor flooding**- Part of River Trail and portions of the Opelofa Trail near the Walnut Creek begins to be submerged	291.4
23	**Minor flooding continues to expand**- Large portions of the Macon Greenway Ocmulgee Heritage Trail floods north of the Martin Luther King Boulevard bridge. The flood waters will be up to 3 feet deep on portions of the trail. Portions of the Opelofa Trail near the Walnut Creek will be submerged. Norfolk Southern Railroad and north part of main unit that above the railroad begin to be submerged	292.4
24	**Minor flooding continues to expand**	293.4
25	Minor flooding expands further into the woodlands and over the Macon Greenway Ocmulgee Heritage Trail north of the Martin Luther King Boulevard bridge. The flood waters will be up to 5 feet deep on portions of the trail	294.4
26	**Moderate Flood Stage**- Moderate flooding begins on the Macon Greenway Ocmulgee Heritage Trail north of the Martin Luther King Boulevard bridge with some areas under 6 feet of water. Portions of the Southern Railroad tracks around Mead Road will become inundated.	295.4
27	**Moderate Flood**-Large part of the Opelofa Trail near the Walnut Creek and portion of Loop Trail will be submerged.	296.4
28	**Moderate Flood**- Large part of the Opelofa Trail near the Walnut Creek and portion of Loop Trail will be submerged.	297.4
29	Significant flooding expands over the Macon Greenway Ocmulgee Heritage Trail north of the U.S. Highway 80 bridge with some areas under 9 feet of water. The water level will reach the bottom of the bridge. Large portions of the Southern Railroad tracks around Mead Road will be a few feet under water. Agricultural lands just east and south of Macon will be under 1 to 10 feet of water.	298.4
30	**Major Flood Stage-**The Ocmulgee Heritage Trail will be under 10 feet of water	299.4
31	Ocmulgee National Park Rd. begins to be submerged	300.4
32	**Dangerous flooding occurs**- the water level approaches the top of the Macon levee. Flood waters will be hitting the three main bridges in Macon. Low portions of Interstate 16 and 75 will begin to experience flooding especially at on and off ramps in Macon	301.4
33	**Dangerous flooding expands-**Interstate 16 in Macon begins to be submerged	302.4
34	**Dangerous flooding expands**- the levee is topped on the east side of Macon. Portions of Interstate 16 will flood at on and off ramps in Macon	303.4
35	**Dangerous flooding expands**- portions of Interstate 16 and 75 in Macon will be flooded and closed	304.4
35.4	**Highest crest in history - two feet of water will be overflowing the levee on the east side of Macon and cause severe erosion. Portions of Interstate 16 in Macon will be flooded and closed**	**305.1**

Flood damage on the OCMU main unit can be classified into two categories: natural ecology and social economy (Table 19, Fig. 4.21). The impacts on natural ecology include the bank erosion, sediments hazards, water quality degradation and decreased biodiversity. The impacts on social economy include inaccessibility to trails and threats to cultural heritage.

Table 19: Flood Damage on the OCMU Main Unit (made by author)

Type	Problems	Far-reaching impact	Location
Natural Ecology	Bank erosion/ sediment transport	Increases soil erosion, impacts soil characteristics: soil water storage ability, nutrient value, permeability, etc	Heritage Trail, River Trail, Walnut Creek
	Sedimentation hazard	Raises the riverbed, Changes the river channel	
	Water quality degradation	Becomes turbid and increases suspended solid matter in water	
	Decreased biodiversity	Loses habitat and later impacts wildlife's growth and reproduction	
		Causes death or threat of survival to animals and plants	
Social Economy	Inaccessibility of trail	Causes unusable trails (submerged/ covered by sediments)	Opelofa Trail, River Trial, Heritage Trail, Loop Trail
	Threats to cultural heritage	Threatens the unexcavated heritage in the flood zone	Unexcavated heritage in the flood zone
		Increases maintenance fee	OCMU Main unit

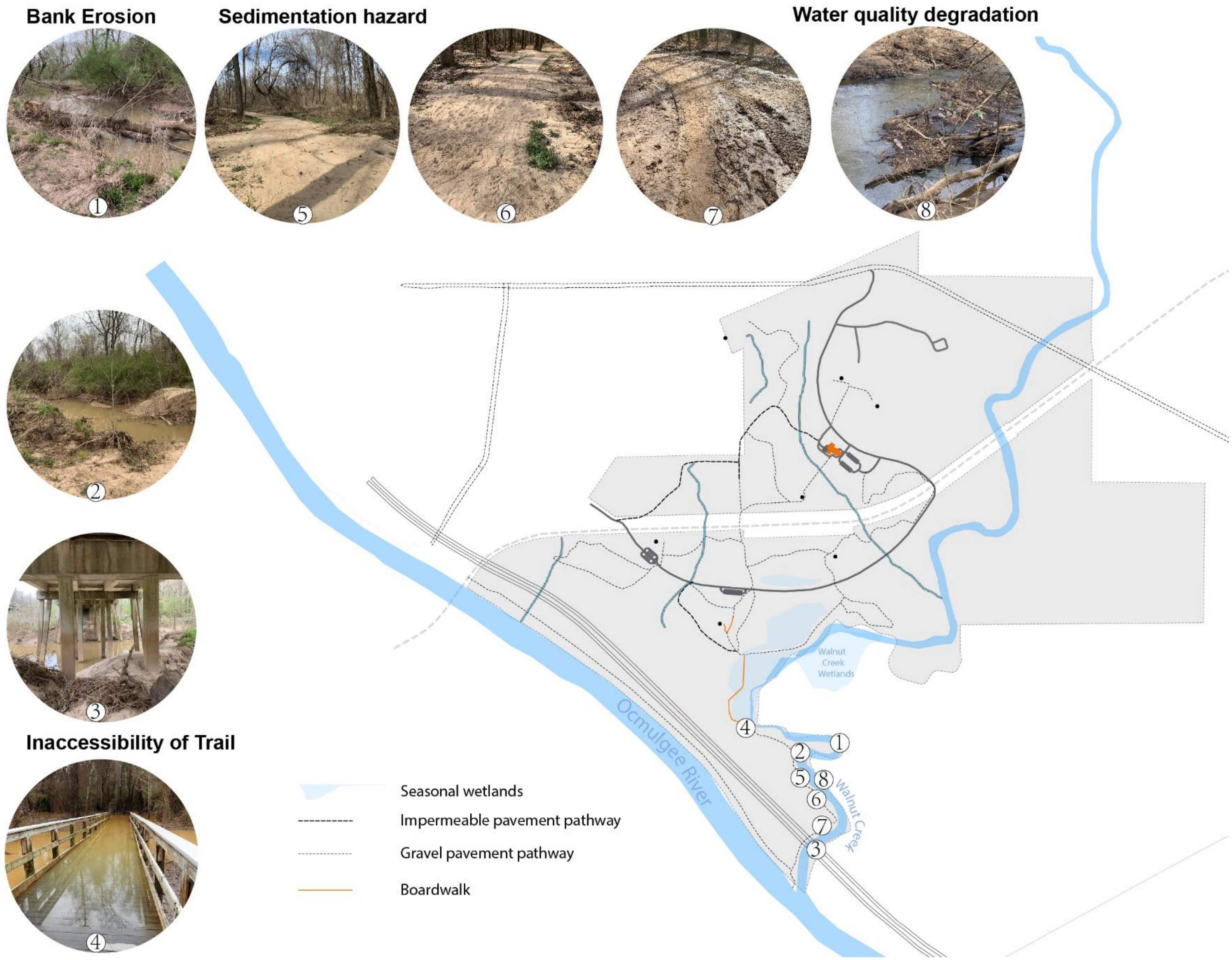


Figure 4.21: Flood Damage Map (made by autho

CHAPTER 5

PROJECTIVE DESIGN

This chapter proposes a design for the Ocmulgee National Monument, located along the Ocmulgee River and its tributary Walnut Creek in Macon, Georgia, which seeks to encourage flood-resilience of the park in all five categories of flood-resilient design. This projective design allows the framework to be further applied and tested as a tool for design. The chapter includes the evaluation of the design using the framework itself.

Because this design is theoretical, the framework could not be applied in the same manner as it was applied to both case studies and was limited, in some capacity, to the evaluation of physical design characteristics and flood-resilient design methods. Other actions, which focus on community and stakeholder involvement, programming, construction and maintenance, among others, could not be evaluated, as these actions could not realistically be carried out for a theoretical design. The framework, however, is still useful as it suggests these actions can be completed as part of the design and implementation process.

5.1 Site & Background

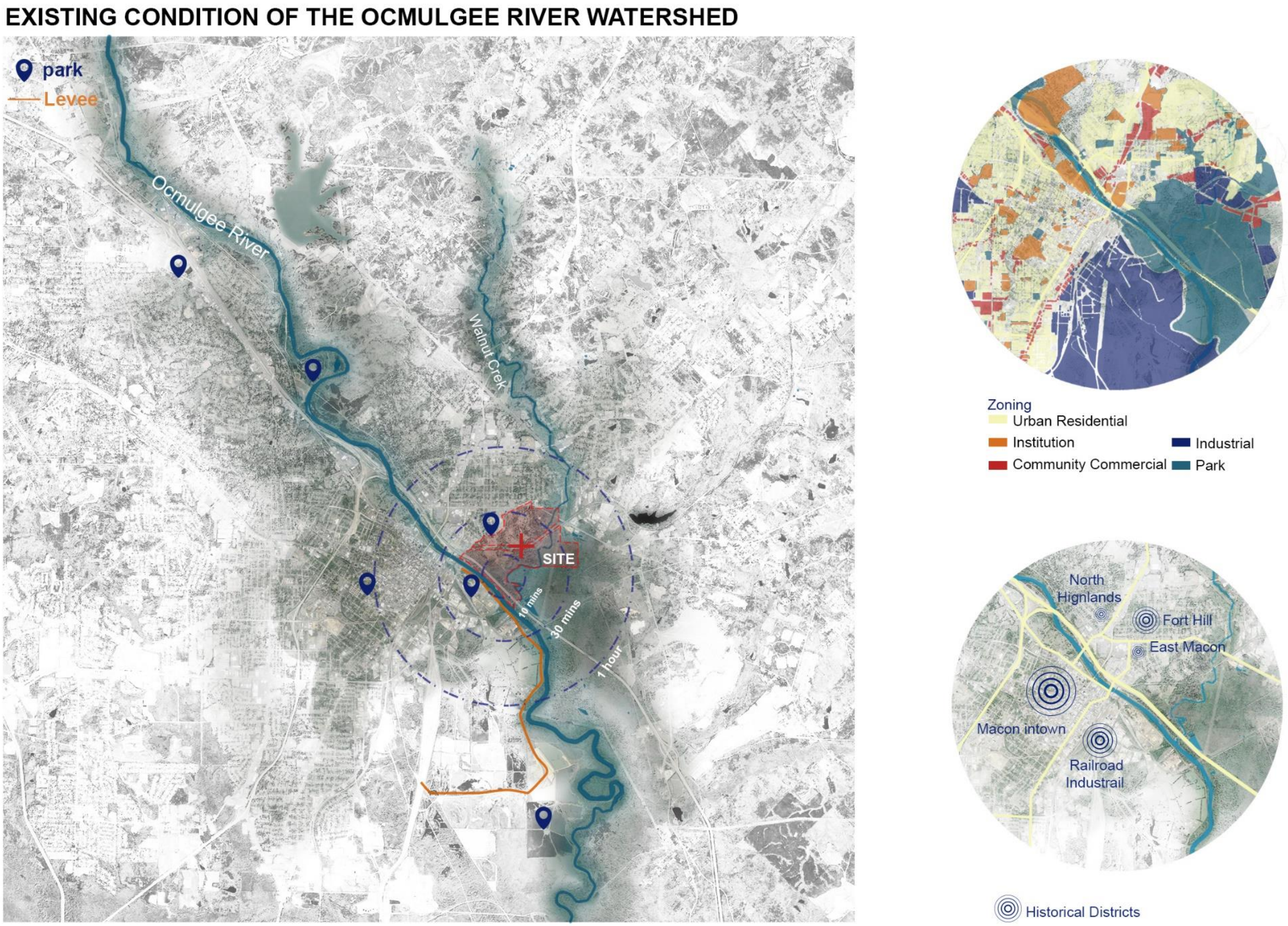


Figure 5.1: Site Background (made by author)

5.2 Problems, Concepts and Design Goals

The design aims at solving three major problems on the site: trail accessibility, bank erosion, and sediment and pollution (Fig. 5.2).

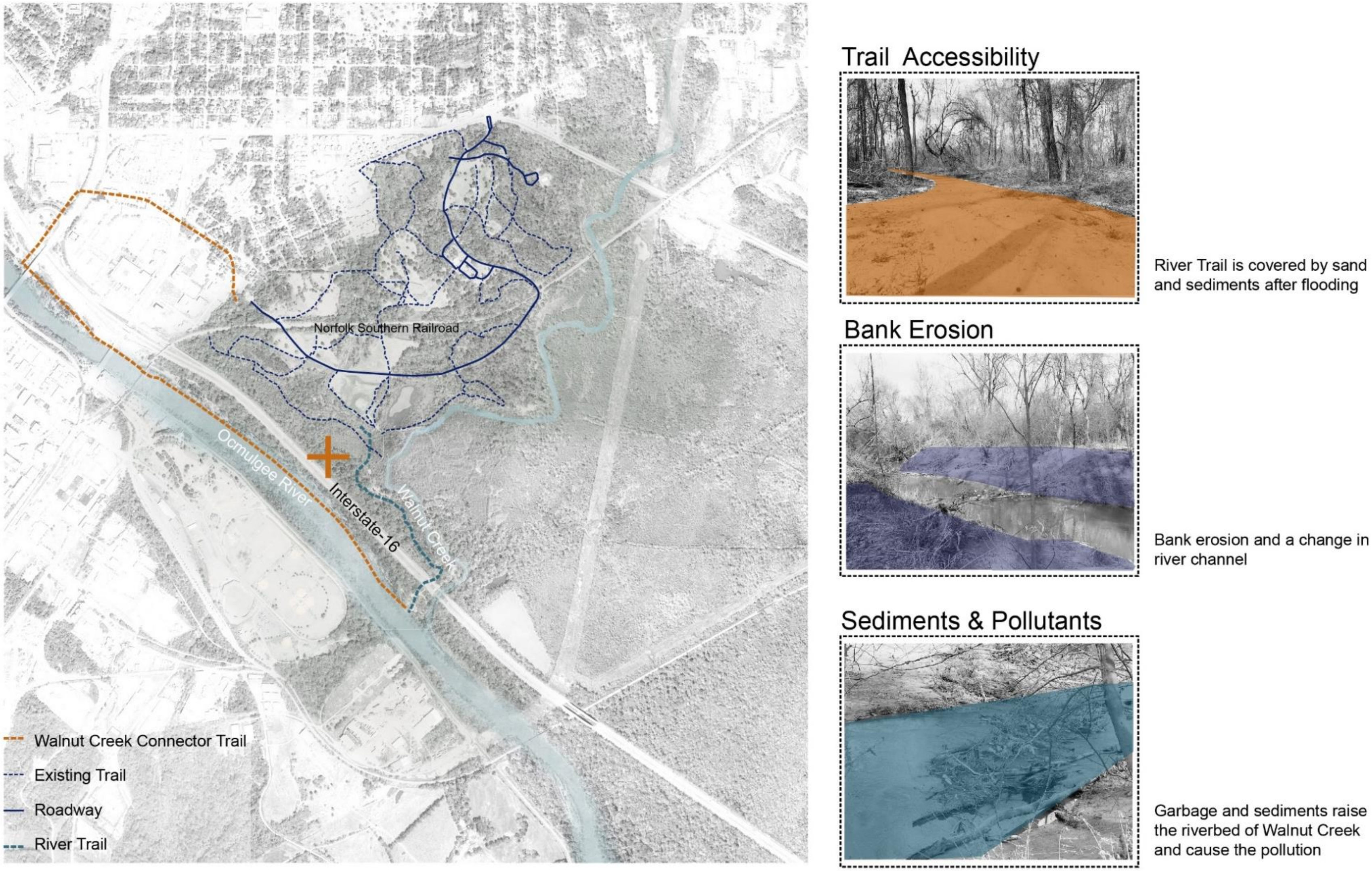


Figure 5.2: Site Problem Analysis (made by author)

The strategies to address these problems are classified into five aspects: water health, soil health, plant communities and animal habitats, infrastructure and management, and environmental education (Fig. 5.3). A master plan is shown below, and four inundation maps are presented together (Fig. 5.4).

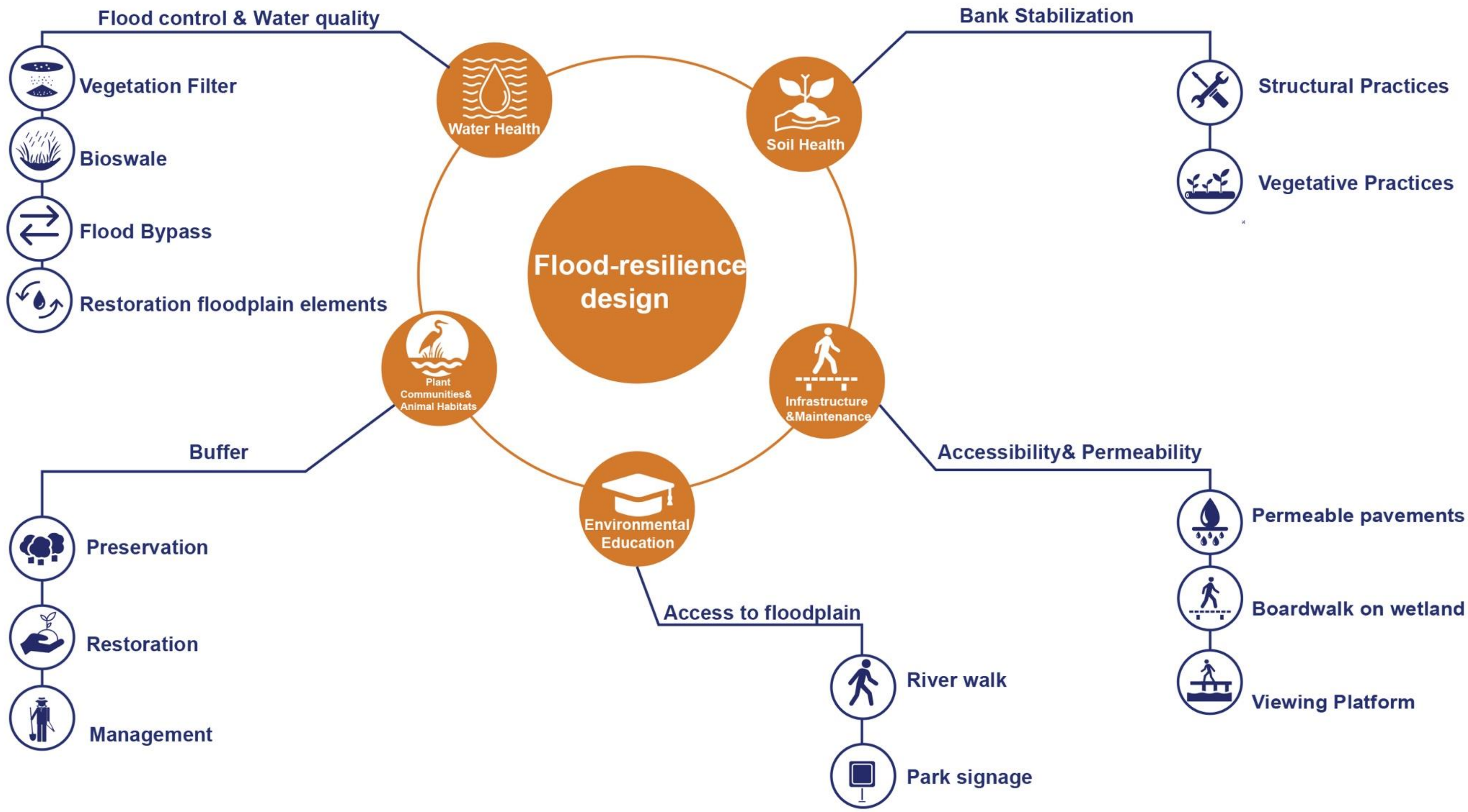


Figure 5.3: Concept Design (made by author)

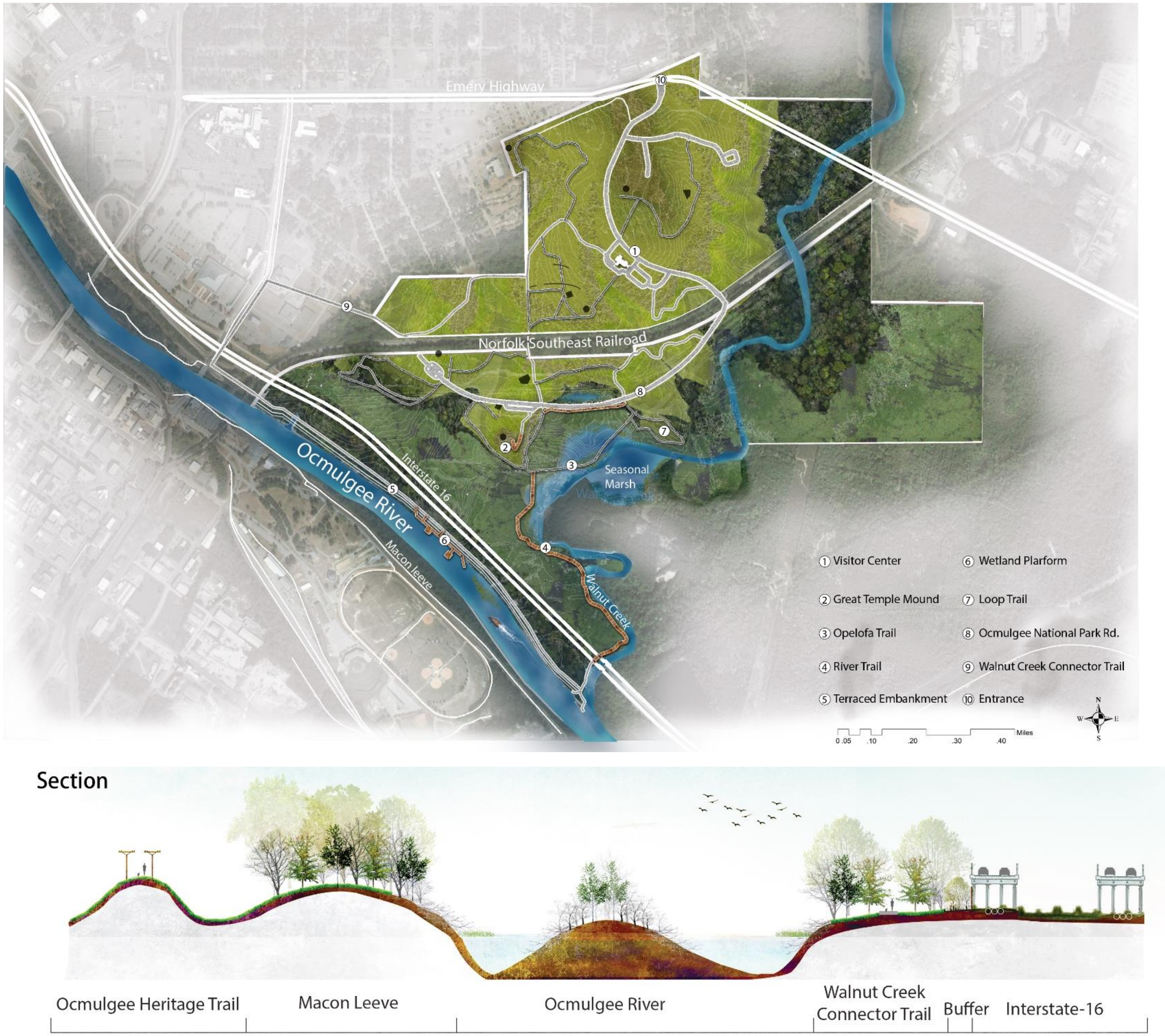


Figure 5.4: Master Plan (made by author)

5.3 Water Health

To improve the water health in the OCMU main unit, four stormwater management strategies are recommended: vegetation filter (Fig. 5.5-5.16), bioswale (Fig. 5.7-5.8), level spreader (Fig. 5.9-5.10), and flood bypass (Fig. 5.11-5.12). Figure 5.13 shows the runoff direction of the park and the suggested implementation location for each strategy.

Vegetated filter strips are filtration practices used to reduce sediments and soluble pollutants, as well as to slow runoff velocity and reduce erosion. They would be ideally placed along the stream bank of Walnut Creek. Therefore, stormwater and runoff would be filtered before they enter Walnut Creek.

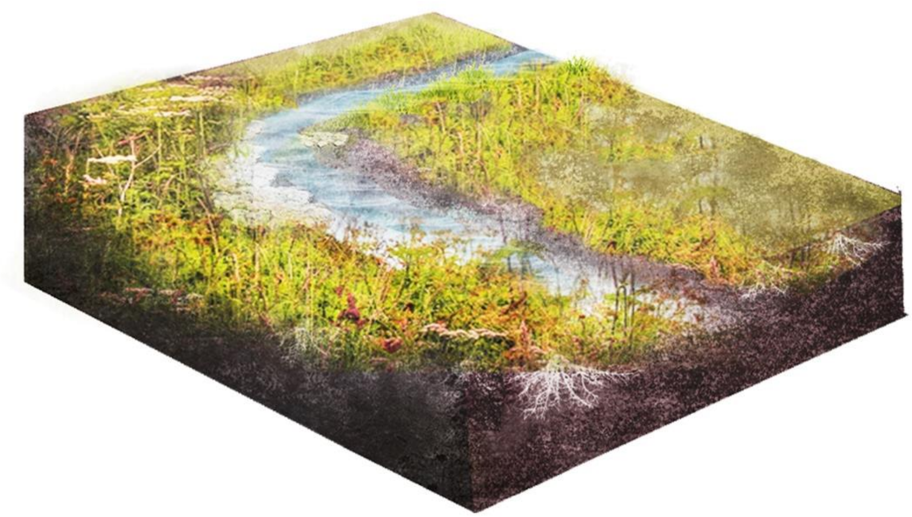


Figure 5.5: Vegetation Filter Strip (made by author)

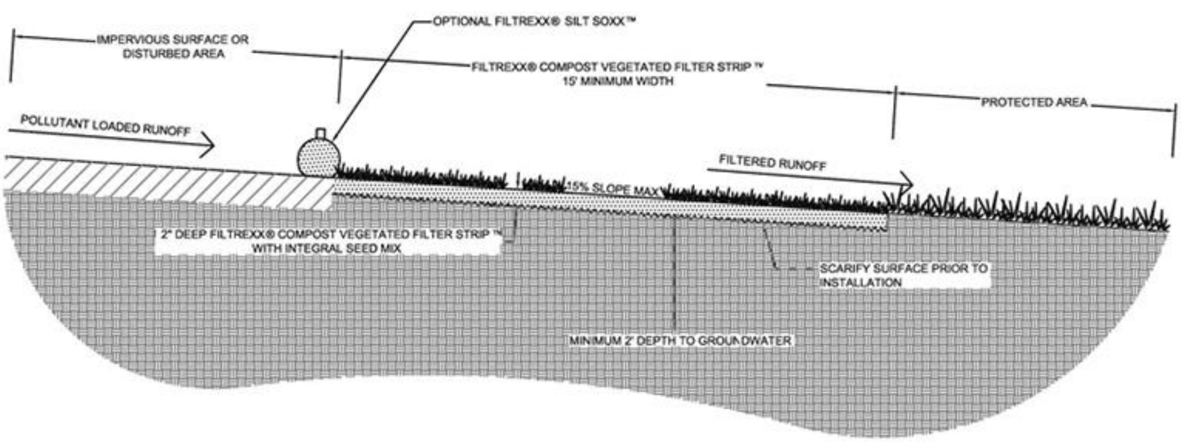


Figure 5.6: Section of Vegetation Filter Strip
Source: https://www.filtrexx.com/en/applications/stabilization/compost-vegetated-filter-stripl

Bioswales are landscape elements designed for removal or concentration of debris and pollution from surface water. They consist of three parts: a swaled drainage course with gently sloped sides (less than 6%), plant material, and a compost or riprap. They are recommended to be built along the Ocmulgee National Park Road and the three parking lots to convey stormwater runoff from the driveway into a wetland or other retention area.

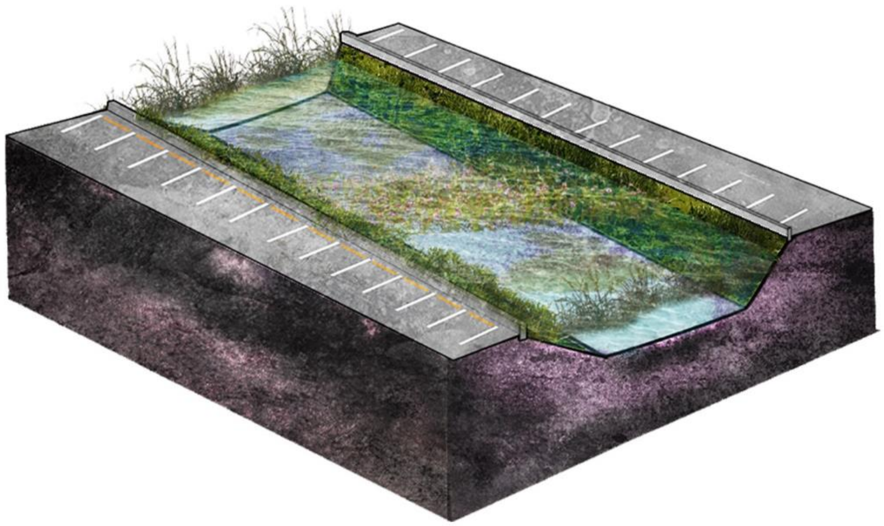


Figure 5.7: Bioswale Near the Parking Lots (made by author)

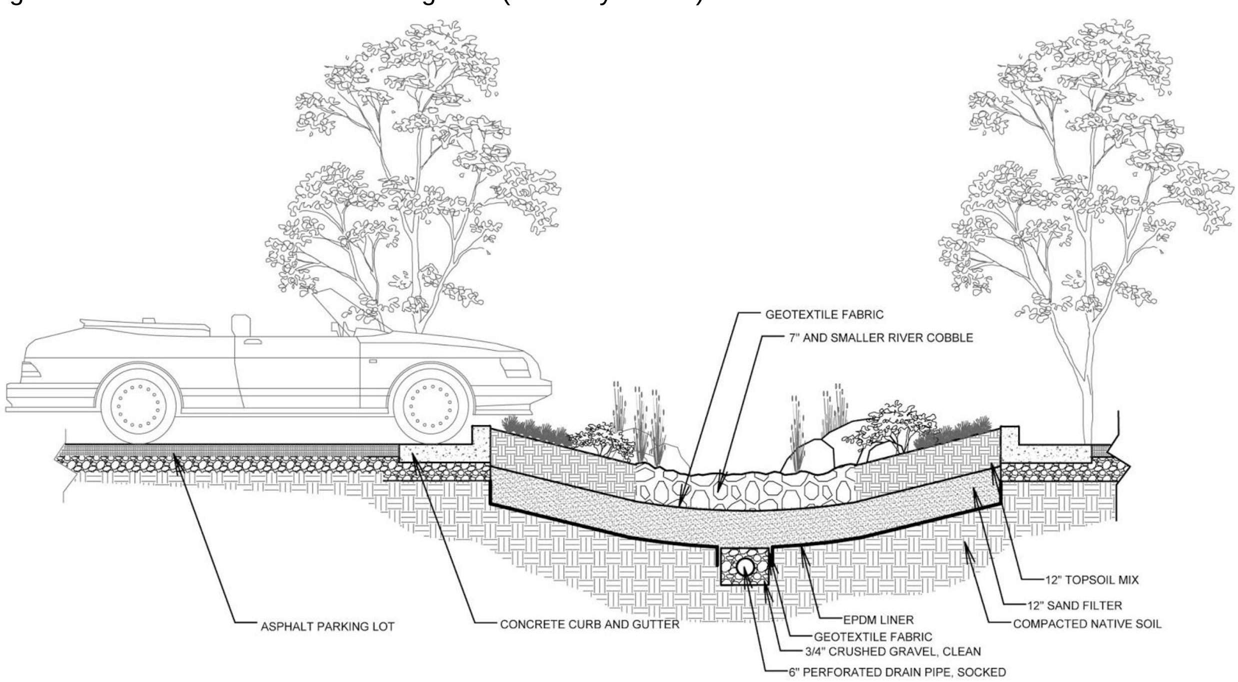


Figure 5.8: Section of Bioswale Near the Parking Lots
Source: DMCA Report - https://ayoqq.org/image/section-drawing-bioswale/940146.html

Level spreaders are erosion control measures designed to mitigate the impact of high-velocity surface runoff, as well as to stabilize vegetative surfaces, promote infiltration, and improve water quality (BMP, 2006). They are proposed along the slopes near Walnut Creek and the boundary of the park.

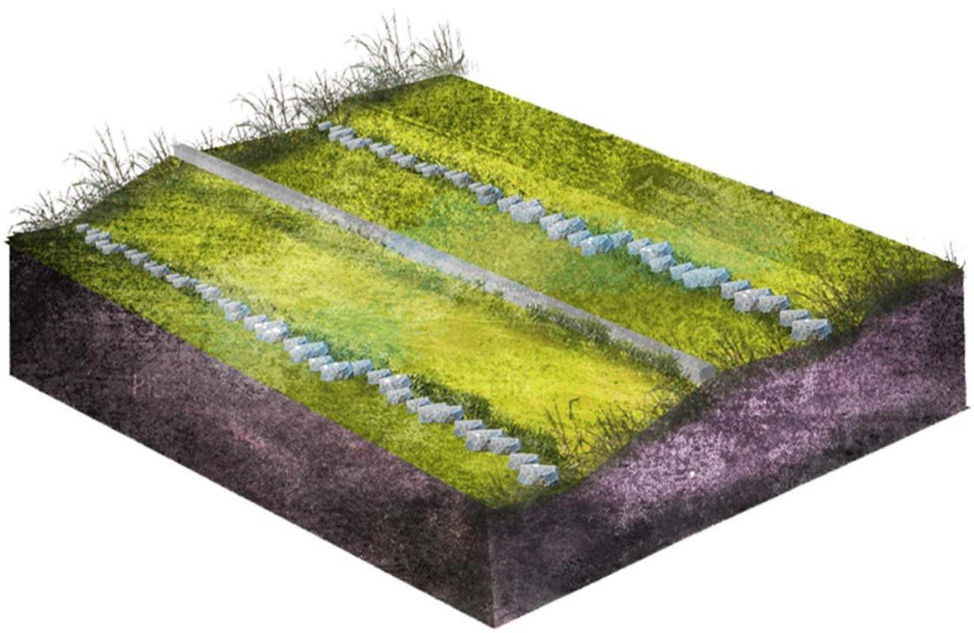


Figure 5.9: Level Spreader (made by author)

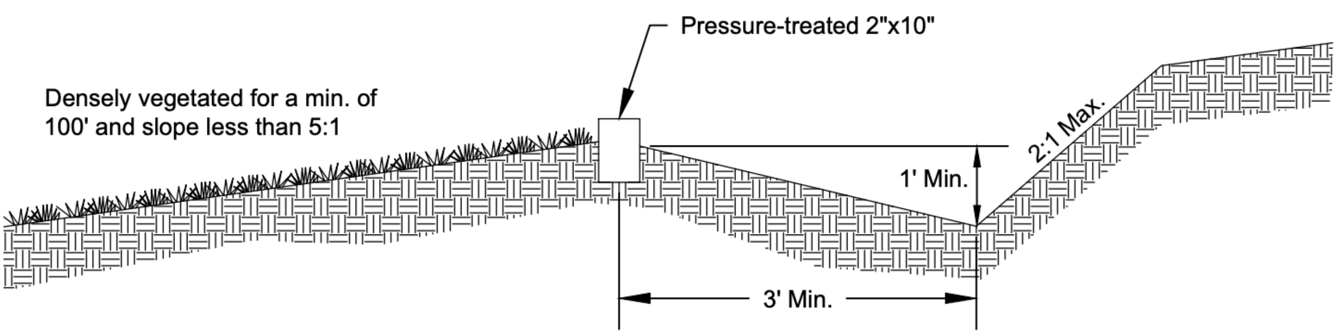


Figure 5.10: Section of Level Spreader
Source: "BMP C206: Level Spreader - Development.bellevuewa.gov." Accessed May 23, 2019. https://development.bellevuewa.gov/UserFiles/Servers/Server_4779004/File/pdf/Development Services/cg-DevStds2017-BMP-C206.pdf.

Flood bypass is an intentionally undeveloped area along a river or within a floodplain so that it can receive diverted excess floodwater during a flood (Naturally Resilient Communities, 2019). It reduces riverine flooding risk by redirecting water from urban business areas into a particular area. It is proposed in the oxbow of Walnut Creek to allow more water to run through it and reduce the sediment hazard.

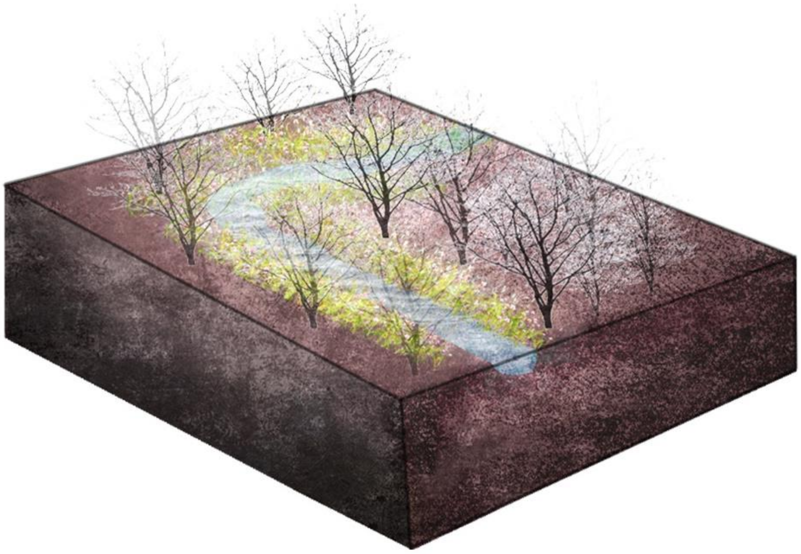


Figure 5.11: Flood Bypass (made by author)

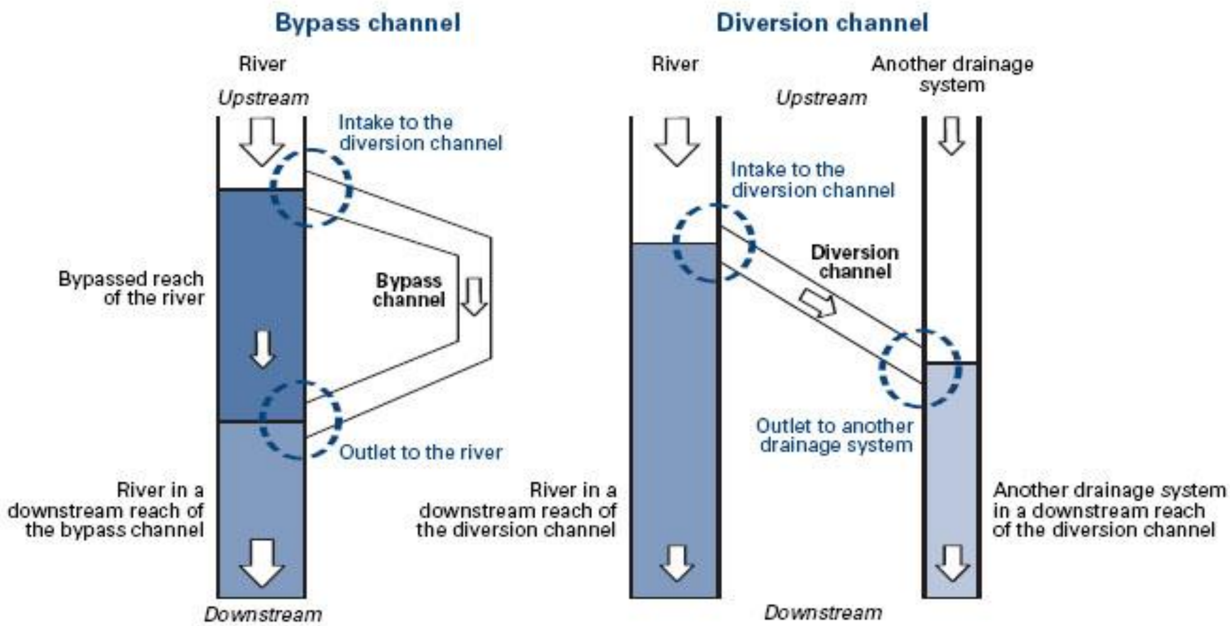


Figure 5.12: Illustration of Flood Bypass
Source: "Bypass and Diversion Channels." E. Accessed May 23, 2019. http://daad.wb.tu-harburg.de/tutorial/integrated-flood-management-ifm-policy-and-planning-aspects/environmental-aspects/flood-management-interventions/bypass-and-diversion-channels/

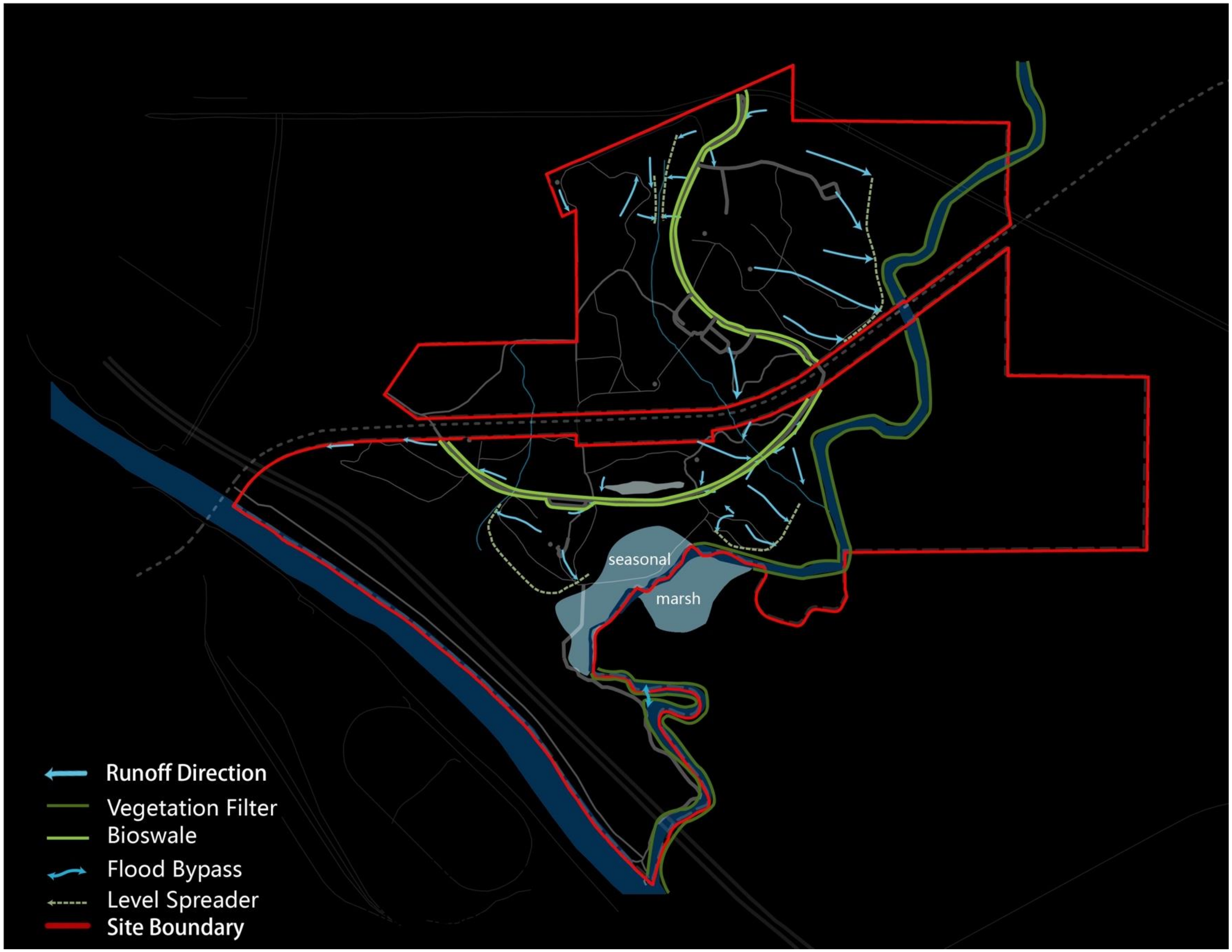


Figure 5.13: Stormwater Management (made by author)

Assessment

The design first analyzes the runoff direction of the site and then proposes several bioswales in the lower area and along the driveway to capture rainwater. Second, the design provides four strategies aimed at addressing the two underlying causes of flooding on the site--soil erosion and irregular precipitation brought about by the humid subtropical climate. Erosion controls like level spreaders are proposed to reduce water pollution by mitigating the impact of high-velocity stormwater surface runoff (U.S. Army Corps of Engineers, 2011). Vegetation filter stripes are another erosion control which also serve as habitats for wildlife, and the design suggests that they be constructed along the riverbank of Walnut Creek. To reduce the risk of flooding, a flood bypass is proposed in the oxbow of Walnut Creek to help limit the expected maximum flood flow of the river. Finally, the floodplain features such as natural levees and point bars should be restored and human disturbances should be controlled. The water quality will be improved since erosion is controlled, and the water is filtered by the plants' roots both in the bioswales and vegetation filter strips.

WATER HEALTH	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
1. Does the project introduce hydrological analysis (concentration, run off rate, water quality, volume)?		√	
2. Does the project restore wetlands and waterways?		√	
3. Does the project implement stormwater management and green infrastructure?		√	
4. Does the project combine sewer overflows to alleviate flood pressures?	√		

Figure 5.14: Assessment of Water Health (made by author)

5.4 Soil Health

Soil erosion is severe along the riverbank of Walnut Creek and the Ocmulgee River, especially in the AE-zone (an area which may experience 100-year flooding). To control the erosion in the riverbank, both structural and vegetation practices are suggested. There are six solutions to these problems selected from the *Manual for Erosion and Sediment Control in Georgia* (Georgia Soil and Water Conservation Commission, 2016): joint planting, live fascine, live cribwall, terraced embankment, and vegetated geogrids and riparian forest buffer (Fig. 5.15). Table 20 compares the application, advantages, and disadvantages of these measures.

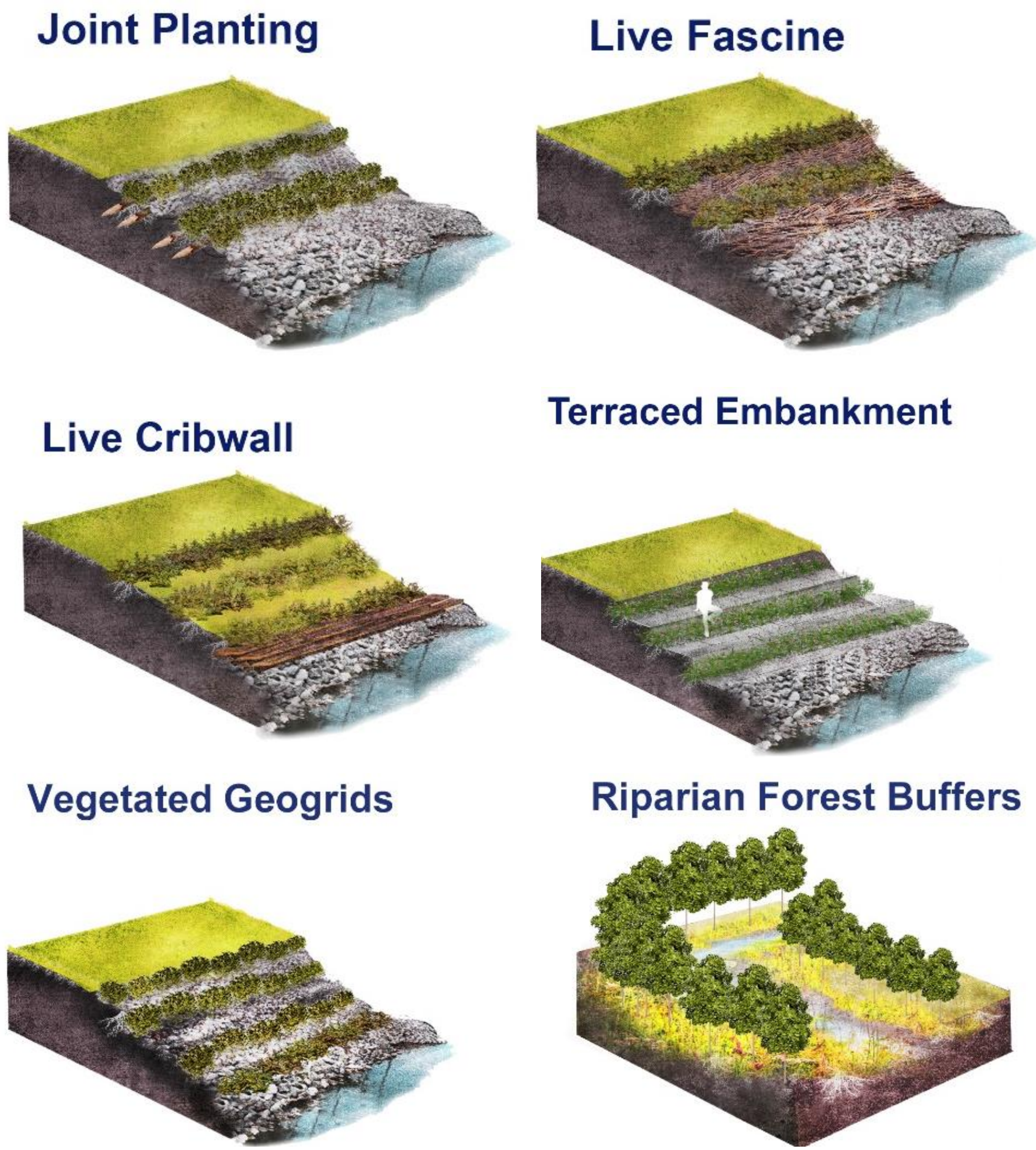


Figure 5.15: Soil Health Solutions (made by author)

Table 20: Soil Stabilization Measures (made by author)
Source: Manual for Erosion and Sediment Control in Georgia, 2016

		Joint Planting	Live Cribwall	Live Fascines	Vegetated Geogrids	Terraced Embankment	Riparian Forest Buffers
Applications	1. Where there is a lack of desired vegetative cover	√					
	2. Where appropriate, can be used with other soil bio-engineering systems and vegetative plantings	√	√	√		√	
	3. May require special tools for establishing pilot holes in rock riprap layers	√					
	4. Appropriate above and below water level where stable streambeds exist		√				
	5. Requires a stable foundation			√	√	√	√
	6. Needs slope stability analyses				√	√	
	7. Requires toe protection where toe scour is anticipated			√			
	8. Appropriate for repair of small earth slips and slumps that are frequently wet			√			
Advantages	1. Improves drainage in the soil base by root systems	√					
	2. Enhances diversity			√			
	3. Reduces soil erosion	√	√	√	√	√	√
	4. Controls the flow of surface runoff				√		
	5. Captures sediment and enhances conditions for colonization of native species		√	√		√	√
	6. Effectively used where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed			√	√		
Disadvantages	1. Can be complex		√		√	√	
	2. Can be expensive		√		√	√	
	3. Has limited life depending on climate and tree species used	√				√	√

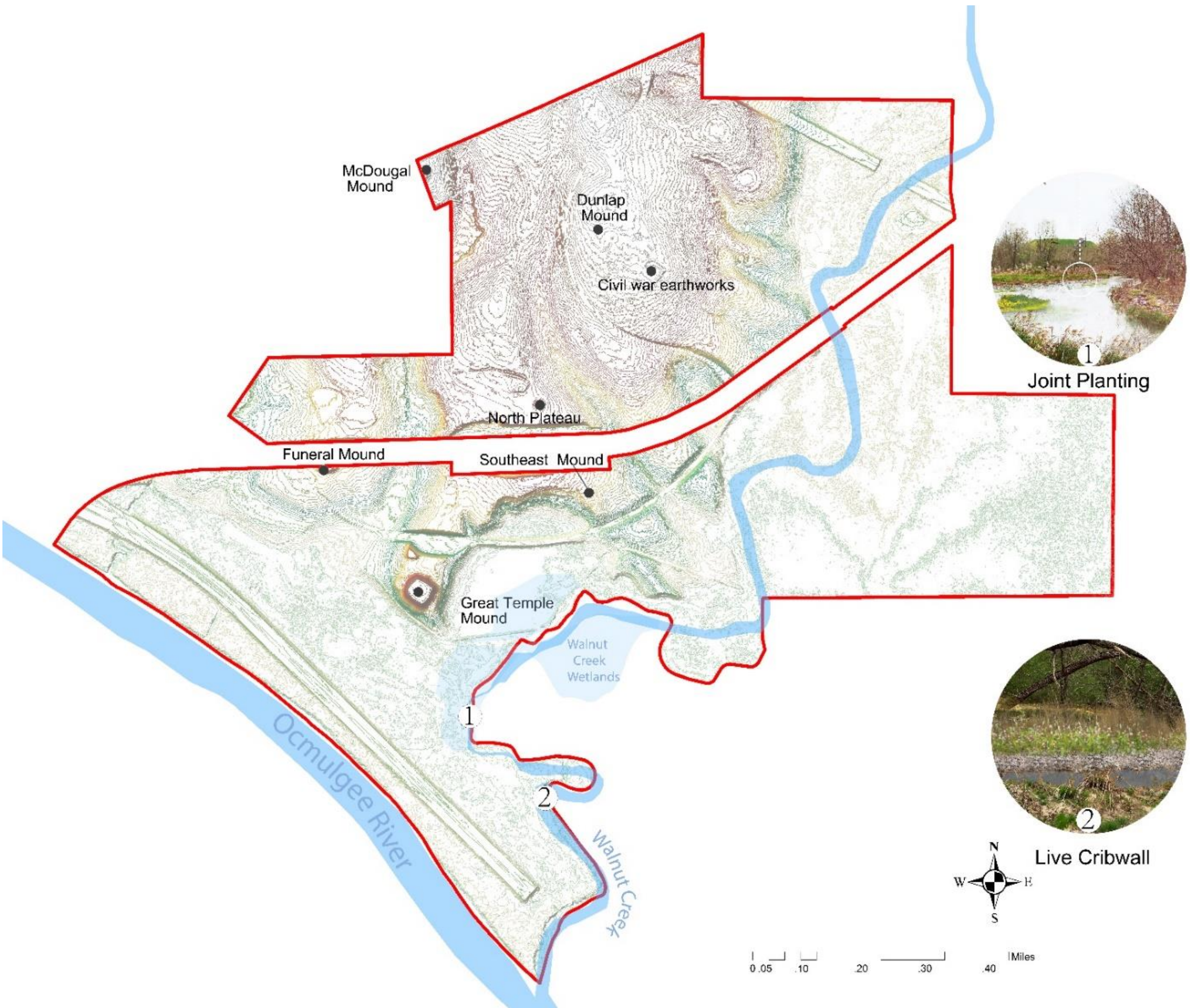


Figure 5.16: Erosion Control Measures Map (made by author)

Joint planting and live cribwall are selected to be discussed in detailed in this design. Figure 5.16 illustrates where to implement these two erosion control measures.

For the River Trail with severe bank erosion in a moderate slope, implementing joint planting is recommended because it will help the plant root system hold more water and thus improve drainage in the soil base, as well as reducing erosion (Fig. 5.17). Walnut Creek flows slowly in this area so a lot of sediment is accumulated here. A reinforced and engineered riverbank is designed with the aim of restoring the riparian area to be covered with adequate plants. Thus, elements like riprap and geotextile fabric are placed at the base of the riverbank to control erosion. The native vegetation can form an intertidal habitat when the water stage varies seasonally. Removing the invasive plants and replacing them with native plants like Whorled Pennywort (Hydrocotyle verticillata), Louisiana Irises (Iris hexagona), and Forked Rush (Juncus dichotomus) is recommended. Figure 5.18 illustrates the river trail before the design, and Figure 5.19 demonstrates the changes after the design.

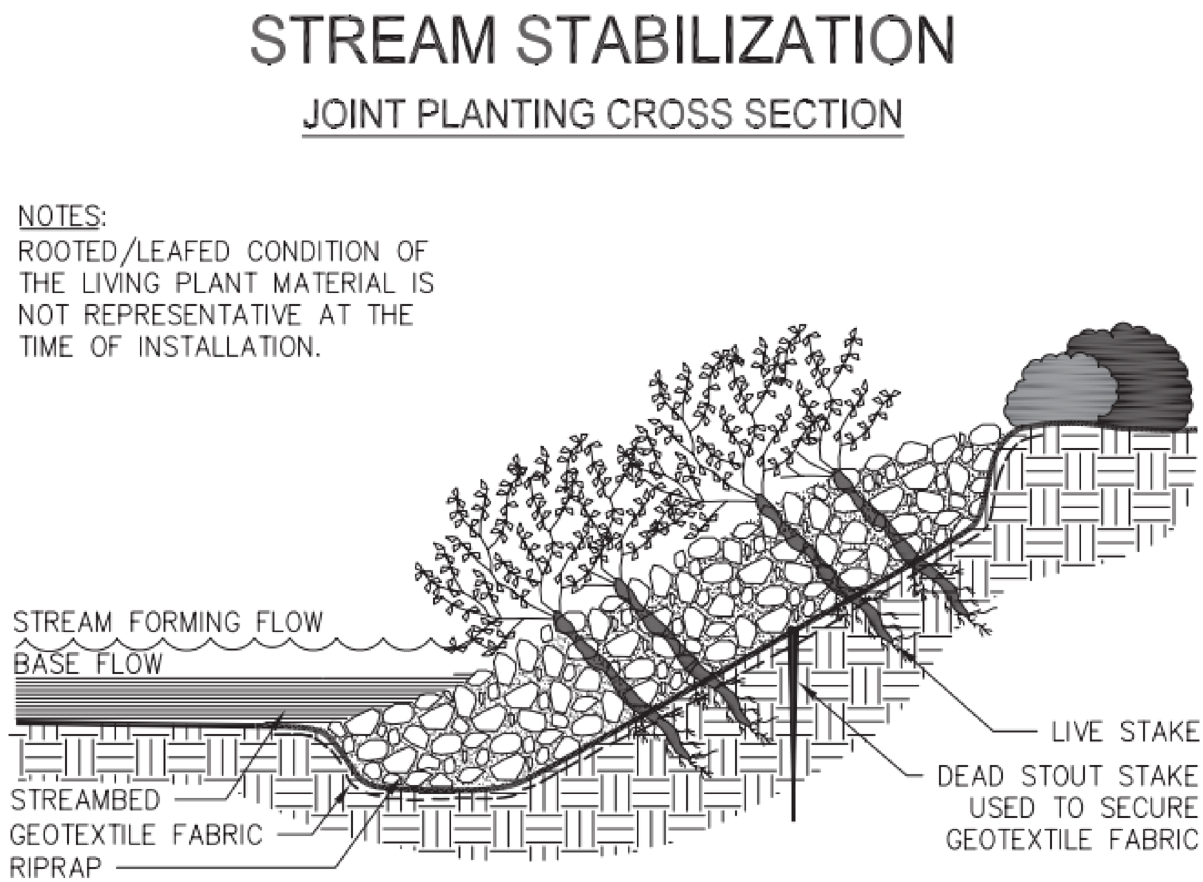


Figure 5.17: Cross Section of Joint Planting (Source: Manual for Erosion and Sediment Control in Georgia)

Figure 5.18: The River Trail before the design (photo by author)

Figure 5.19: The River Trail after the design (made by author)

Another recommended measure is live cribwall because it can capture sediment and enhance the conditions for the colonization of native species (Fig. 5.12). A live cribwall is a box-like structure made up by logs or timbers, rocks and live cuttings. It can help the mature plants take over the structural functions of the logs or timbers once live cuttings become established (Georgia Soil and Water Conservation Commission, 2016). Figure 5.21 illustrates the river trail before the design, and Figure 5.22 demonstrates the changes after the design.

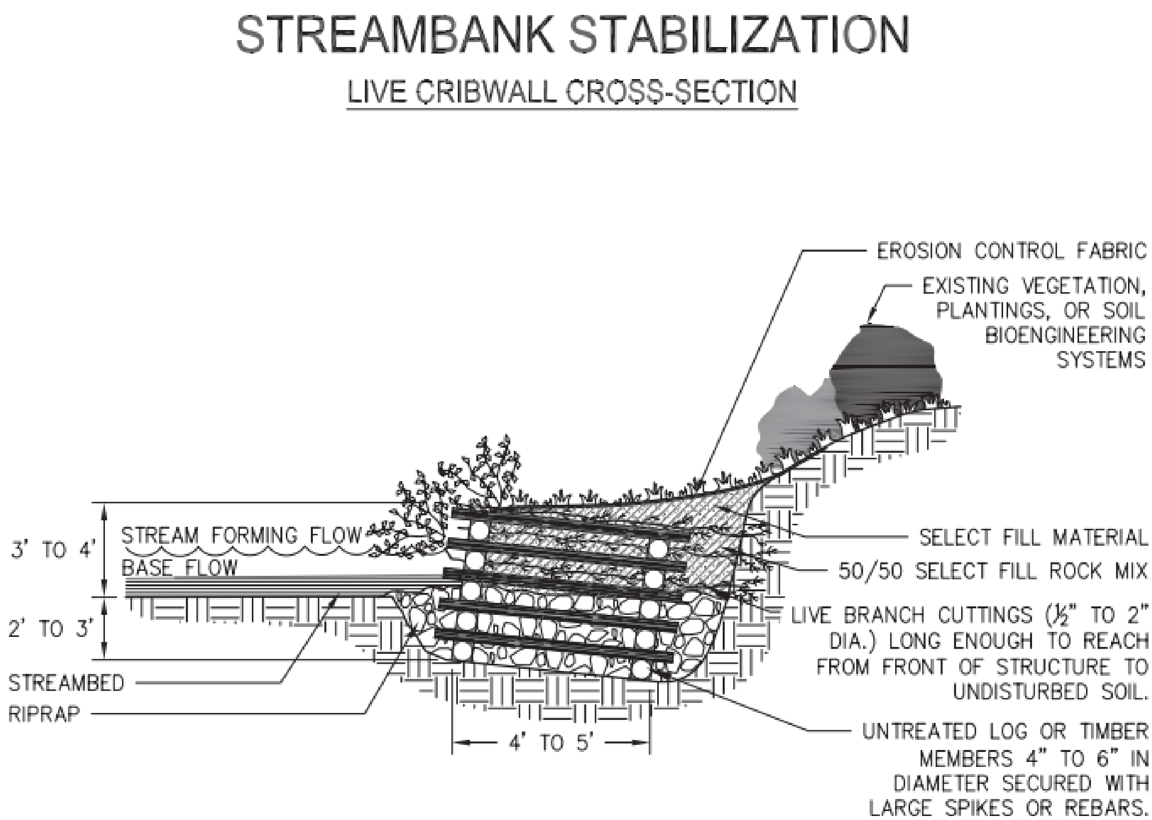


Figure 5.20: Cross Section of Live Cribwall (Source: Manual for Erosion and Sediment Control in Georgia)

Figure 5.21: The Riverbank of Walnut Creek before the design (photo by author)

Figure 5.22: The Riverbank of Walnut Creek after the design (made by author)

Assessment

The design aims at erosion control and it helps create a reinforced and bioengineered riverbank. The existing health soil is well preserved and covered with adequate vegetation. The root system of the native vegetation also helps improve drainage in the soil base.

SOIL HEALTH	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
5. Does the project manage soil erosion and bank stabilization?			√
6. Does the project limit disturbance of existing health soil?		√	
7. Does the project minimize impervious area?		√	

Figure 5.23: Assessment of Soil Health (made by author)

5.5 Plant communities and Animal Habitats

Three measures are recommended for improving the ecosystem of the site. First, preservation is proposed to be implemented on site to protect the integrity of the mounds and their surrounding environment. Second, restoration is recommended for the park to provide better habitats for water fowls and other birds. Last, management such as invasive species control is needed.

Preservation refers to the strategies for protection of buildings, objects, and landscapes (NPS, 2015). In this design, preservation is associated with protection of these historic mounds and landscape. The buffer along Interstate16 should be preserved both for noise control and disturbance limitations to the OCMU main unit. Figure 5.16 illustrates the preservation scenario on the site.

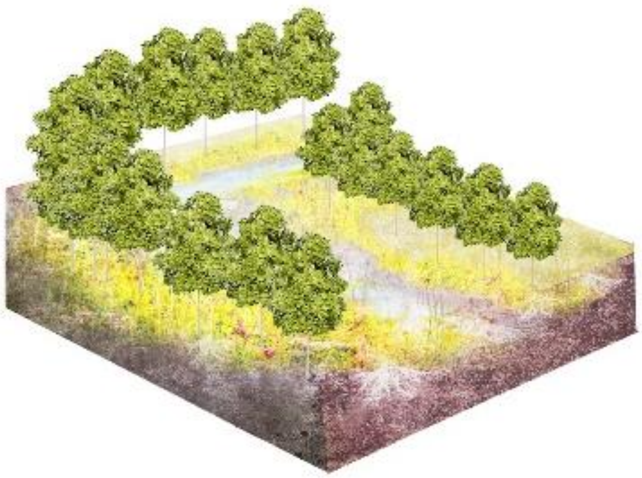


Figure 5.24: Preservation Scenario (made by author)

Restoration refers to the work conducted to improve the environmental health of a river, in support of biodiversity, recreation, and flood management (European Centre for River Restoration, 2014). In this design, the prority of restoration is to assess Walnut Creek's current condition: the stream, its banks and floodplain, and associated wildlife and vegetation. Figure 5.25 illustrates the restoration scenario. Based on data collected by the National Park Service, the recorded animals appearing in the park and their preferred habitats are shown in Figure 5.26 and Table 21.

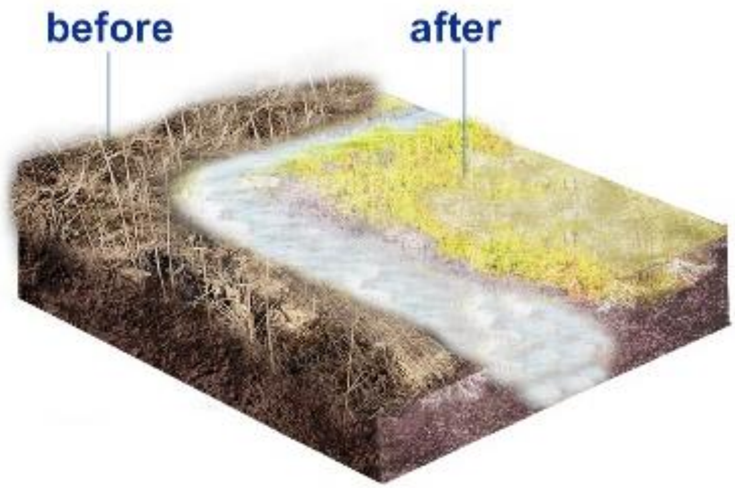


Figure 5.25: Scenario of Restoration (made by author)

Table 21: Recorded Animals and Their Habitats (made by author)
Source： National Park Service

Animal	Habitat	Location in the Park
Frog	Wetland	Walnut Creek wetlands, grassland near the mounds
Alligator	Freshwater environments, such as ponds, marshes, wetlands, rivers, lakes, and swamps, as well as in brackish water	Walnut Creek wetlands, marsh and swamp
Salamander	In forests and woodlands. It can be found in a variety of habitats, from moist sandy areas to dry hillsides	Upland wood forest, Floodplain Forest
Turtle	In fresh or brackish water. They prefer water with muddy bottoms and lots of vegetation	Walnut Creek wetlands, marsh and swamp
Snake	Live in a range of habitats, from terrestrial to semiaquatic, including rocky, forested hillsides and wetlands	Upland wood forest, Floodplan Forest, Walnut Creek wetlands, Marsh and Swamp
Lizard	Most common in hot, open areas such as fields, woodland edges, and sand dunes and is almost always found on the ground	Upland Forest
Canada Goose	Ponds, lakes, rivers, grain fields, fresh and saltwater marshes	Walnut Creek wetlands, Marsh and Swamp
Great Blue Heron	Can adapt to almost any wetland habitat in its range. It may be found in numbers in fresh and saltwater marshes, mangrove swamps, flooded meadows, lake edges, or shorelines.	Walnut Creek wetlands, Marsh and Swamp
Wood Stork	In fresh and brackish forested wetlands	Walnut Creek wetlands, Marsh
Little Heron	Quiet waters ranging from tidal flats and estuaries to streams, swamps, and flooded fields	Walnut Creek wetlands, Marsh
Bobcat	Diverse habitats such as forests, swamps, deserts, and even suburban areas	Upland wood forest, Floodplain Forest
Grey Fox	A combination of forest and brushy woodland	Upland wood forest, Floodplain Forest
American Beaver	Near rivers, streams, ponds, small lakes, and marshes. They build lodges of sticks and mud on islands, on pond banks, or on lake shores	Walnut Creek wetlands
Raccoon	Heavily wooded areas with access to trees, water, and abundant vegetation	Upland wood forest
Brown Bullhead	Lakes, ponds, and slow-moving streams with low oxygen and/or muddy conditions	Walnut Creek wetlands, Walnut Creek and Ocmulgee River
Whitetail Deer	A mixture of hardwoods, croplands, bushlands and pasturelands. They prefer an interspersed habitat including meadows, forested woodlots, bushy areas, and croplands	Upland wood forest

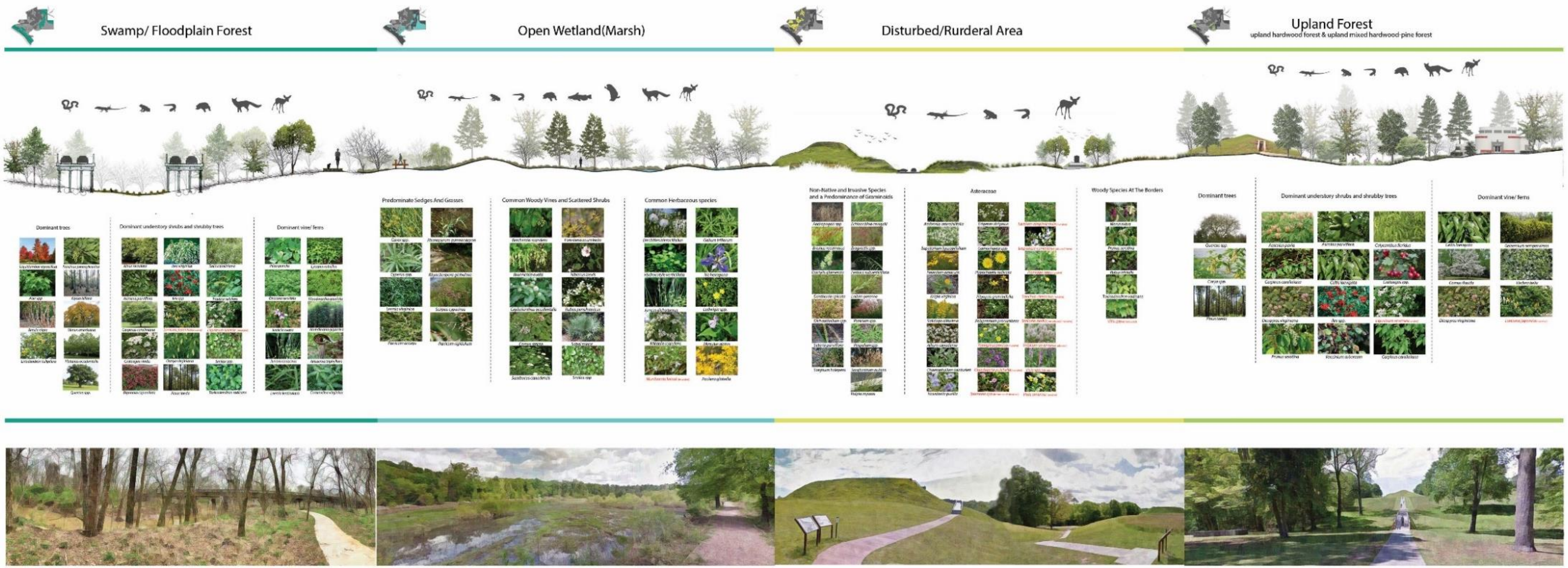


Figure 5.17: Plant communities and animal habitats (made by author)

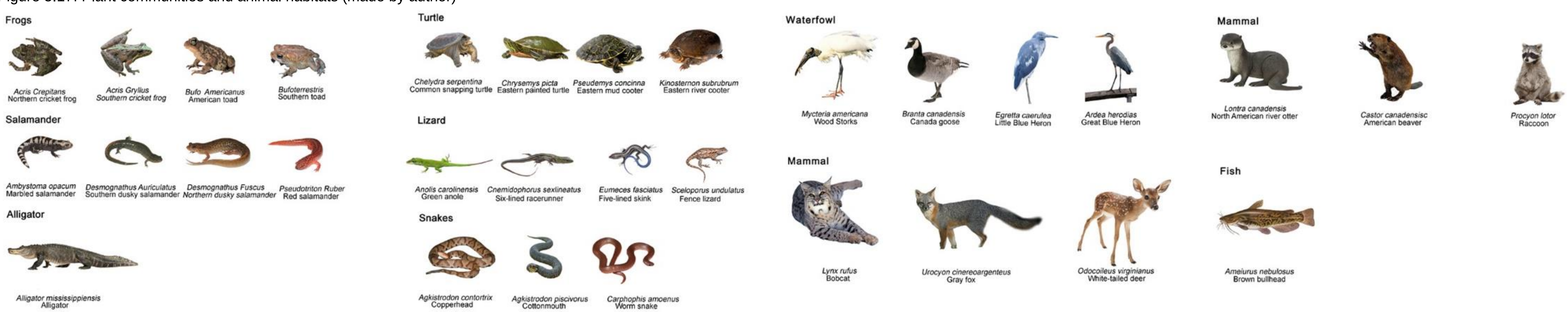


Figure 5.26: Recorded Animals in the Park (made by author)

Stream buffer management consists of permitted, restricted, and prohibited uses (University of Virginia, 2002). The priority of this management plan for this site is to control invasive and introduced species, like Japanese honeysuckle (Lonicera japonica) and Chinese privet (Ligustrum sinense). Based on the Baseline Vascular Plant Survey (Zomlefer et al., 2013), OCMU has four types of plant communities. In the **floodplain forest**, the buffer along Interstate 16 should be preserved both for noise control and disturbance limitations to the OCMU main unit. Invasive species like Japanese honeysuckle (Lonicera japonica) and Chinese privet (Ligustrum sinense) should be controlled and cleaned out regularly. The invasive and introduced plants in the **upland forest** are Chinese privet (*Ligustrum sinense*) and Japanese honeysuckle (*Lonicera japonica*). The o**pen wetland or marsh** is bisected by the Opelofa Trail and railroad, invasive species like Marsh Deflower (*Murdannia keisak*) should be controlled and managed. For **the Disturbed area**, there are ten species in the family of *Asteraceae* listed as invasive or introduced species. Since there are more invasive plants here than in other areas, management here is needed more.

The following figures show the selected sections of plant communities and several invasive plants are highlighted (Fig. 5.28-31).

Figure 5.27: Management Scenario (made by author)

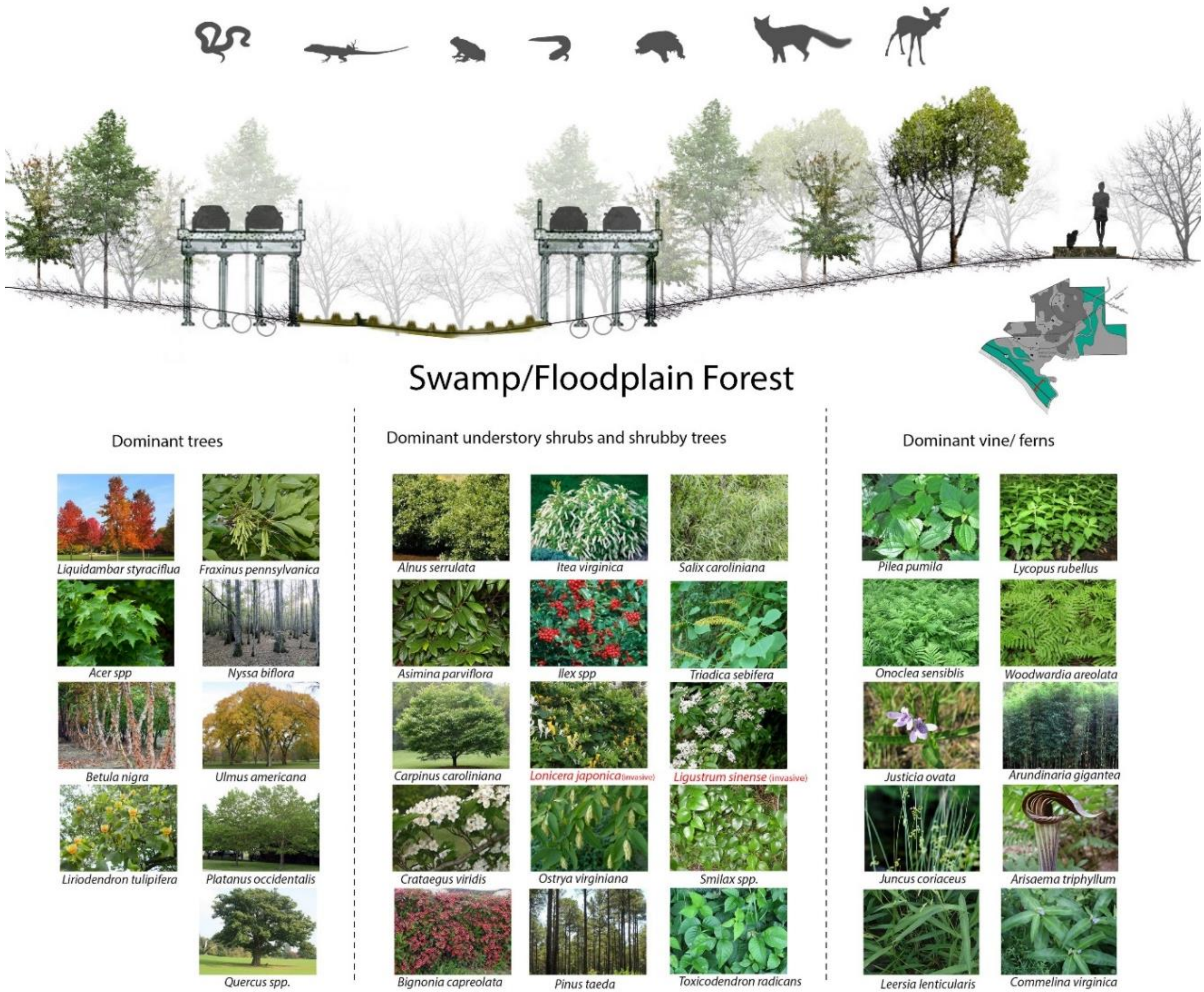


Figure 5.28: The Swamp/Floodplain Forest System (made by author)

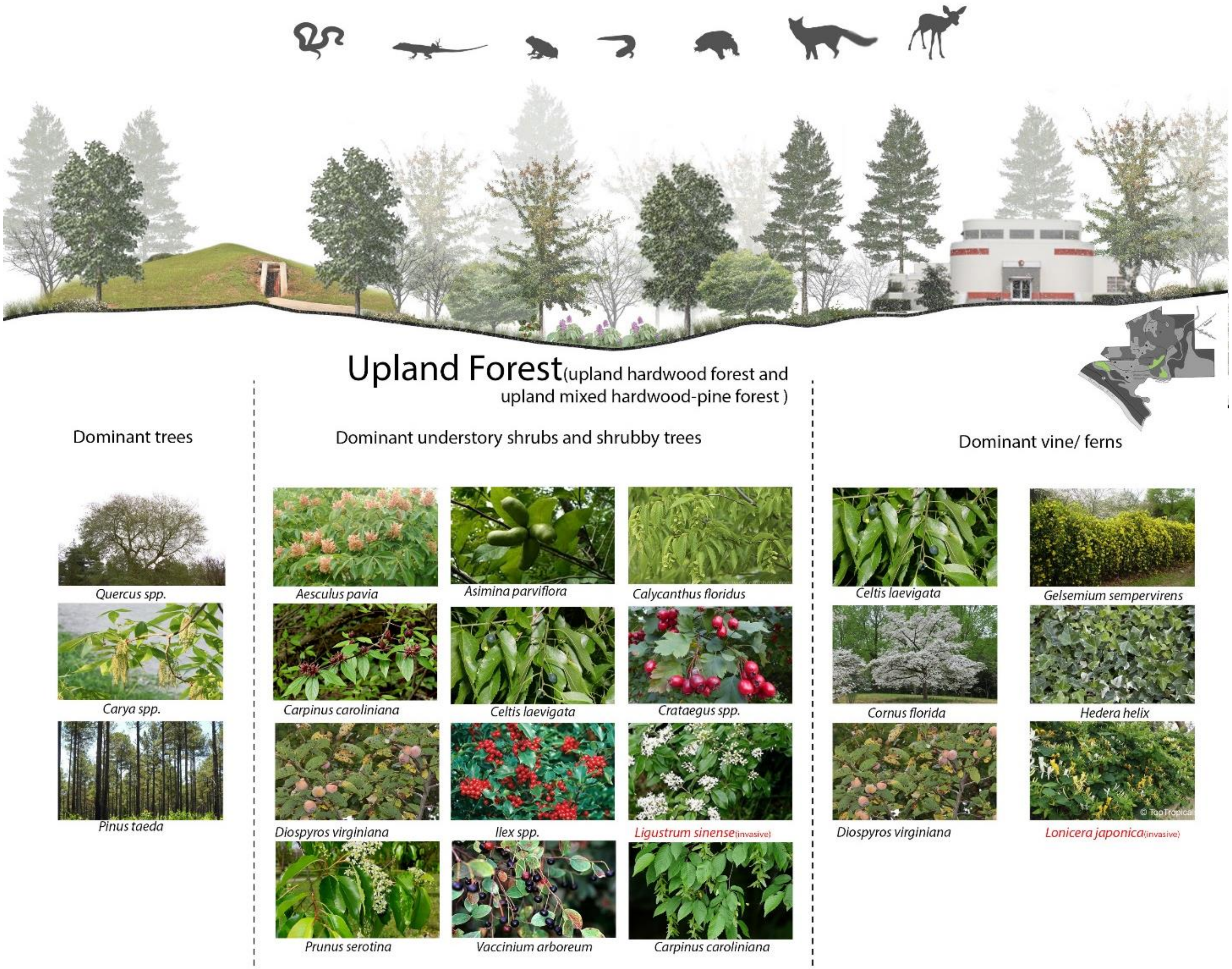


Figure 5.29: The Upland Forest Ecosystem (made by author)

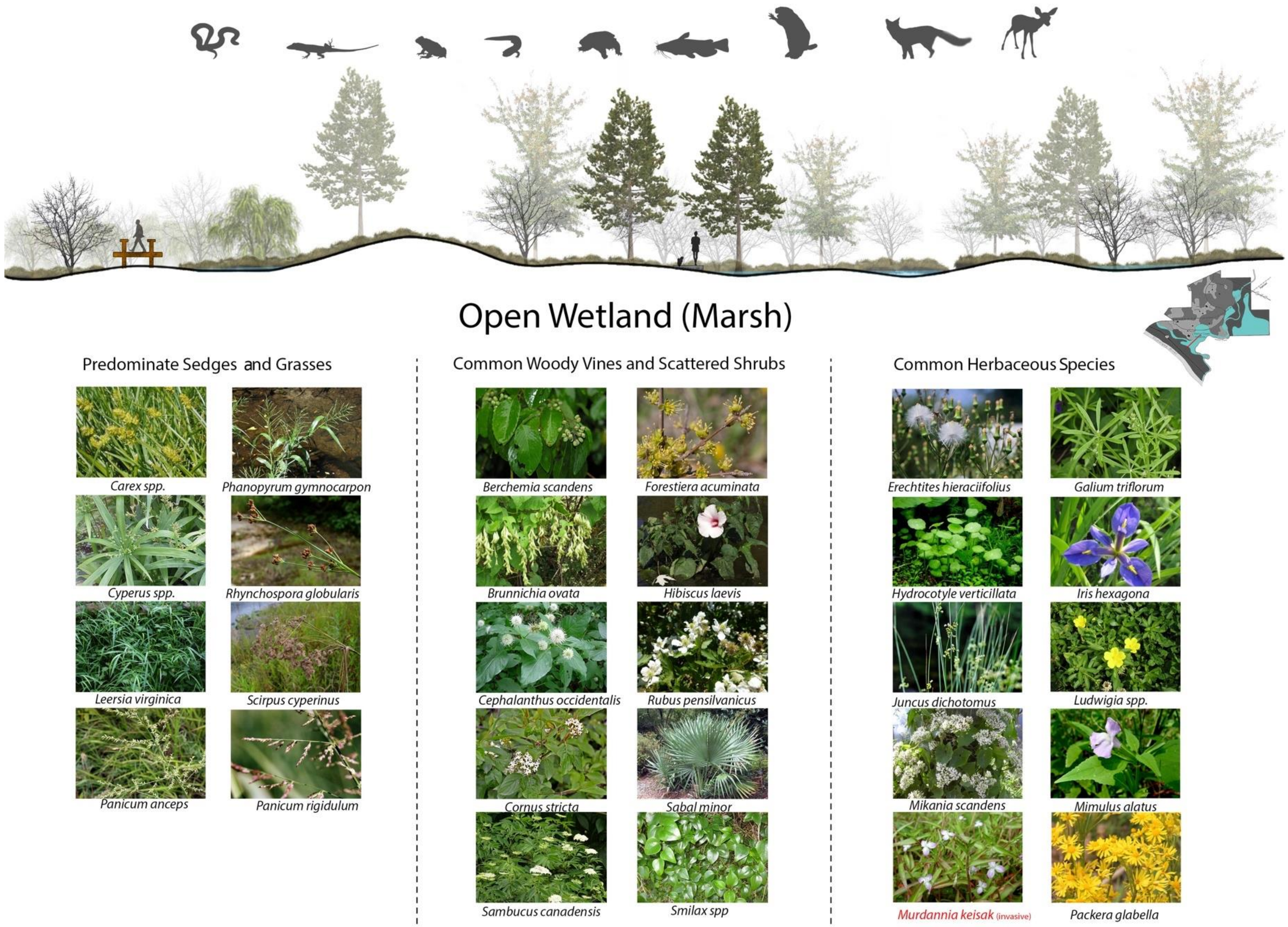


Figure 5.30: The Open Wetland Ecosystem (made by author)

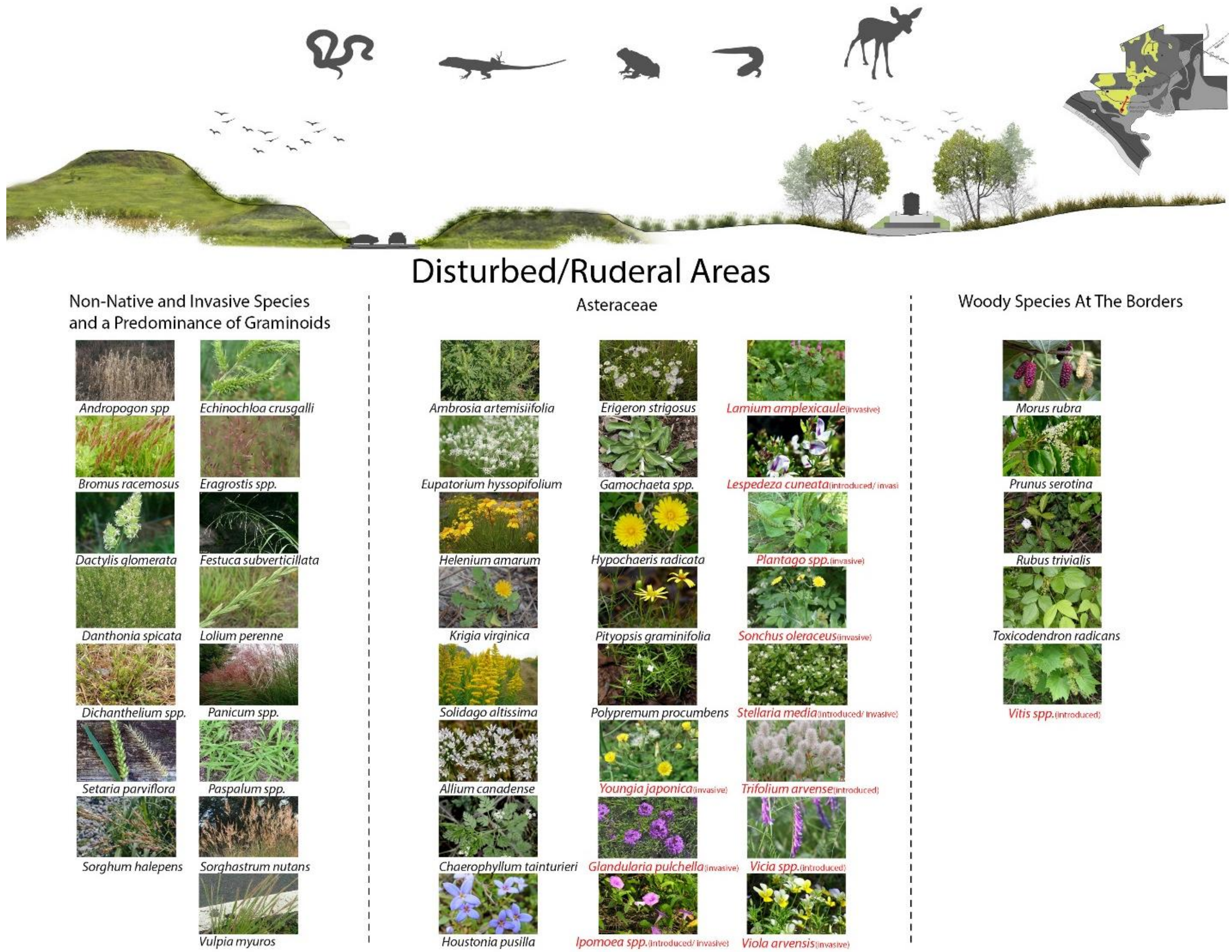


Figure 5.31: Disturbed /Ruderal Areas Ecosystem (made by author)

Assessment

Based on *A Baseline Vascular Plant Survey* by Zomlefer and his associates (2013), the design analyzes the four plant communities and invasive plants in the OCMU main unit. Four sections of plant communities and the majority of plants are presented. Animals that have been recorded in the park and their habitat preferences are analyzed and illustrated. A illustrated map demonstrates where conserved buffers are located. Control and management of invasive species are discussed. Measures to protect animals and plants from the threat of flooding need to be considered more in the future.

PLANT COMMUNITIES & ANIMAL HABITAT	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
8. Does the project conduct ongoing biological research and evaluation?		√	
9. Does the project prevent fragmentation and provide sustainable buffers for fauna ?		√	
10. Does the project control and manage invasive species?		√	
11. Does the project enhance or enlarge the habitat?		√	

Figure 5.32: Assessment of Plant Communities & Animal Habitat (made by author)

5.6 Infrastructure and Management

Portions of trails can be submerged by water or covered by sediment and become unaccessible during or after flooding. The design seeks to improve the accessiblilty of the trail system and conducts a a maintenance plan for it.

Before the projective design, the park had impervious trails and only part of the River trail was constructed as boardwalk. The impervious trails were covered by asphalt or gravel (Fig. 5.33). The design made the highly used River Trail into a complete boardwalk to enhance its accessibily. The Opelofa Trail is suggested to be constructed as a causeway and the Walnut Creek Connector Trail is designed as a terraced embankment with a boardwalk (Fig. 5.34).

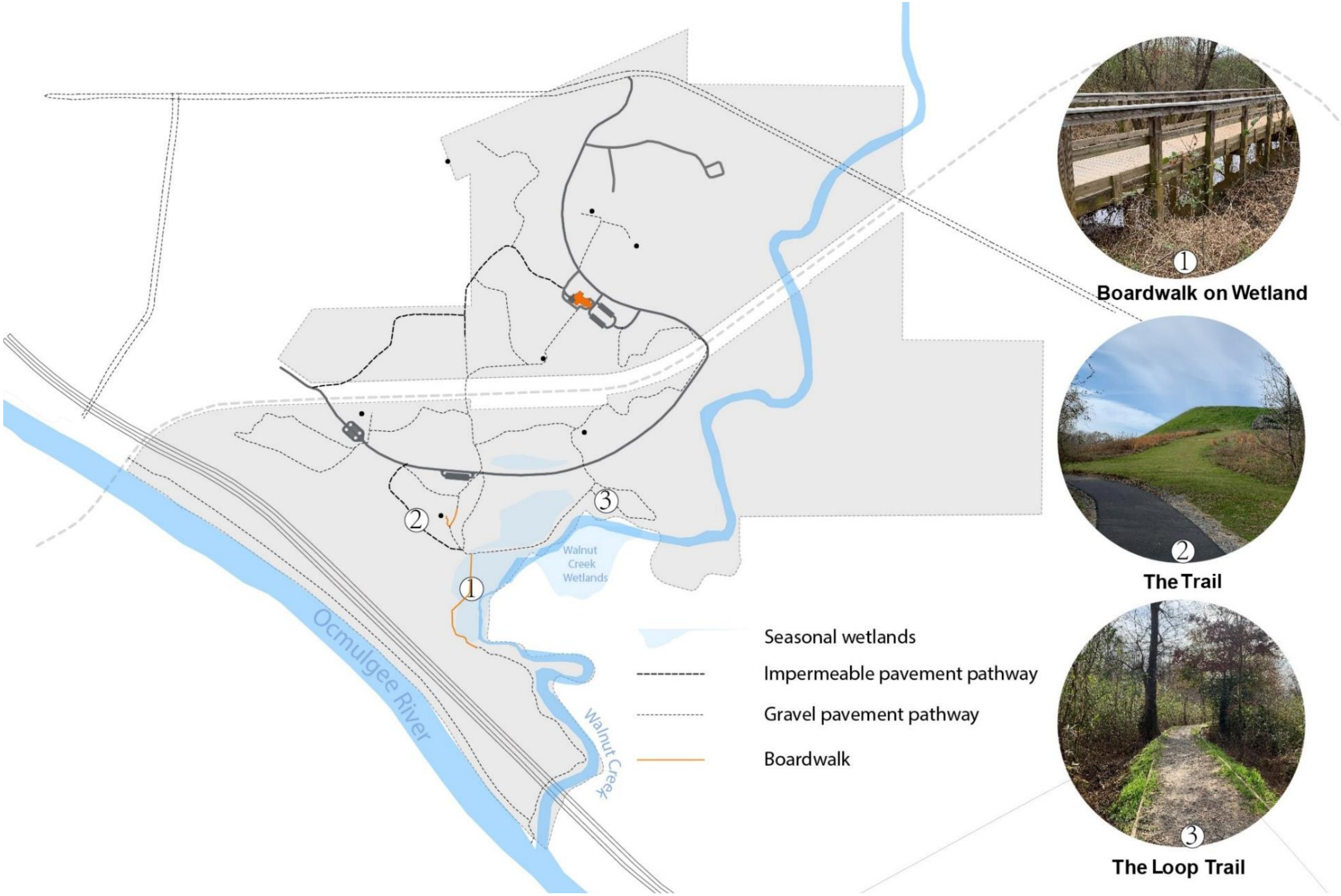


Figure 5.33: Existing Infrastructure (made by author)

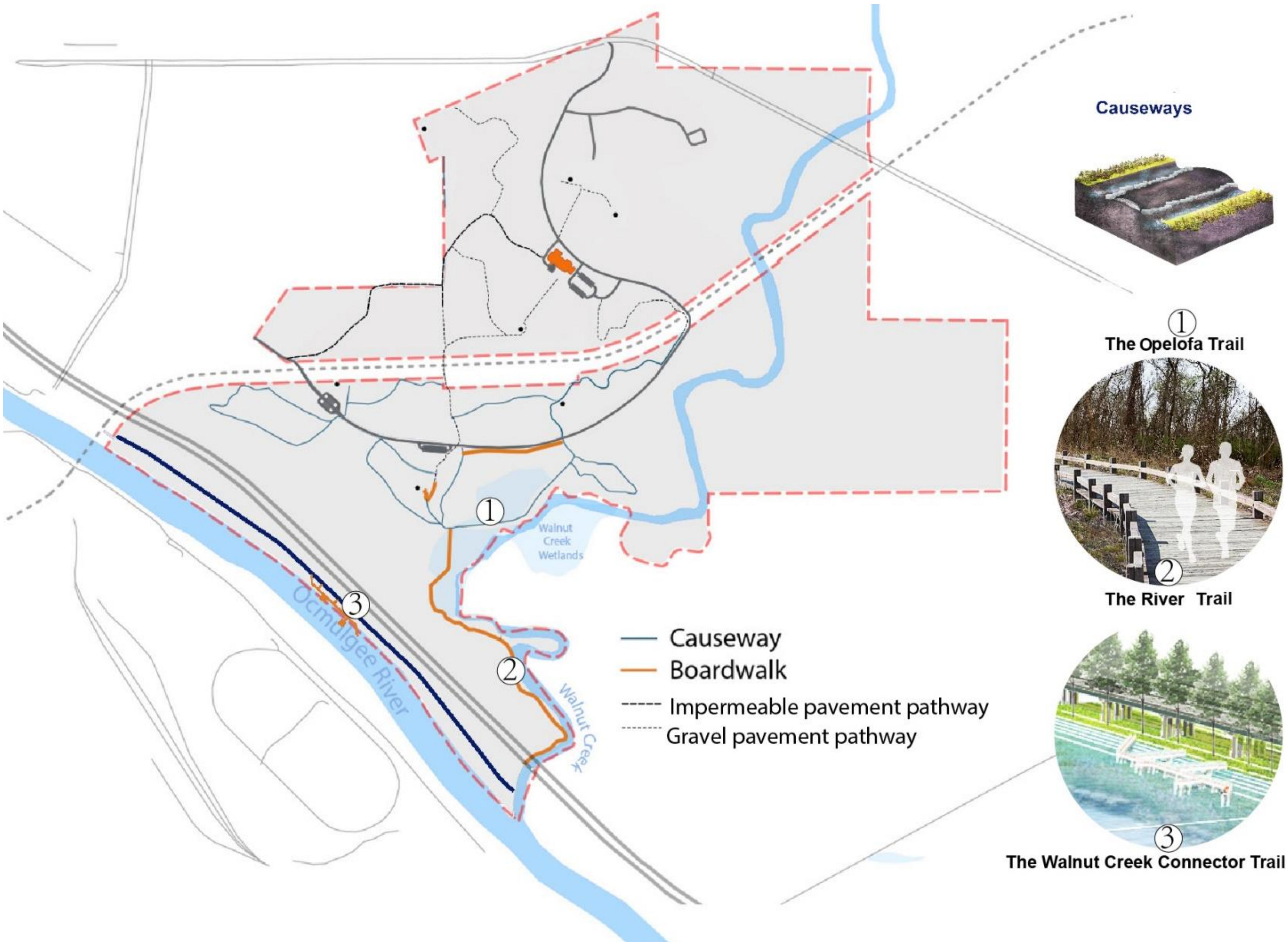


Figure 5.34: Proposed Location for Infrastructure and Management Measures (made by author)

A boardwalk is a series of connected bridges supported by spaced posts or piers. It gives visitors safe and clean access while limiting its impact to the surrounding environment (Steinholtz and Vachiowski, 2007). Seasonlly submerged by water and sediment, a boardwalk is an ideal alternative to a concrete walkway. However, due to the sophisticated construction and materials needed, a decision on the length of the boardwalk should be based on the type of users and foot traffic frequency. Previously, the highly used River Trail—part boardwalk and part concrete pavement—has always needed sediment management after flooding. Thus, it is recommended that the rest of the concrete River Trail be replaced with an elevated culvert or boardwalk. Figure 5.35 shows the boardwalk scenario and Figure 5.36 illustrates the section of a double brace boardwalk.

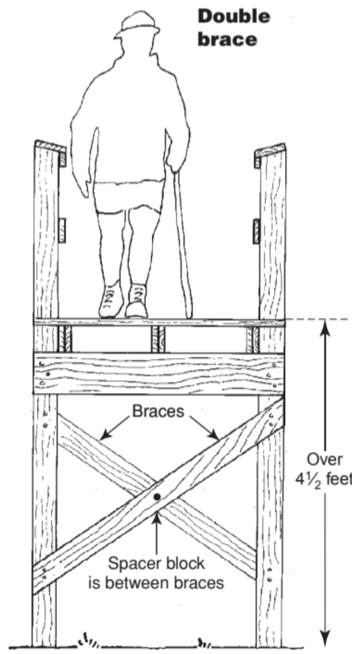


Figure 5.35: Boardwalk Scenario (made by author)
Figure 5.36: Section of Double Brace Boardwalk (Source: Steinholtz, Robert T., and Brian Vachowski. Wetland Trail Design and Construction 2007 Edition. January 2007. Accessed May 25, 2019. https://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232804/page07.htm.)

Causeways are one of the most environmentally friendly wetland trail structures. They create an elevated, hardened tread across seasonally wet area. They are filled with pervious materials, such as gravel, limestone, or sod, allowing moisture to soak into the ground naturally. It is important to lower the water level below the trail base and to carry the water under and away from the trail at frequent intervals (Steinholtz and Vachiowski, 2007). Figure 5.37 shows the causeway scenario and Figure 5.38 illustrates a section of causeway.

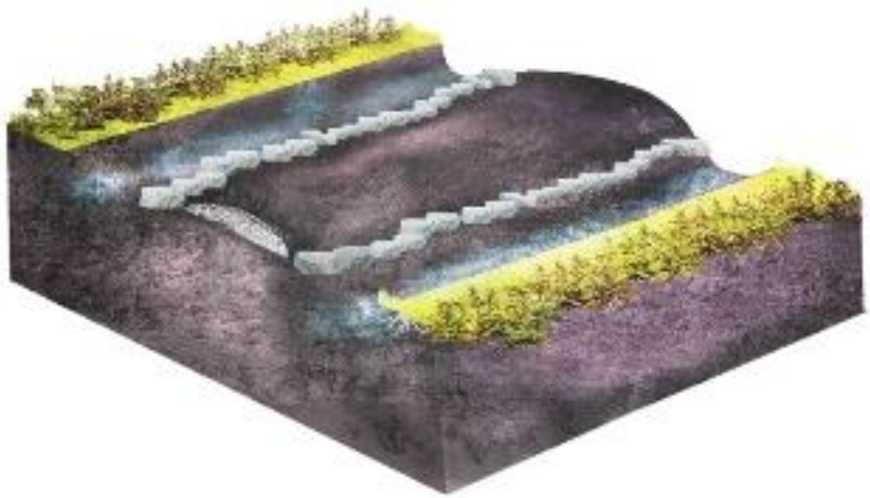


Figure 5.37: Causeway Scenario (made by author)

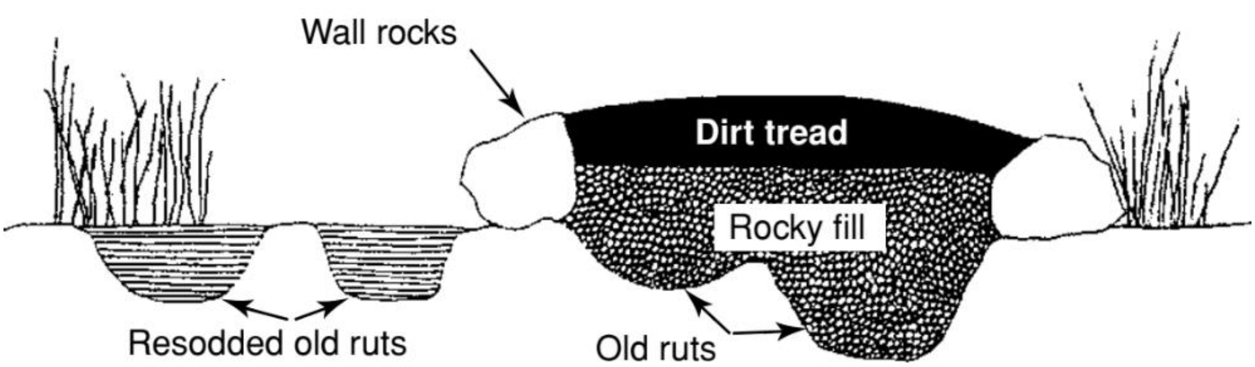


Figure 5.38: A Section of Causeway (Source: Steinholtz, Robert T., and Brian Vachowski. Wetland Trail Design and Construction 2007 Edition. January 2007. Accessed May 25, 2019. https://www.fs.fed.us/t-d/pubs/htmlpubs/htm07232804/page07.htm.)

Usable Trail before and after Design

Figure 5.39 -5.46 illustrates the usable tail before and after design during four critical stages: flood stage, moderate stage, major stage, and dangerous stage.

When flood stage reaches 18 feet, the existing useable trail is 7. 54 mile; after design, the usable trail would be 7.71 mile.

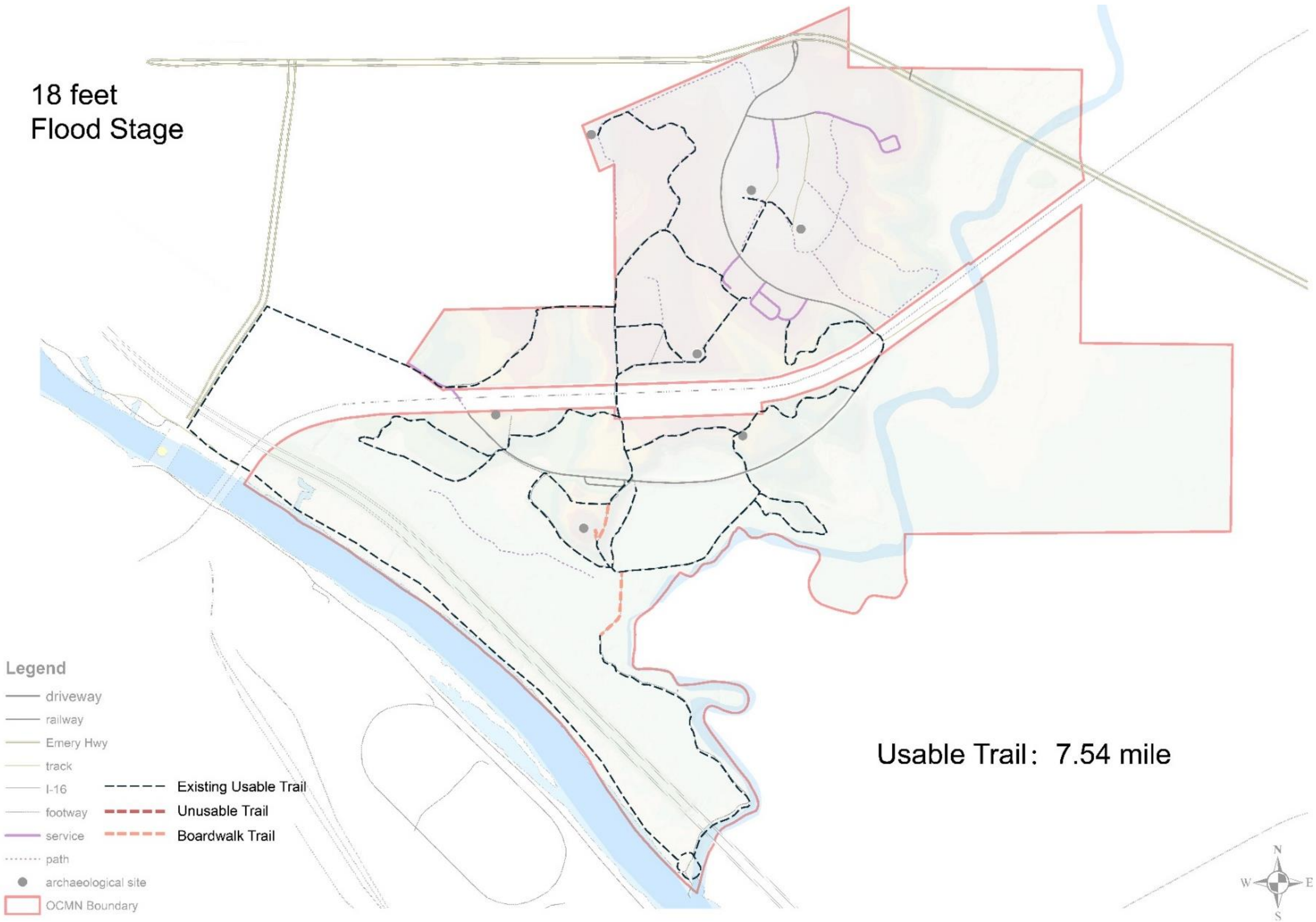


Figure 5.39: Existing Trails at Flood Stage (made by author)

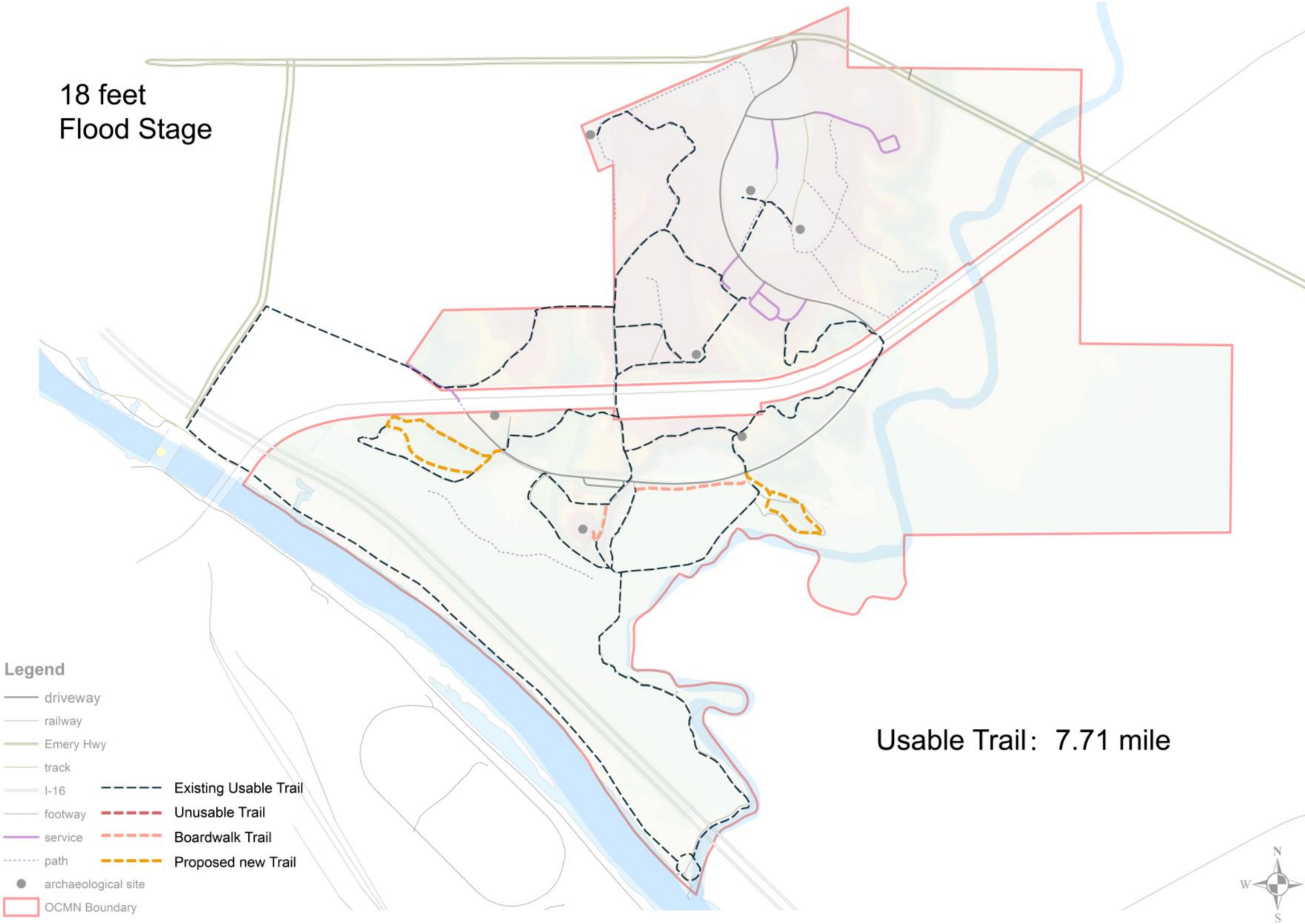


Figure 5.40: Proposed Trails at Flood Stage (made by author)

When flood stage reaches 26 feet, the existing useable trail is 4. 93 mile; after design, the usable trail would be 7.31 mile.

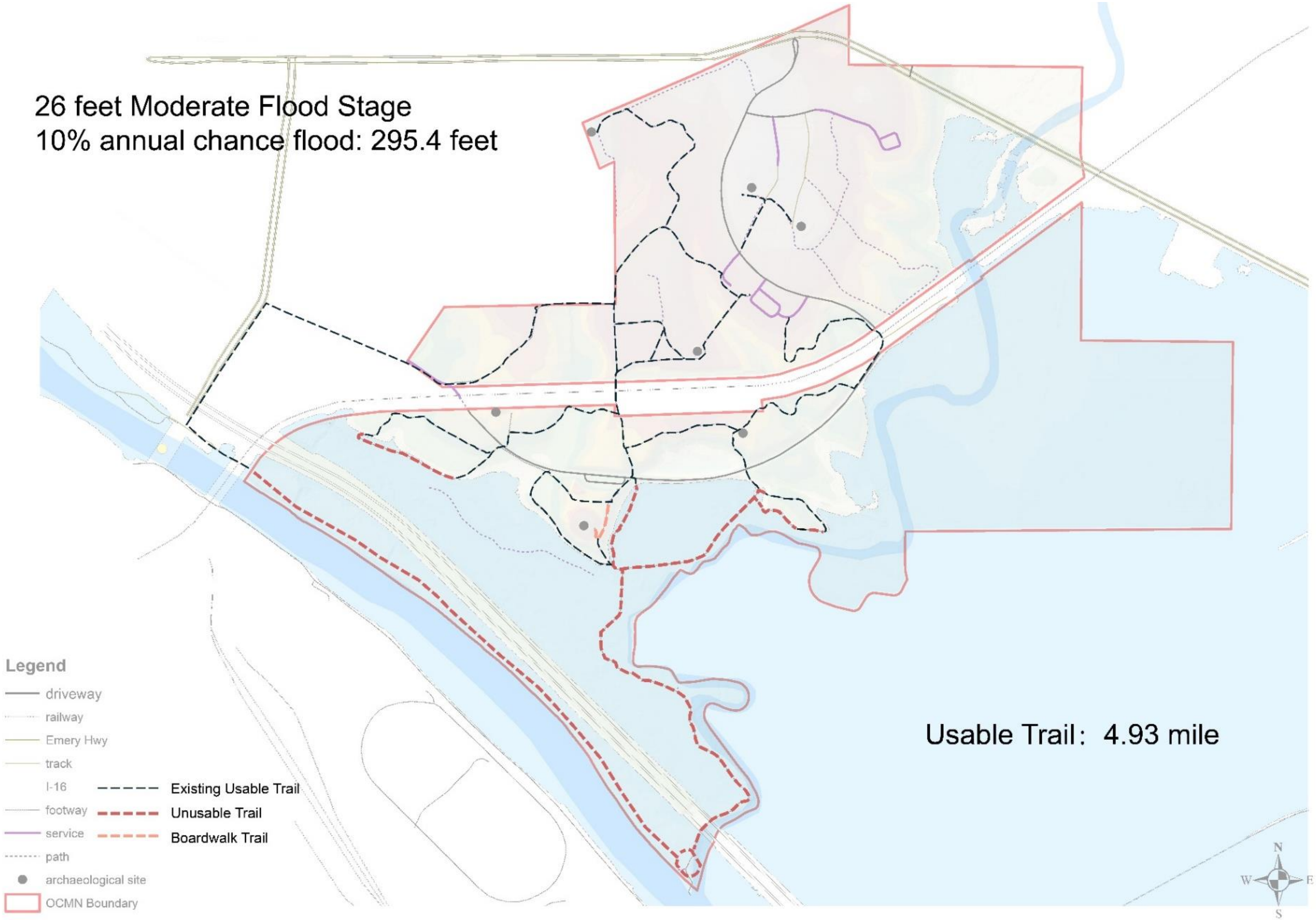


Figure 5.41: Existing Trails at Moderate Flood Stage (made by author)

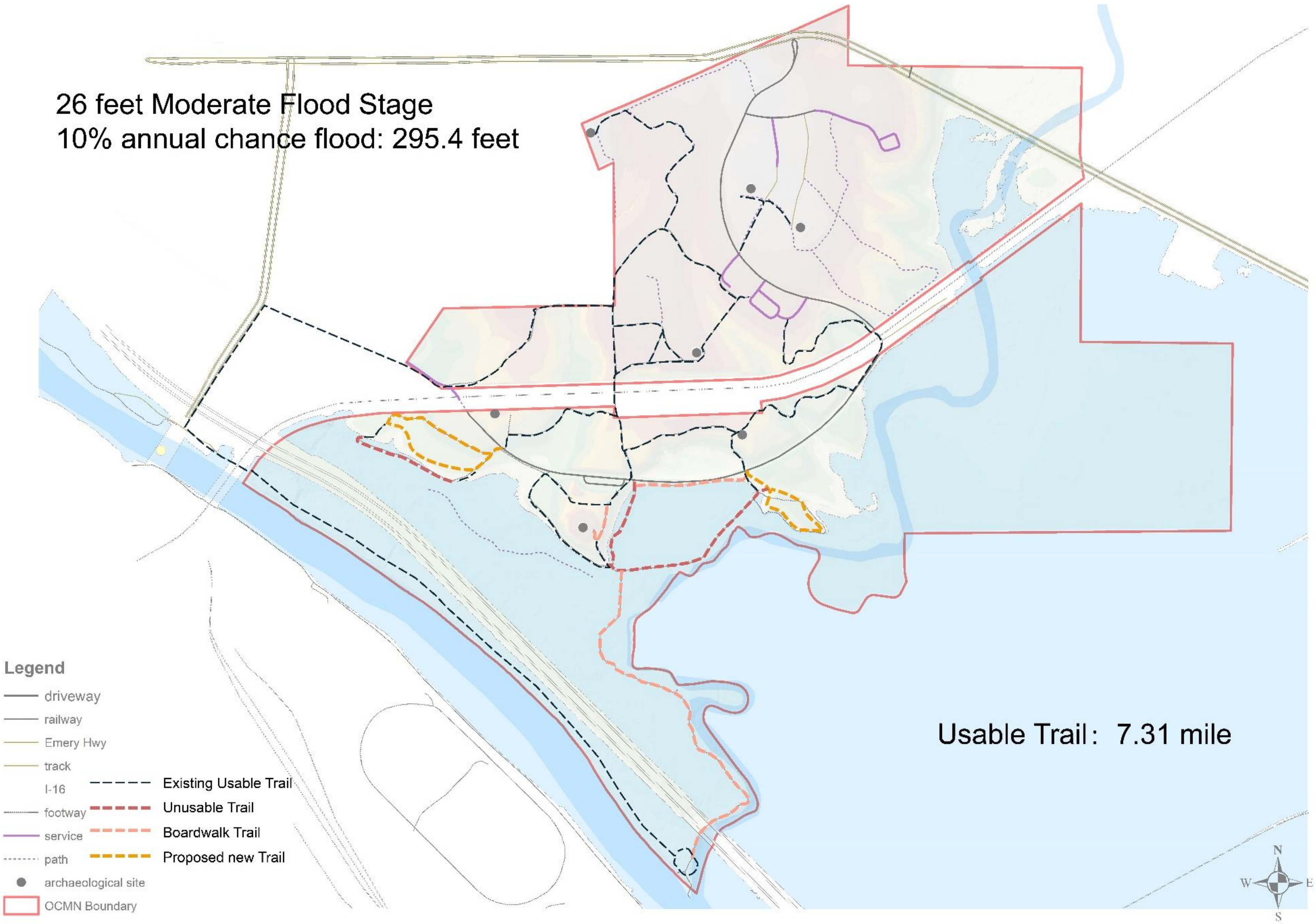


Figure 5.42: Proposed Trails at Moderate Flood Stage (made by author)

When flood stage reaches 30 feet, the existing useable trail is 4.87 mile; after design, the usable trail would be 5.14 mile.

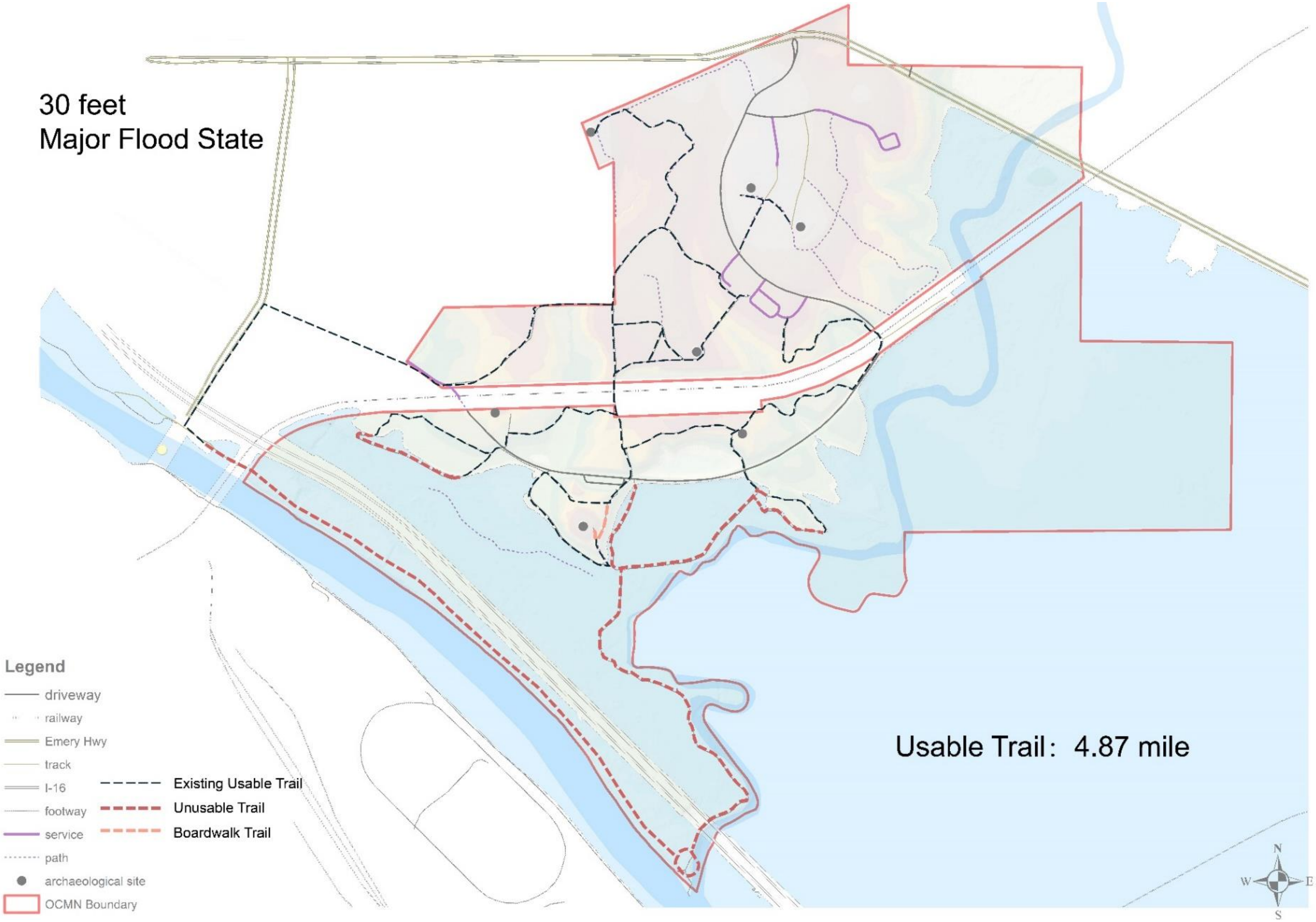


Figure 5.43: Existing Trails at Major Flood Stage (made by author)

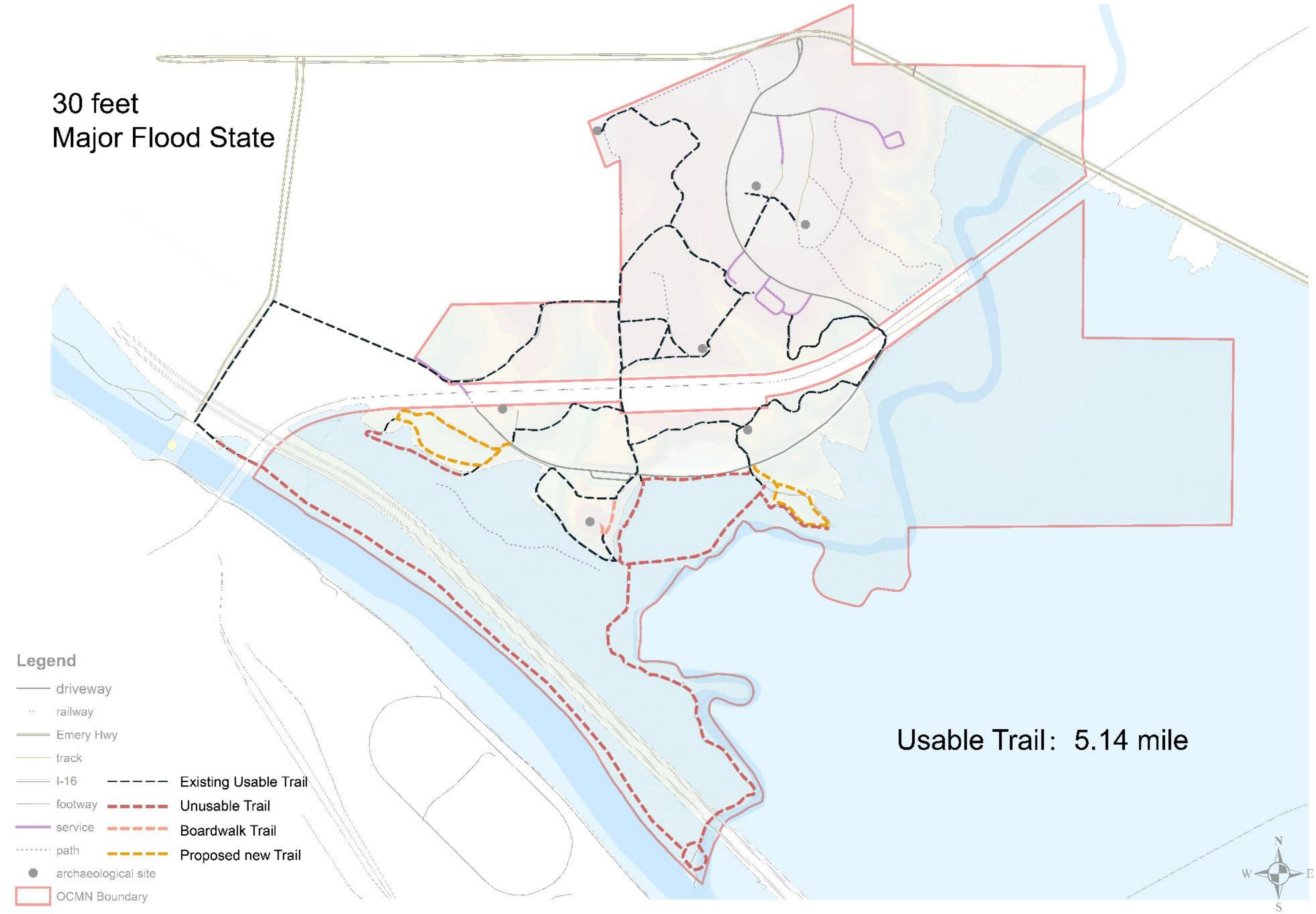


Figure 5.44: Proposed Trails at Major Flood Stage (made by author)

When flood stage reaches 32 feet, the existing useable trail is 4.84 mile; after design, the usable trail would be 5.03 mile.

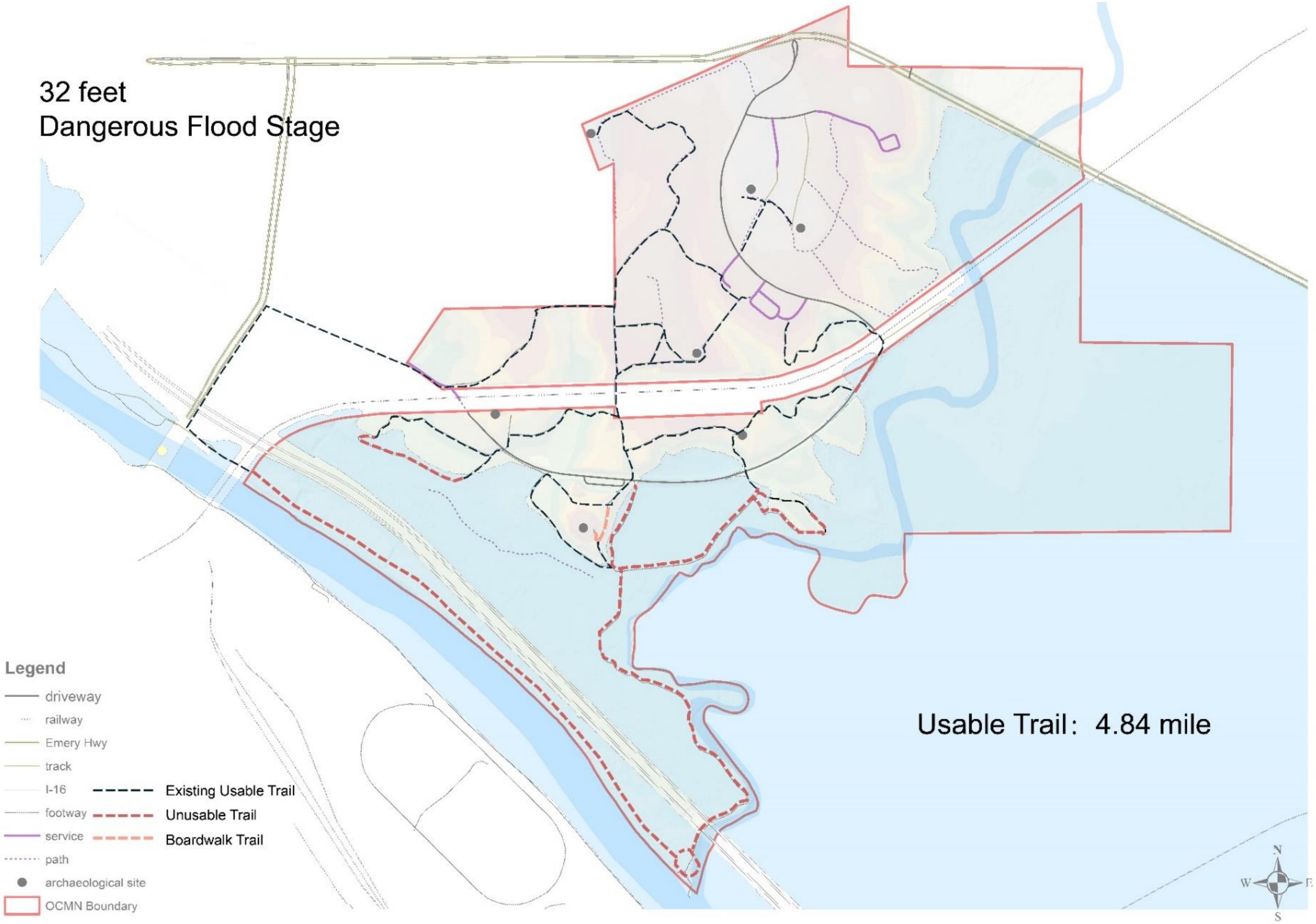


Figure 5.45: Existing Trails at Dangerous Flood Stage (made by author)

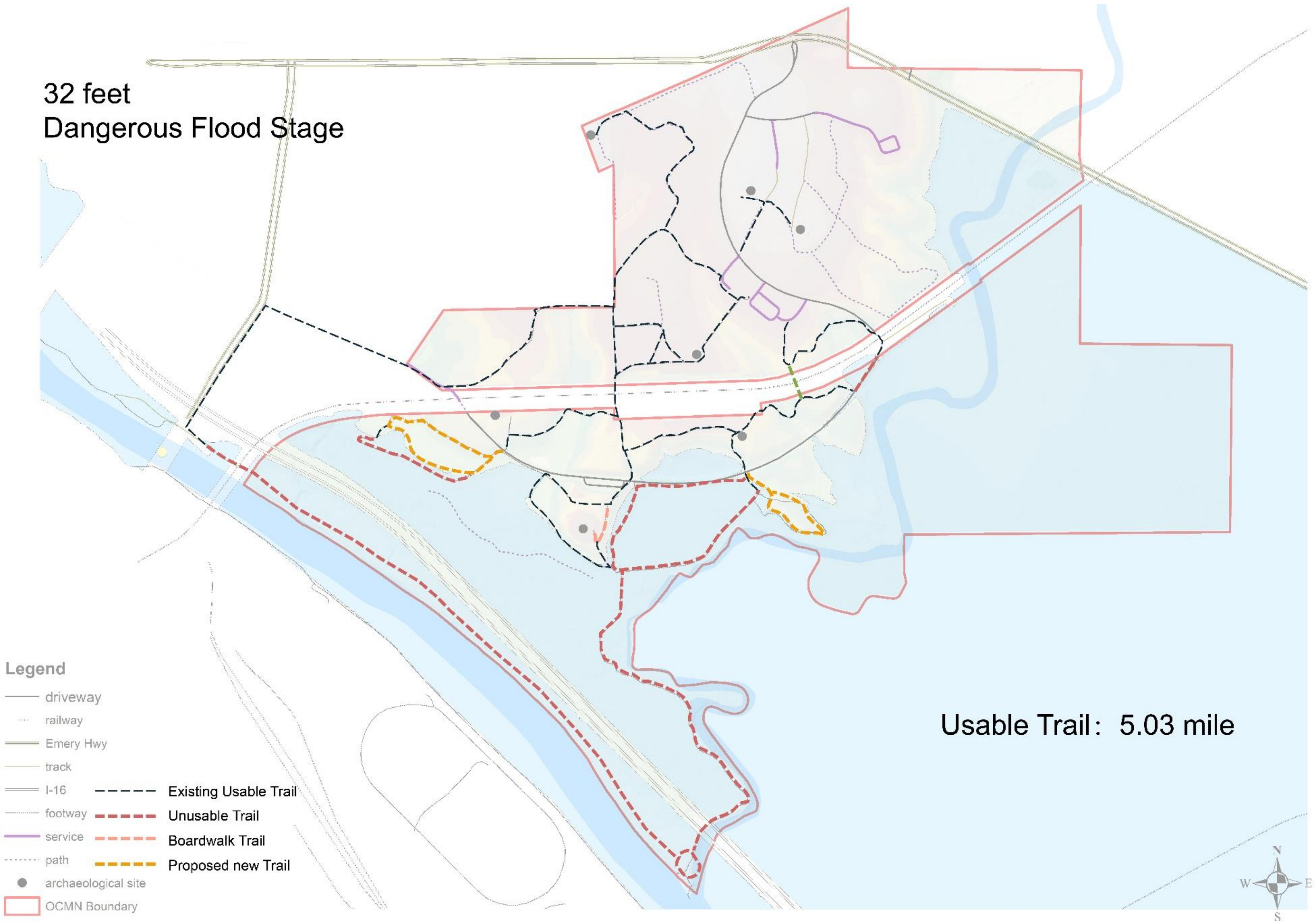


Figure 5.46: Proposed Trails at Dangerous Flood Stage (made by author)

Detail Design

The elevation of the Opelofa Trail is 288 feet currently, and it is just 0.6 feet above the minor flood stage (287.4 feet). The ten-year annual chance flood stage is 295.5 feet. To improve the accessibility of the trail, the projective design raises the Opelofa Trail 2.5 feet higher by adding rocky fills under the dirt tread. Geotextiles may be added to help prevent the trail from sinking into the ground. The trail has experienced 167 floods from 1880 to 2018, and 78 of them were minor floods below 290.5 feet (flood crests: 21 feet). By raising the trail 2.5 feet higher, the flood frequency would decline by 46.7 %. Figure 5.39 shows the Opelofa Trail before the projective design and Figure 5.40 illustrates the Opelofa Trail after the projective design.

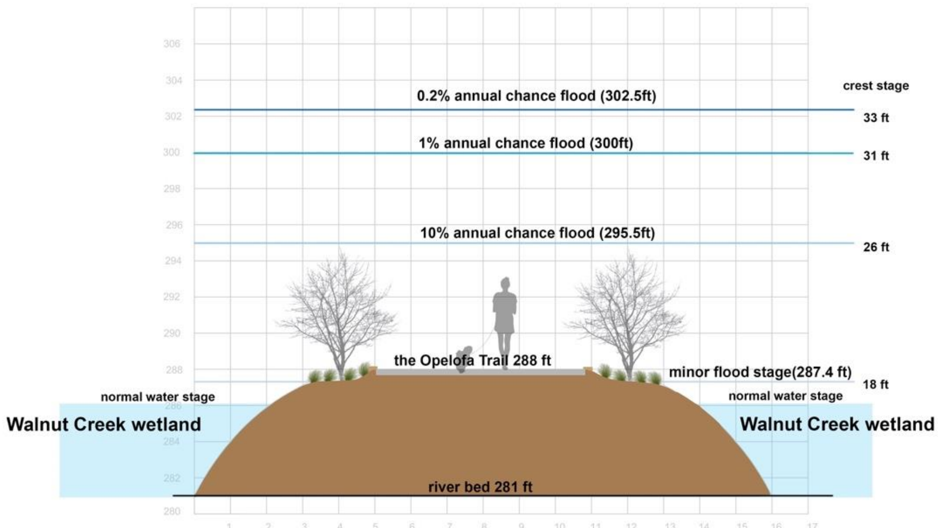


Figure 5.47: The Opelofa Trail before the Projective Design (made by author)

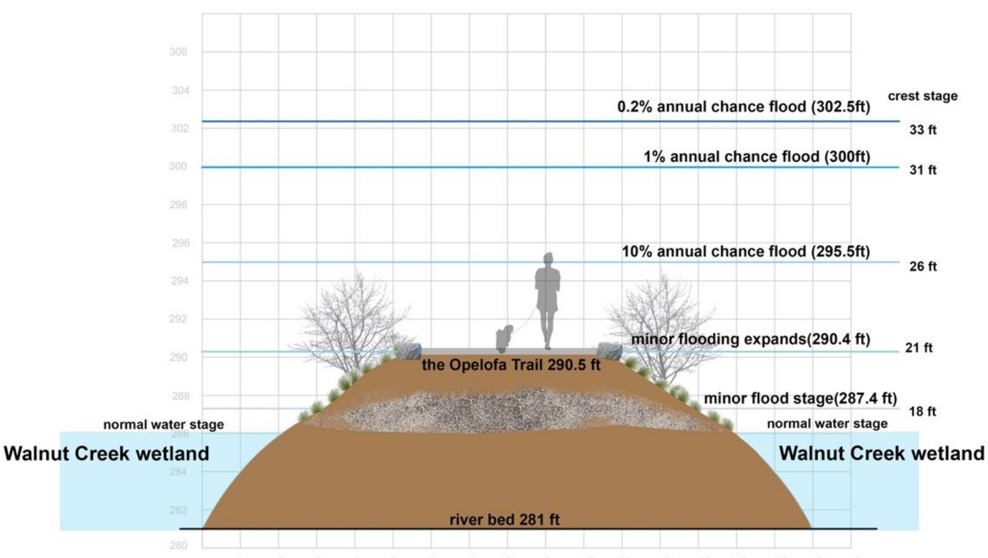


Figure 5.48: The Opelofa Trail after the Projective Design (made by author)

The elevation of the River Trail is 289.4 feet currently, which is two feet above the minor flood stage (287.4 feet). The ten-year chance flood stage is 295.5 feet. Thus, to improve the accessibility of the trail, the projective design replaces the concrete pavement trail with an elevated boardwalk. The tread of the boardwalk is 293.4 feet and it is four feet above the ground. The trail has experienced 167 floods from 1880 to 2018, and 142 of them were minor floods below 293.4 feet (flood crests: 24 feet). By raising the trail four feet higher, the flood frequency would decline by 85%. Figure 5.41 shows the River Trail before the projective design and Figure 5.42 illustrates the River Trail after the projective design.

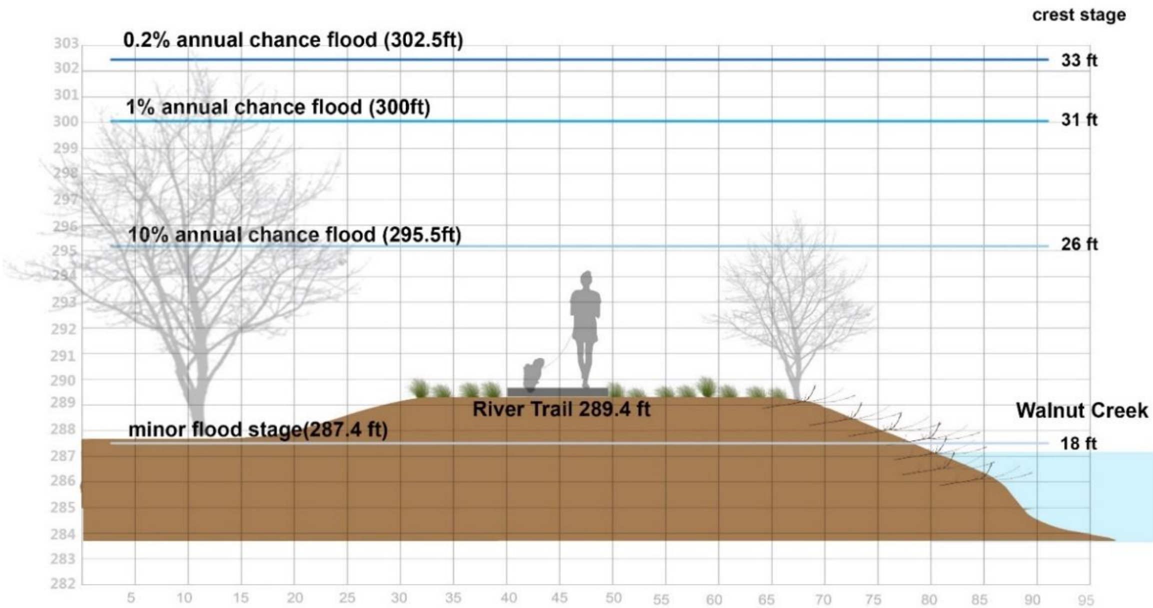


Figure 5.49: The River Trail before the Projective Design (made by author)

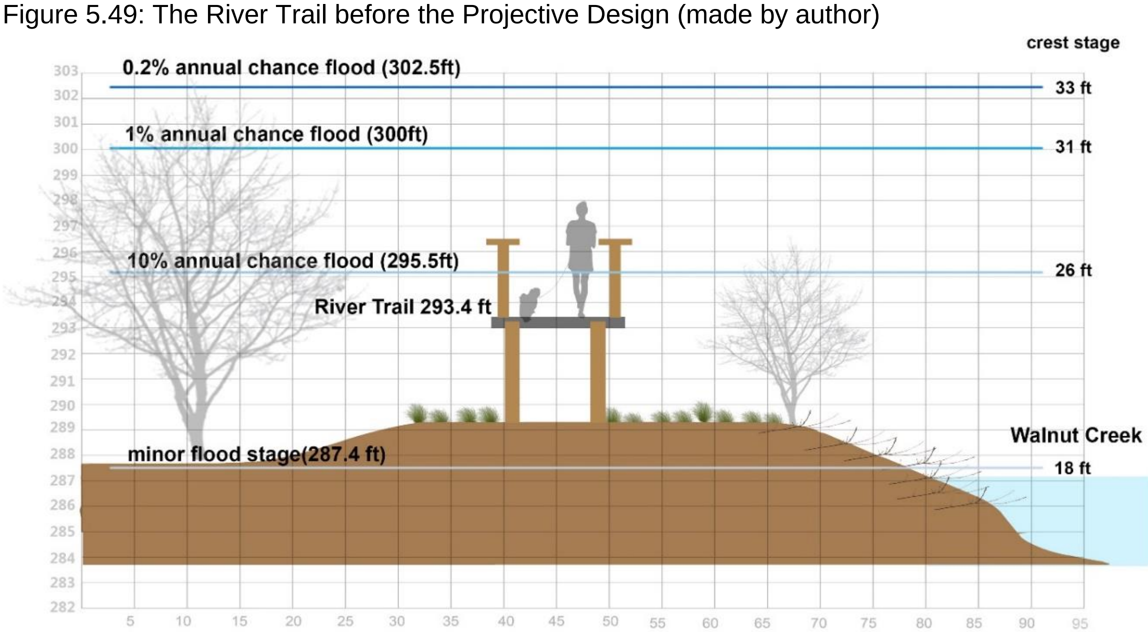


Figure 5.50: The River Trail after the Projective Design (made by author)

A terraced embankment system is proposed on both sides of the Ocmulgee River. The native plants covering the terraced embankment will help filter the water and stabilize the riverbank. The terraced embankment will function as a pathway that people can walk on. The tread of the boardwalk is at 295 feet. The trail has experienced 167 floods from 1880 to 2018, and 156 of them were minor floods below 294.5 feet (flood crests: 26 feet). By raising the trail threr feet higher, the flood frequency would decline by 93.4 %. Figure 5.43 shows the WCCT before the projective design and Figure 5.44 illustrates it after the projective design.

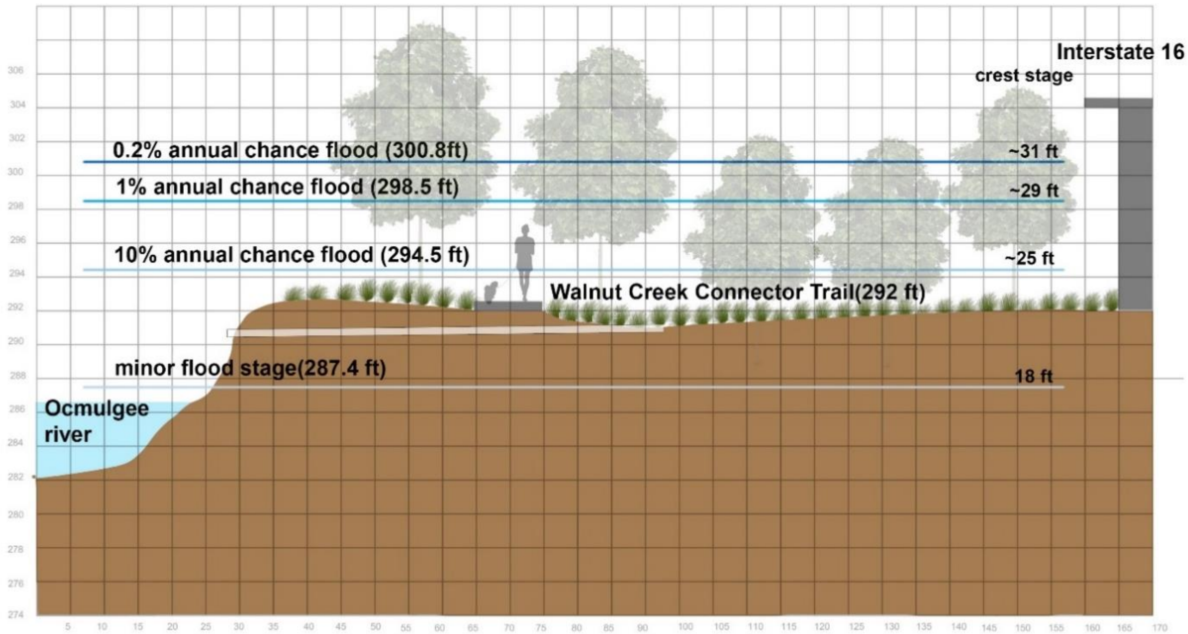


Figure 5.51: The Walnut Creek Connector Trail before the Projective Design (made by author)

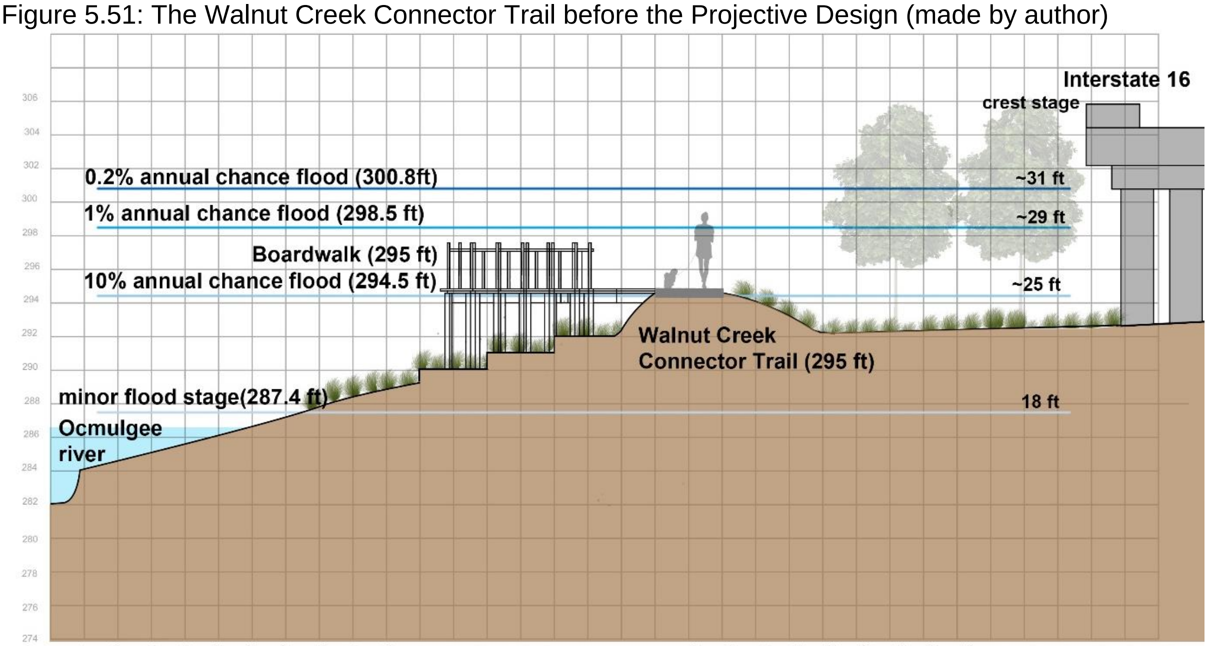


Figure 5.52: The Walnut Creek Connector Trail after the Projective Design (made by author)

Assessment

The design seeks to improve the accessibility of the road and trail systems. A terraced embankment is proposed to replace the existing Walnut Creek Connector Trail along the Ocmulgee River. In order to provide access for people to the floodplain during flooding, a boardwalk will link to the top of the embankment above the historical maximum flood stage (34.5 feet). Along Walnut Creek, an elevated boardwalk is proposed to replace the existing concrete paved trail which needs sediment management regularly. Permeable pavements like gravel, limestone, or sod will replace the asphalt paved trails in the park. Hazard mapping and identification mapping are conducted and illustrated, but appropriate community-based remediation for stormwater and flood hazards needs further discussion and consideration.

INFRASTRUCTURE & MANAGEMENT	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
12. Does the project improve accessibility of road and trail systems?			√
13. Does the project accquire land and discourage development in river corridors?	√		
14. Does the project introduce permeable pavements?		√	
15. Does the project conduct hazard mapping, hazard identification, and land use mapping?		√	
16. Does the project have a maintenance plan for infrastructure?	√		

Figure 5.53: Assessment of Infrastructure and Management (made by author)

5.7 Environmental Education

Figure 5.54: Environmental Education Solutions (made by author)

To improve the public awareness of flood hazards and promote ecological and environmental education, several programs could be implemented in the Park. First, a bird observation station could be constructed in the riparian area of the seasonal marsh near the Great Mound (Fig.5.48-49). Second, a boardwalk with three platforms is recommended to be built along the Ocmulgee River. This boardwalk will be elevated above the normal level of the Ocmulgee River and could be submerged during major flooding. It would give people access to the wetland and riverbank, as well as stabilizing the river bank.

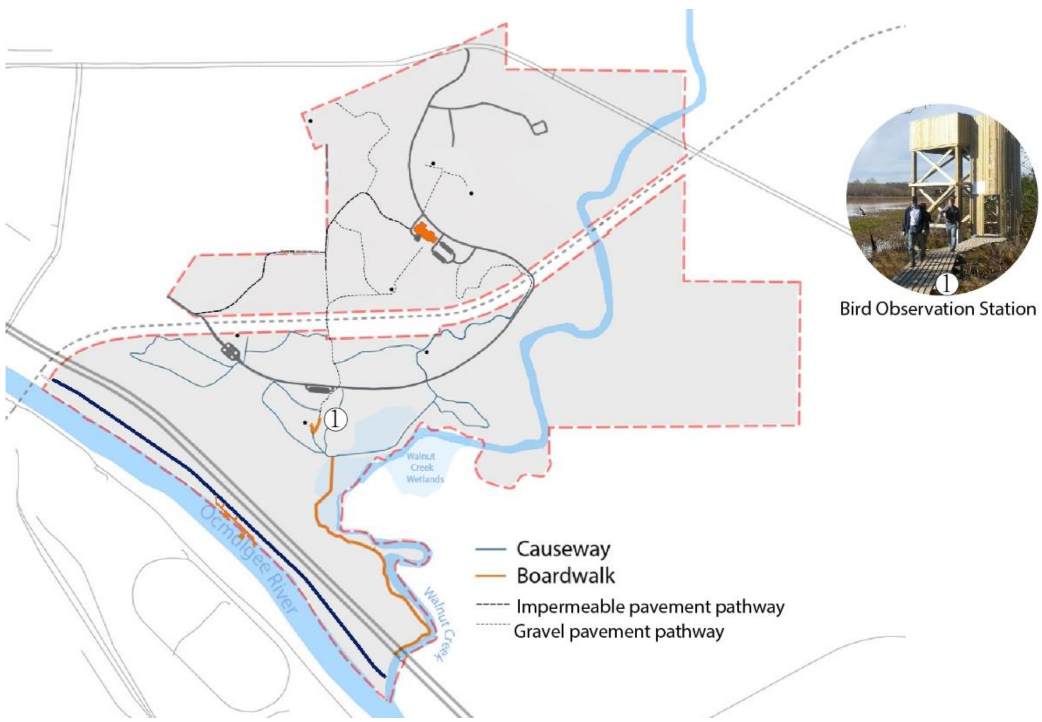


Figure 5.55: Bird Observation location map (made by author)

Figure 5.56: Bird Observation Station (made by author)

Figure 5.57: Bird Observation Station near the wetland (made by author)

Assessment

The design encourages both active and passive recreation in the park for the local community. A floodable trail system and a bird observation station are proposed to be added in the park. Environmental education programs like bird watching, plant identification, and access to the floodplain are proposed. The terraced embankment and elevated boardwalk ensure the accessibility to the floodplain even during flooding and can provide people with intimate connections to the water and help raise the awareness of flooding in the community.

ENVIRONMENTAL EDUCATION	STRATEGIES ACHIEVEMENT		
STRATEGIES	MINIMALLY	FULLY	EXCEEDED
17. Does the project encourage eco-tourism, active recreation (walking, jogging, cycling) and other passive recreation (birdwatching, canoeing, or hiking on nature trails)?		√	
18. Does the project promote local environmental education (access to floodplain, flood circle) ?		√	
19. Does the project promote community engagement and actions for flood management? Does the project have adequate resources located in a region or community to conduct maintenance needs or has it undertaken flood-resilient strategies?	√		

Figure 5.58: Assessment on Environmental Education (made by author)

5.8 Framework Evaluation

The design achieved all the goals in the framework. Within the framework, it exceeded the goals in managing soil erosion and bank stabilization and improving accessibility of road and trail system. It did well at conducting hydrological analysis and biological research. Based on the detailed inventory of the site, the design chooses appropriate measures to address the specific problems of the site. The inundation maps help identify the potential hazard areas and define the critical facilities of the park. The improved trail system encourage recreation in the park and also promotes local environmental education by providing access to the floodplain. However, it has more potential to improve the flood resilience of the park by combining the stormwater management system with local sewer overflows and to promote community engagement and actions for flood management.

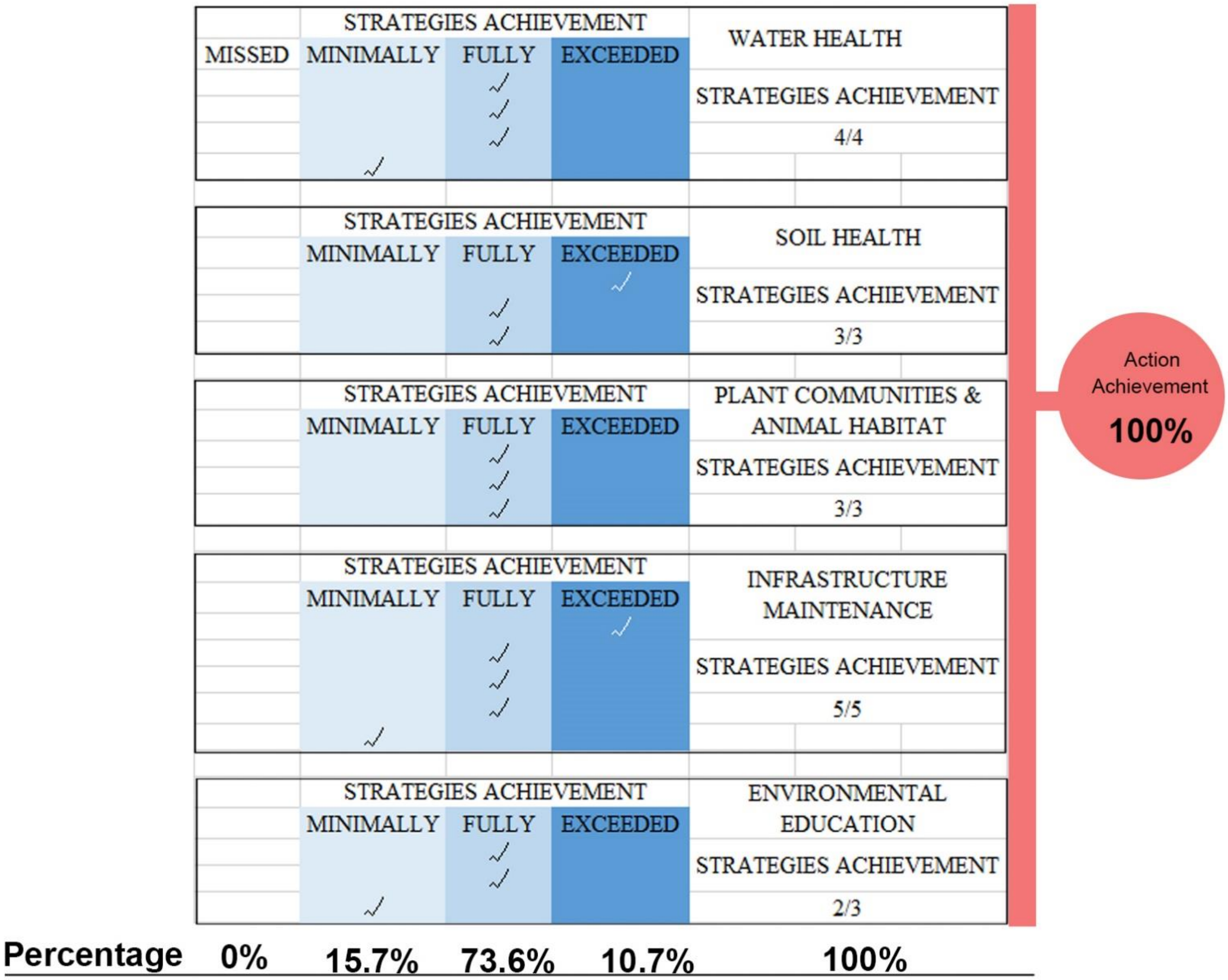


Figure 5.59: Framework Evaluation (made by author)

CHAPTER 6

DISCUSSION

Some aspects of the case studies and the projective design are very similar, while others are very different. However, the fundamentals of a flood-resilient landscape are universal.

Water Health

Floodplains are "hydrologically important, environmentally sensitive, and ecologically productive areas that perform many natural functions" (Walton County, 2019). They play four major roles in the ecosystem: a surface hydrological transition zone, an ecological buffer, a biodiversity-rich area and high-productivity ecosystem area, and an important space for regional water resources (Zhang et al. 2003). To protect these vital areas, five strategies to combine ecosystem rehabilitation and flood safety should be implemented in the future:

- Promote emission capacity and flood storage capacity through river engineering measures (Klijn et al., 2004) to compensate for vegetation succession in natural floodplains
- Conduct careful watershed planning and forest protection
- Put into effect stormwater management and encourage green infrastructure
- Restore wetlands and waterways
- Use hydrological and hydraulic modeling studies to guide flood prevention investments

Soil Health

In the flood season or year, in addition to directly capturing the precipitation, a floodplain can absorb the floodwater that stays in the overflow river channel. Also, in the dry season or the year after the flood peak, it can slowly release a water supply to the river, shortening the time for the downstream river to dry up. Consequently, it can maintain the base flow of rivers and regulate river runoff. The runoff regulation capacity of a floodplain is closely related to its soil properties, the floodplain micro-geomorphology, and the biological growth status. The herb swamp wetland in a floodplain has the strongest ability to regulate river runoff, which is related to the special hydrological and physical properties of the swamp soil such as high porosity (80%-90%) and high water holding capacity (4 500-99000 g/kg). Thus, as the floodplain faces the negative effects caused by human activities, there are several measures to promote the soil health:

- Implement biological riverbank stabilization and manage soil erosion
- Limit development rights in floodplains and the disturbance of existing health soil
- Minimize impervious area

Plant Communities & Animal Habitats

The runoff regulation capacity of a floodplain is closely related to its soil properties, the floodplain micro-geomorphology, and the biological growth status. Also, the grass root layer water holding capacity is generally between 300% and 800%, which has a huge water holding capacity (Zhang and Huang 1981).Thus, protection and restoration of vegetation are vital in the floodplain. Several measures can help protect the riverine buffer:

- Conduct ongoing biological research and evaluation
- Prevent fragmentation and provide sustainable buffers for fauna
- Control and manage invasive and introduced species

Infrastructure & Management

The main road of a floodable park should be usable during the floods and the facilities need regular maintenance after flooding. Three measures are recommended:

- Conduct a maintenance plan for infrastructure
- Improve accessibility of the road and trail system
- Conduct hazard mapping and identification, and land use mapping

Environmental Education

A well-designed community flood education program will help people better prepare for flood hazards and living with nature. Programs should consider the following measures:

- Improve public information on flood hazard and evacuation by providing access to floodplains
- Encourage eco-tourism, active recreation (walking, jogging, cycling) and passive recreation (birdwatching, canoeing, hiking)
- Engage communities in resilience planning
- Build climate change issues into school curriculum

CHAPTER 7

CONCLUSION

The purpose of this thesis is to study how to encourage flood resilience in the Ocmulgee National Monument (OCMU), Macon, Georgia, as well as to mitigate the flood hazards to downtown Macon. The research proposed a suitable flood resilient system in this historically valuable park.

By comparing the strategies of flood-resilient design and flood-resistant design, it is evident that implementation of flood-resilient strategies in the Ocmulgee National Monument is more suitable since these strategies are aimed at living with water rather than fighting with it. It seeks to find sustainable ways to deal with flooding in the long term and considers extreme events. It is a systematic solution which considers the full life cycle impact for long-lived elements of the built environment. It consists of structural measures and non-structural measures. Structural measures include engineering constructions such as run-off management, flood adaptation, dispatch and architect design. Non-structural measures include risk insurance, public education and community engagement such as risk communication and perception, flood policy and institutional interplay, and flood management tools.

Based on the existing research on flood-resilient design, a framework was developed to evaluate the case studies and projective design in terms of five aspects: soil health, water health, plant communities and animal habitats, infrastructure and management, and environmental education. Each aspect has four to seven specific goals, and the projective design aimed to complete most of them.

Mill Race Park in Columbus, Indiana, USA and Yanweizhou Park in Zhejiang, China were chosen as case studies. These two case studies were analyzed and evaluated using the framework. Mill Race Park established an early model on flood-resilient design, and this precedent of floodable park design focused on topographic tactics. It also provided a series of wet and dry programs to address flooding and to meet the residents' needs. Yanweizhou Park established a successful model for floodable parks worldwide, and it was recognized as the

World Landscape of the Year 2015. The design team of Turenscape paid much attention to the improvement of the pavement permeability and made the park an experimental place for environmental education. Ecological design like the terraced river embankment, bio-swales, and the inner pond in the Central Water Feature Zone make the park unique and attractive. These two case studies did a good job in conducting hydrological analysis and pre-design inventory, preserving the floodplain features and reducing infrastructure maintenance, encouraging eco-tourism, and providing places for recreation and environment education. However, both design teams did not consider conducting specific hazard identification for infrastructure and utilities and developing remediation for flood hazards. Future design should take infrastructure maintenance after flooding and invasive species control into consideration.

Before designing the project, an in-depth inventory of the five aspects of the framework was conducted. Nearly half of the site is in the 100-year flood risk area, and major flooding damage appearing in the main unit of the OCMU can be classified as natural ecology damage and social economy damage. Natural ecology damage refers to bank erosion, sediment hazards, water quality degradation and decreased biodiversity. Social economy damage refers to inaccessibility of trails and threats to cultural heritage.

The projective design seeks to mitigate flood hazards while promoting local environmental education and raising public awareness of flooding. Based on the *Manual for Erosion and Sediment Control in Georgia* (Georgia Soil and Water Conservation Commission, 2016) and *Stream Restoration Design* (National Engineering Handbook 654), several flood-resilient strategies were selected to address bank erosion, sediment hazard, and water pollution in the site. The projective design achieved all the goals in the framework, but appropriate community-based remediation for stormwater and flood hazards require further discussion and consideration.

<u>Feature Research Needs</u>

For future research, there are four development opportunities. First, the thesis considered only the main unit of the park (701.5 acres) while the White House designated 2100 acres land to the Ocmulgee National Monument on March 12 of this year and changed its name to the Ocmulgee Mounds National Historical Park (total approximately 2,800 acres). The expanded park has more possibility to be developed as a floodable park to mitigate the flooding in the Macon-Bibb County because it contains considerable undeveloped land and more vegetation.

Second, the sediments hazard and water quality problems cannot be fully solved unless traced back to the source of impairment. According to *A Revised Total Maximum Daily Load (TMDL) Implementation Plan for Walnut Creek / Stone Creek Watershed* (2003), runoff from road crossings and severe bank erosion contribute to the high rate of sediment disposition. It would require an 18.5 percent reduction in sediment load to reach an acceptable limit for allowable pollutant loading. The three possible pollutant sources are urban runoff and the velocity of stormwater runoff, runoff originating from development on Graham Road, and "legacy sediment." Addressing these pollution sources properly in the scope of the whole watershed is the only way that the water quality and erosion downstream of the Ocmulgee River and Walnut Creek can be improved and mitigated.

Third, the site analysis detail was limited due to the lack of up-to date plants, soil and topography information. The topography information from the National Oceanic and Atmospheric Administration (NOAA) database provided poor details about the riverbank of the Ocmulgee River and Walnut Creek. Thus, the model of the boardwalk and terraced embankment is not very accurate. Unmanned aircraft is prohibited in the park so that there is no access to aerial photos of the Ocmulgee River and Walnut Creek riverbanks. If future design and practices have access to aerial photos of the park, the sediment pattern could be studied in detail.

Lastly, the design is limited in the Ocmulgee National Monument since it is a preserved national park. The site has been home to Native Americans for more than 17,000 years and is considered sacred to members of the Muscogee (Creek) Nation as well as to other federally recognized tribes (such as the Cherokee, Chickasaw, Choctaw, and Seminole). Thus, the main priority of the park is to preserve this precious land rather than develop it. Therefore, large construction to encourage flood resilience is not suitable for the site. Future design should combine preservation of the OCMU cultural heritage and improvement on flood-resilient design.

Although flood-resilient landscape research and practice are in the very early stages of development, this thesis suggests that a floodable park can be successfully integrated into urban public space and can mitigate the flooding hazards. However, the prolonged success of these initiatives will require considerable effort in management and funding. Equally important will be the sustained dedication from users and city government. It is quite feasible that these needs will be more easily met as public perception and cultural values continue to shift in favor of a more resilient landscape in the future.

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Appendix 1 USGS discharge data for the Ocmulgee River near the OCMU. The USGS maintains a stream gage (funded in cooperation with the City of Macon, Georgia)in the Ocmulgee River just upstream from OCMU（Hydrologic Unit Code 03070103; Latitude 32°50'19", Longitude 83°37'14", NAD83;Drainage area 2,240 square miles; Gage datum 269.80 feet above NGVD29）.

00060, Discharge, cubic feet per second,												
YEAR	Monthly mean in ft3/s (Calculation Period: 1910-10-01 -> 2018-03-31) Calculation period restricted by USGS staff due to special conditions at/near site											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1910										1,127	785.1	1,045
1911	1,369	1,590	1,445	2,557	1,225	742.2	1,486	1,719	616.2	2,474	2,402	3,926
1912	4,408	6,659	10,130	8,046	4,798	7,142	5,037					
1928										1,681	1,932	1,744
1929	1,800	7,519	16,370	4,397	5,419	3,690	2,614	2,141	3,615	6,404	3,764	3,765
1930	3,834	3,692	4,522	3,379	2,386	1,256	1,685	1,044	1,528	932.2	2,834	2,984
1931	2,645	2,163	2,115	2,432	2,417	710.9	1,575	940.7	419.4	333.7	387.3	1,695
1932	3,586	5,361	2,862	2,250	1,558	1,682	1,404	1,662	751	1,535	1,708	5,134
1933	3,282	5,249	3,389	2,795	2,061	1,367	1,280	750.2	772	590.3	893	1,223
1934	1,360	1,427	3,792	2,384	1,624	3,571	1,559	1,494	1,298	3,270	1,092	1,594
1935	2,013	1,568	3,994	2,954	1,870	973.9	1,677	1,162	981.5	761.2	1,563	1,145
1936	11,880	8,855	3,736	14,610	2,119	1,406	1,001	3,255	1,481	3,064	1,434	3,750
1937	9,394	7,448	4,755	6,369	4,913	1,919	1,471	1,938	1,733	2,425	1,748	1,646
1938	1,477	1,168	1,851	8,571	1,352	2,098	1,724	1,315	600.5	490.8	665.6	948.6
1939	1,888	5,836	6,527	2,911	1,565	1,810	921.6	2,754	929	851.2	954.7	1,049
1940	2,562	3,508	3,450	2,429	1,177	1,309	3,646	1,854	1,065	666.6	1,088	2,061
1941	2,244	1,458	2,280	2,199	1,101	828.7	1,626	915.1	667.7	509	517.6	3,220
1942	2,683	3,294	11,020	3,221	1,960	1,355	1,244	1,378	845.9	1,270	1,438	2,815
1943	7,864	3,788	8,260	4,556	2,696	1,597	1,734	1,145	701.7	722	1,020	1,213
1944	2,847	4,983	10,650	6,645	2,924	1,312	1,405	952.2	1,323	1,020	828.2	1,259

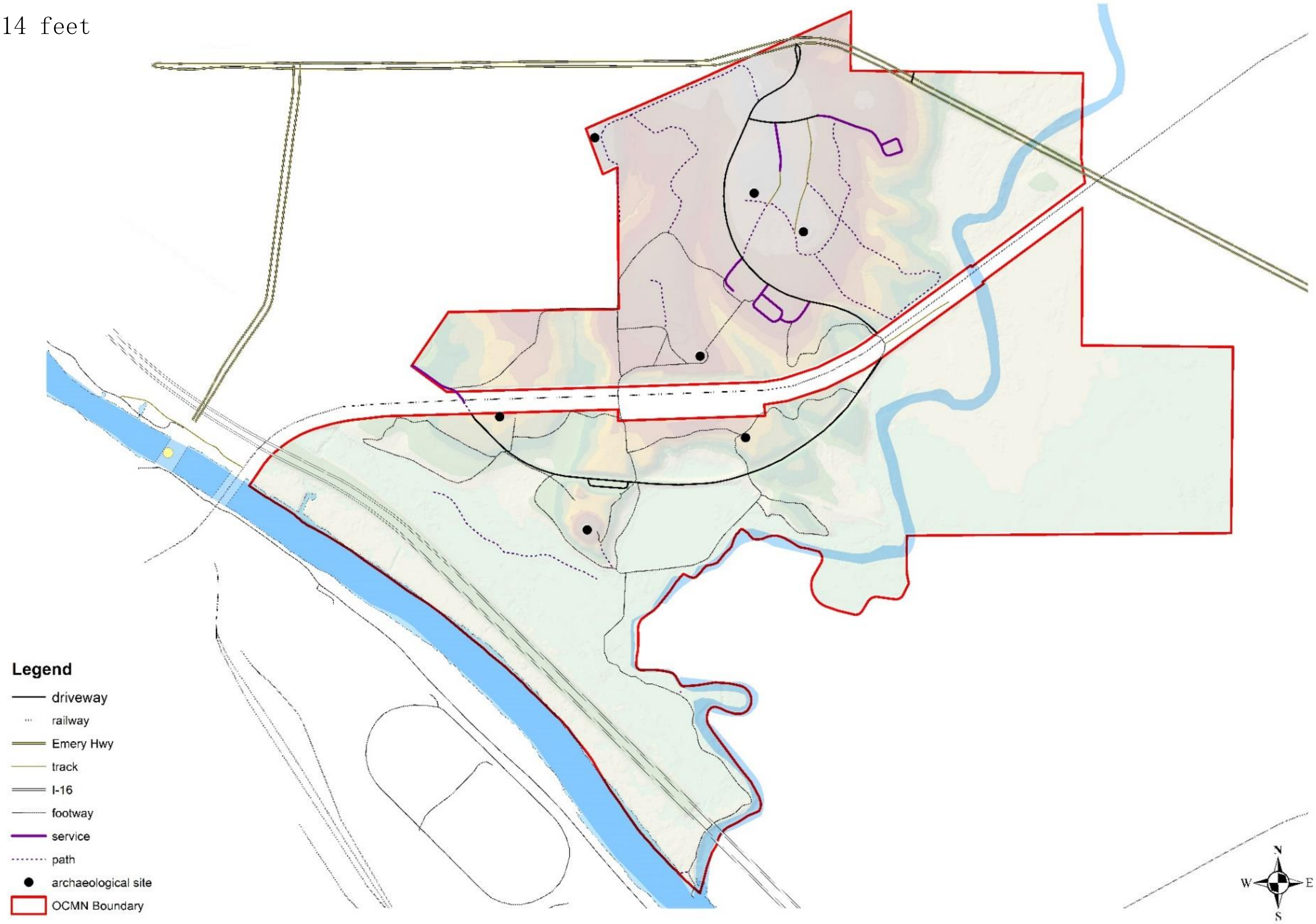
1945	1,745	4,129	2,773	5,207	2,504	1,346	1,411	1,415	1,006	1,165	1,401	4,781
1946	9,222	4,526	4,409	3,870	3,173	2,420	1,532	1,140	929.2	1,296	1,267	1,181
1947	5,398	2,558	7,046	4,323	2,267	2,830	1,750	1,748	806.7	1,130	5,177	4,593
1948	3,564	7,775	7,876	5,874	2,363	2,061	2,796	1,803	1,140	1,136	9,624	6,742
1949	4,325	5,579	3,856	3,708	4,257	2,522	1,825	2,238	1,802	1,516	1,271	1,423
1950	1,442	1,663	3,496	1,929	1,247	1,548	1,088	1,244	2,049	1,033	1,354	1,557
1951	1,923	1,786	2,328	3,176	1,440	910.5	1,098	731.6	646.5	651.2	944.7	3,173
1952	2,694	3,631	11,720	3,280	2,032	1,440	759	893.9	1,019	861.4	795.8	1,292
1953	3,864	4,827	4,463	2,865	6,236	1,490	2,141	880.4	1,904	1,339	882.3	5,071
1954	3,117	2,228	2,505	1,633	1,071	826.8	642.4	551	364.9	164.8	186.3	617.5
1955	2,230	2,781	2,251	2,837	1,395	732	1,239	903.5	547.8	529.3	679.8	871.4
1956	762	3,471	4,483	4,545	1,609	787.6	1,637	693.8	2,065	1,066	884.4	3,179
1957	3,009	2,919	4,588	4,929	3,822	1,719	1,366	833.6	1,112	1,623	3,837	3,698
1958	3,055	5,611	5,537	5,737	2,330	1,378	2,398	1,127	764.8	728.4	593.8	762.5
1959	1,403	3,994	3,543	2,272	1,691	3,839	1,215	819.6	911.8	1,568	1,142	1,353
1960	4,660	8,244	5,412	5,601	1,748	1,013	790.2	902.9	850	861.3	705.5	841.5
1961	981.8	10,220	5,020	7,437	4,315	2,536	1,857	2,008	1,479	798.3	765.3	4,225
1962	4,431	5,472	6,301	6,624	1,614	1,644	1,515	1,036	747	1,068	1,546	1,318
1963	5,616	3,436	5,762	2,080	5,454	5,245	3,804	1,317	1,036	979.5	1,082	3,019
1964	7,754	5,801	11,360	11,430	7,305	1,604	3,465	2,041	1,359	3,802	1,933	5,269
1965	2,967	4,714	5,705	4,373	1,536	3,141	1,737	1,083	993.9	2,574	1,197	1,293
1966	5,459	8,494	7,234	3,032	5,024	2,595	1,589	1,589	996.8	1,758	2,639	2,871
1967	4,807	4,266	3,324	1,831	2,300	2,175	2,785	2,922	1,602	1,092	2,621	4,742
1968	5,020	2,198	5,167	2,907	2,779	1,935	1,505	1,029	736.3	905.9	1,847	2,571
1969	2,855	3,405	3,874	5,953	3,435	1,492	899.8	1,567	1,108	876.1	1,157	1,617
1970	1,893	2,374	6,308	2,503	1,395	1,297	1,019	1,021	704.9	876.9	1,413	1,765
1971	3,952	5,278	11,630	4,017	3,109	1,551	2,675	2,741	1,394	711.9	1,065	2,502
1972	6,325	4,588	3,620	2,287	2,178	2,013	1,307	1,501	689.8	551.8	1,288	5,215
1973	6,224	5,145	5,950	8,366	4,434	3,638	2,126	2,134	871.7	1,392	985.3	2,217

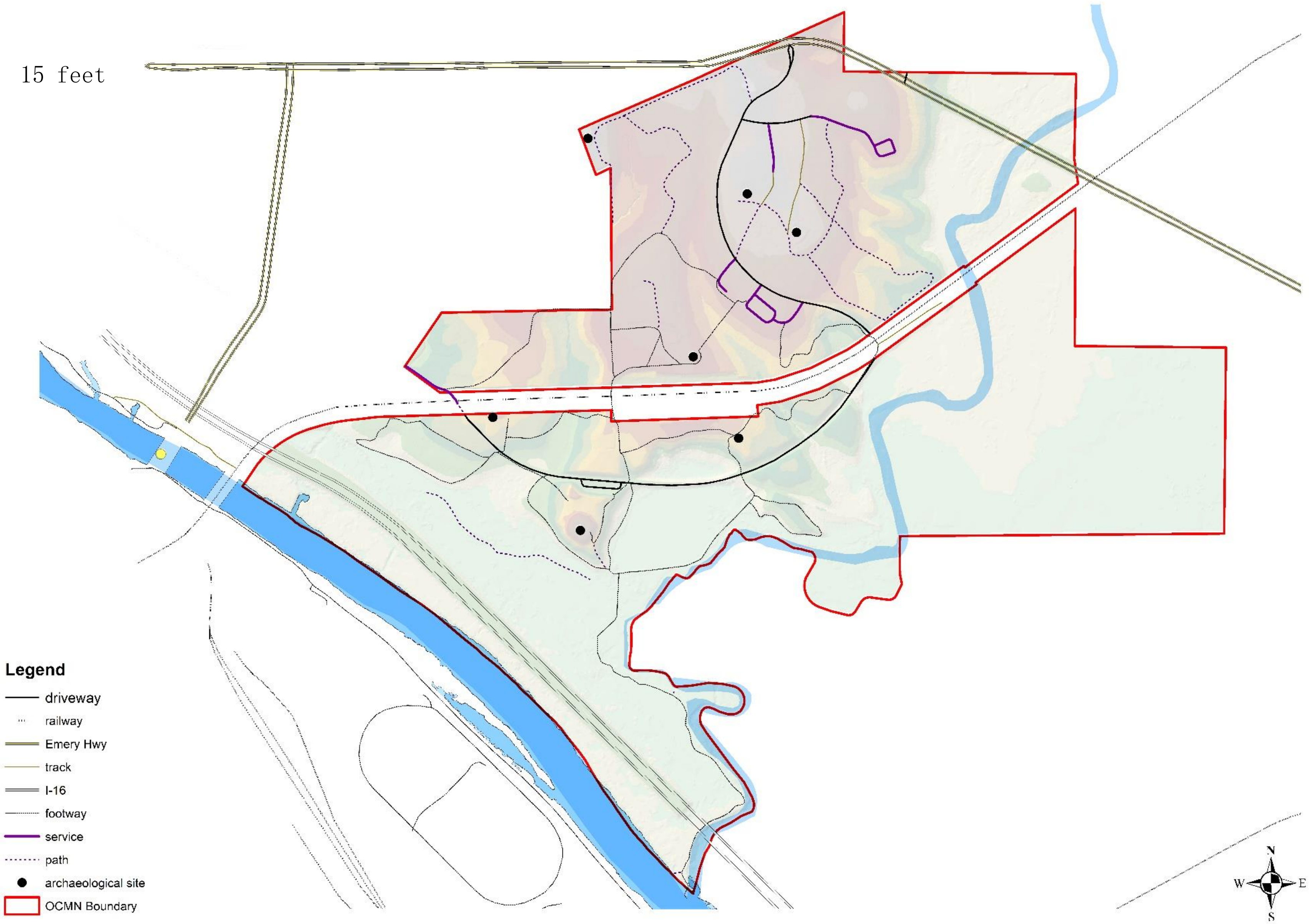
1974	6,226	7,068	2,982	5,002	2,221	1,746	1,303	2,192	1,418	573.4	812.8	2,812
1975	5,064	8,147	9,776	7,966	4,381	4,074	2,490	2,773	2,011	2,910	2,027	2,277
1976	3,811	2,850	7,846	2,929	5,625	2,907	2,352	1,258	1,018	1,507	1,945	4,291
1977	3,919	2,212	6,717	4,387	1,610	980	894.6	1,569	994.3	1,649	3,272	1,663
1978	7,091	2,908	3,598	2,016	4,216	1,164	791.5	1,970	759.4	589.5	663.3	1,332
1979	3,237	7,525	4,025	8,304	2,325	1,543	1,270	1,102	1,373	1,797	2,322	1,554
1980	3,847	3,449	10,740	5,363	5,194	1,981	978.7	731.8	663.6	833.3	846.1	934.3
1981	749.8	5,218	1,688	2,038	837.2	740.7	453.6	503.1	421.6	391.5	397.7	1,595
1982	4,559	6,213	2,659	3,994	1,960	1,477	1,239	1,293	762.8	1,260	1,299	4,399
1983	3,646	5,551	6,636	7,582	2,189	1,699	894.9	574.6	1,138	897.8	3,006	7,222
1984	4,969	4,729	5,522	5,125	4,318	1,406	2,789	5,050	936.7	971.2	1,305	1,906
1985	2,020	5,960	2,276	1,535	1,943	923.1	1,828	1,779	670.1	1,329	1,179	2,299
1986	1,126	1,698	2,397	971.5	581.2	546.7	405.5	405.5	542.3	582.1	1,815	4,037
1987	4,682	4,127	6,006	2,808	1,499	1,545	950.3	619.6	393.2	243.2	434.8	965.7
1988	2,541	2,924	1,319	2,055	844.7	300.7	214.4	298.6	1,987	939.3	1,283	1,172
1989	1,316	1,309	2,431	4,124	1,940	2,832	3,796	1,121	1,463	5,544	1,961	3,756
1990	6,325	8,704	10,280	3,088	2,220	1,009	1,097	1,232	1,325	1,066	946	934.4
1991	3,050	3,583	4,794	4,758	4,646	2,557	2,934	1,551	1,122	694.9	1,081	1,336
1992	3,002	3,490	2,950	1,584	803.9	1,398	1,398	3,608	3,071	2,067	8,387	6,367
1993	5,610	6,400	8,595	5,406	2,410	1,677	897.2	781	536.8	1,032	1,748	2,161
1994	3,046	3,787	4,859	3,167	1,216	1,248	12,880	5,054	3,886	4,455	2,191	3,327
1995	3,194	8,593	5,203	2,163	1,343	2,060	1,124	1,219	1,309	4,727	5,433	2,771
1996	5,439	6,827	7,553	3,321	2,262	1,619	775.6	1,232	1,186	945.5	1,190	2,047
1997	3,856	5,150	5,055	2,723	2,604	2,258	1,398	1,030	1,543	2,873	3,553	6,725
1998	6,551	10,640	11,430	6,885	3,927	1,915	1,120	1,782	1,143	1,055	1,042	1,417
1999	1,765	3,449	1,768	1,234	1,341	973.8	1,207	461.7	295.7	779.9	937.4	1,382
2000	2,428	1,945	2,082	1,763	618.2	362.8	323.4	422.3	1,440	537.6	920.6	1,430
2001	1,520	2,224	8,424	3,138	1,437	3,177	1,442	814.1	647.7	425	421.8	650.8
2002	1,427	2,008	1,882	2,154	1,382	771.8	565.6	406.5	727.1	1,574	3,265	3,387

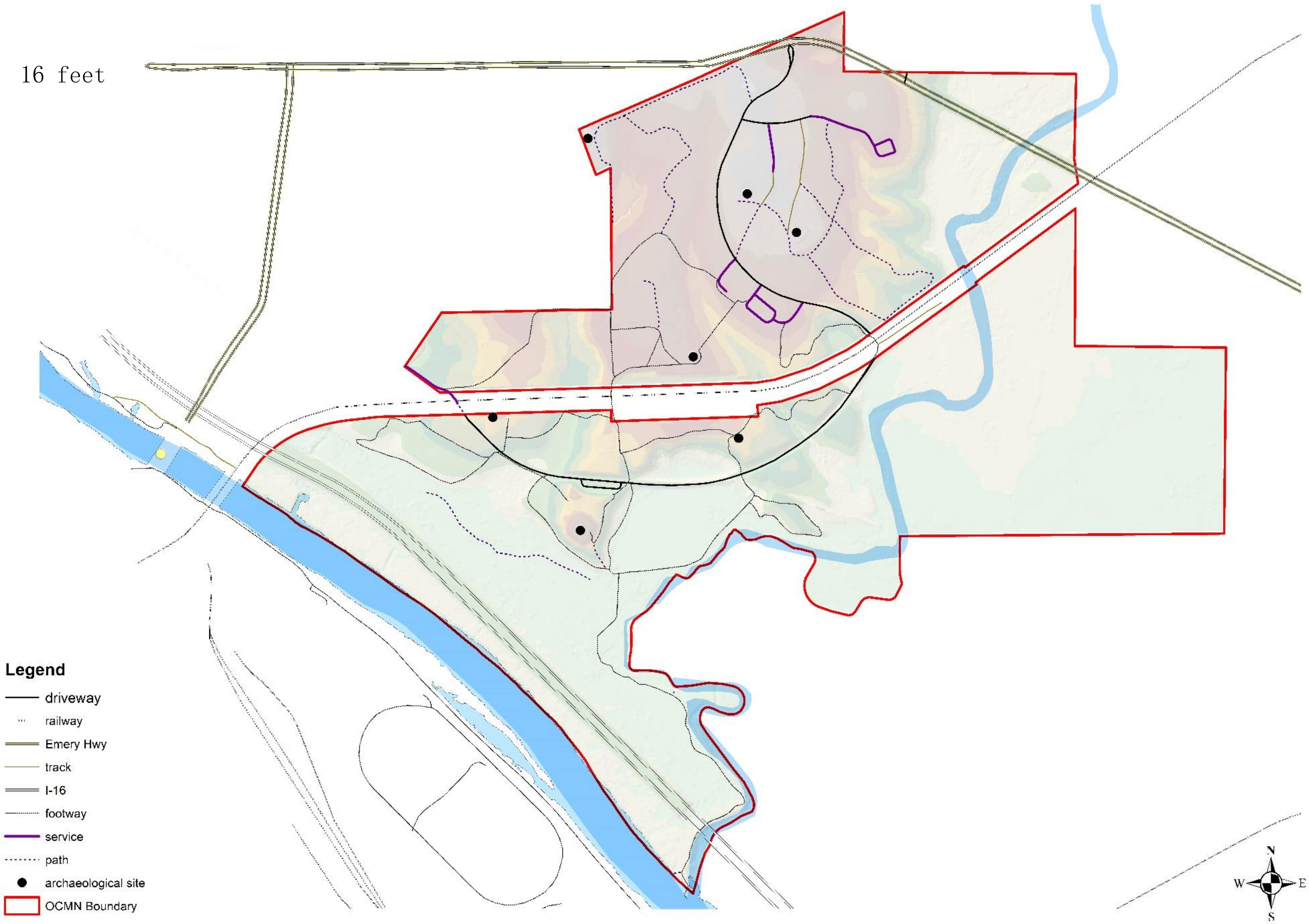
2003	2,141	4,261	7,225	3,624	8,050	4,430	6,172	3,008	1,639	1,257	1,965	2,282
2004	2,204	4,653	1,766	1,299	1,207	1,915	1,855	876.7	6,047	2,021	4,190	3,353
2005	2,611	4,840	5,895	6,475	2,295	3,255	8,307	4,885	1,617	2,018	1,423	2,424
2006	2,945	3,740	3,395	1,788	1,367	992.2	567.5	867.8	1,097	727.2	1,558	1,209
2007	2,718	1,655	3,009	1,142	658.9	445.8	630.5	435.6	489.6	397.2	341.3	741.8
2008	1,554	2,480	2,214	2,338	1,080	423.7	499.2	631.6	345.4	479	646.8	2,095
2009	1,322	1,085	8,489	6,759	2,085	1,198	584.1	782.9	5,909	4,870	6,699	10,640
2010	6,906	7,156	5,380	2,267	4,093	2,043	1,652	1,430	1,103	1,218	1,286	2,121
2011	1,707	3,845	4,279	3,419	1,103	653.5	651.5	366.9	392	336.6	560	1,138
2012	1,499	1,265	2,199	767.6	514.7	362.3	486.5	447.2	293.9	723.4	293.2	1,369
2013	1,522	6,608	3,899	2,974	4,948	3,014	4,482	2,565	845.9	672.3	672.2	4,578
2014	4,272	3,746	3,532	4,614	1,923	1,081	1,203	1,080	861.5	1,046	1,041	2,462
2015	2,411	2,889	2,705	6,022	1,871	1,591	897.5	1,057	1,117	1,337	6,851	13,010
2016	10,000	6,221	3,784	4,667	1,633	935.7	803.3	675.5	401.2	288	232.3	712.8
2017	4,420	1,897	1,459	3,011	1,580	2,917	2,005	1,278	1,552	1,049	961.8	1,543
2018	1,799	4,320	2,718									
Mean of monthly Discharge	3,630	4,410	5,130	4,020	2,520	1,810	1,800	1,440	1,220	1,380	1,760	2,690
** No Incomplete data have been used for statistical calculation												

Appendix 2 Inundation maps (made by author)

14 feet




15 feet
Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S


16 feet
Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
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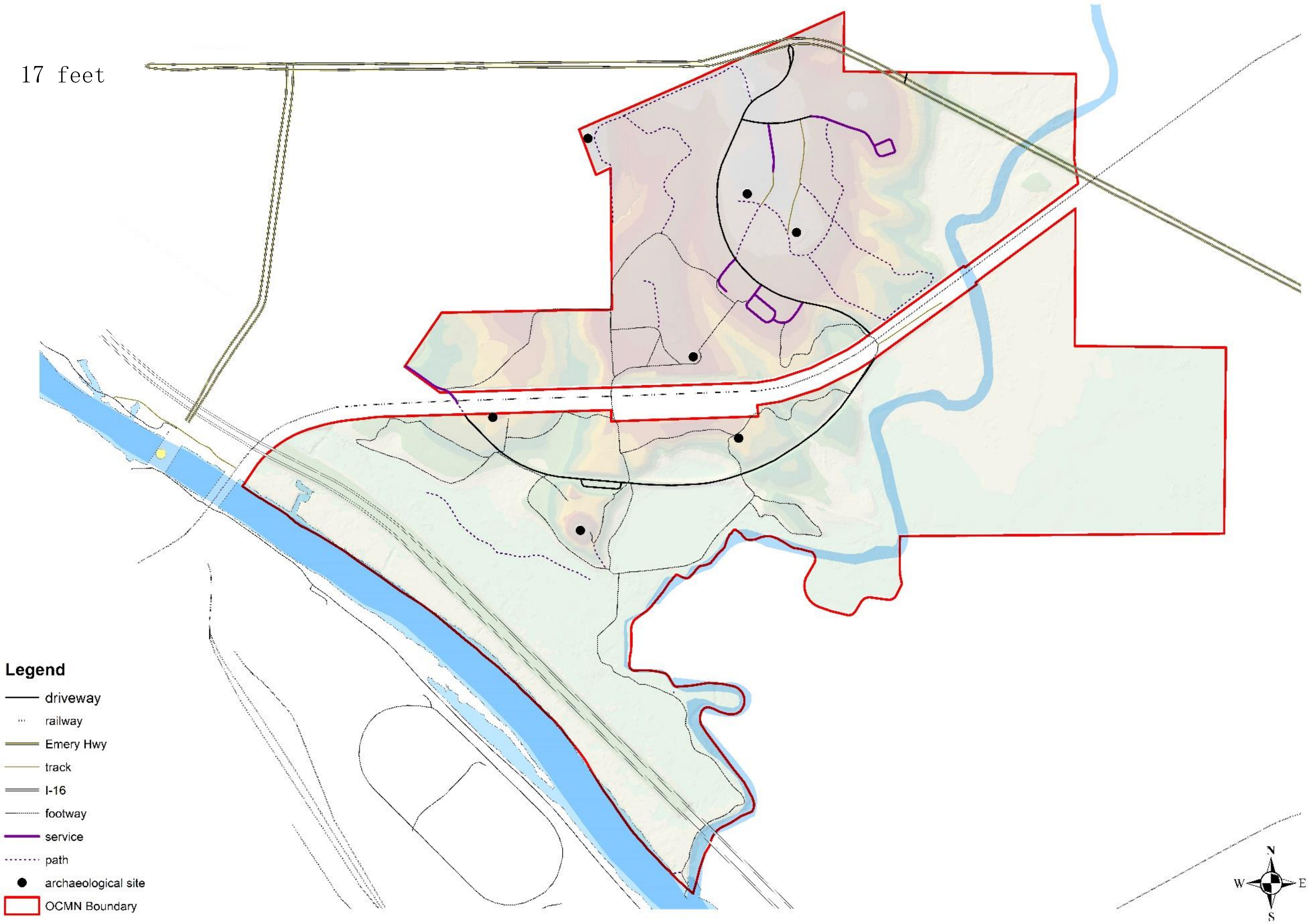
S


17 feet
Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
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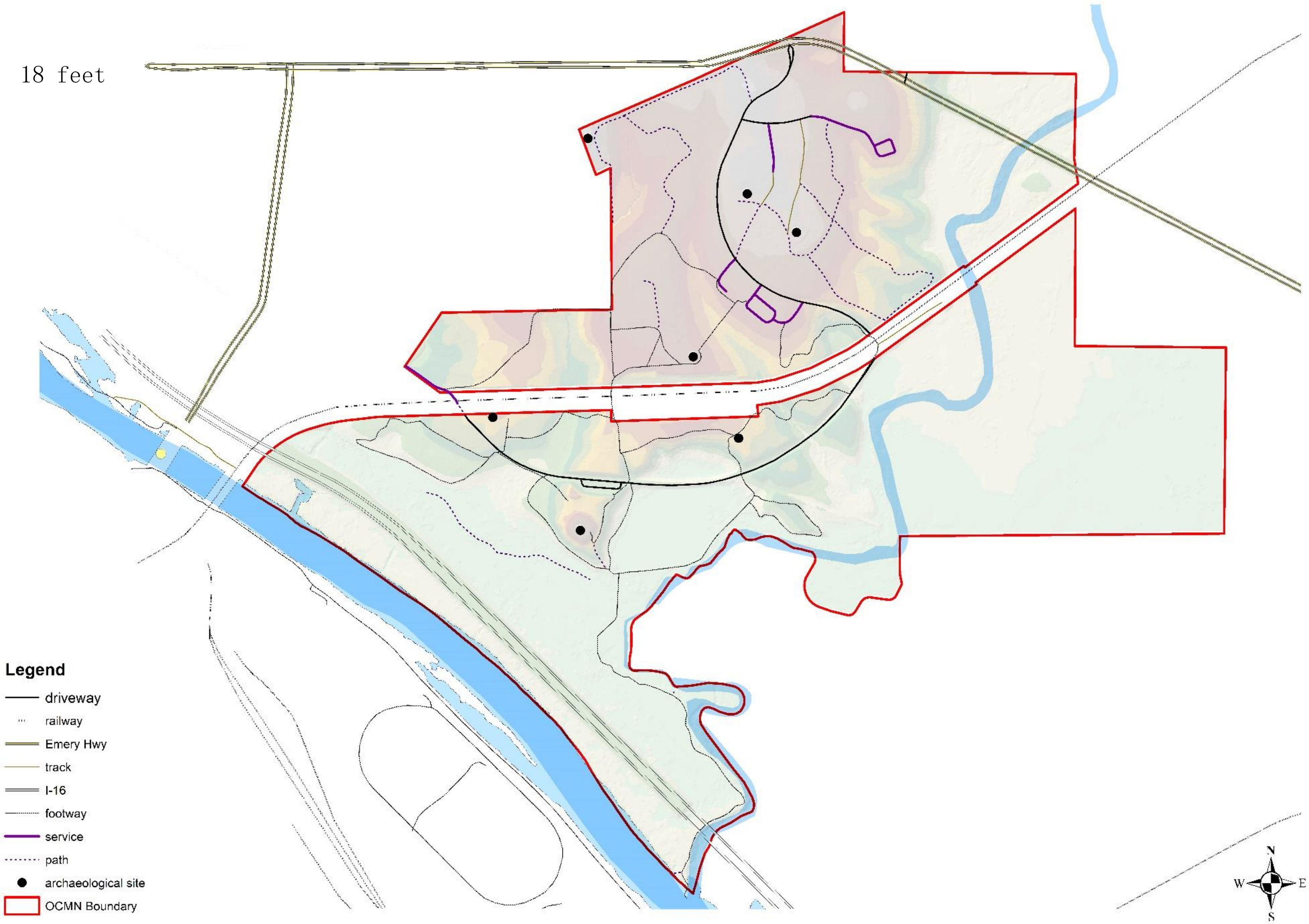
S

18 feet


Legend
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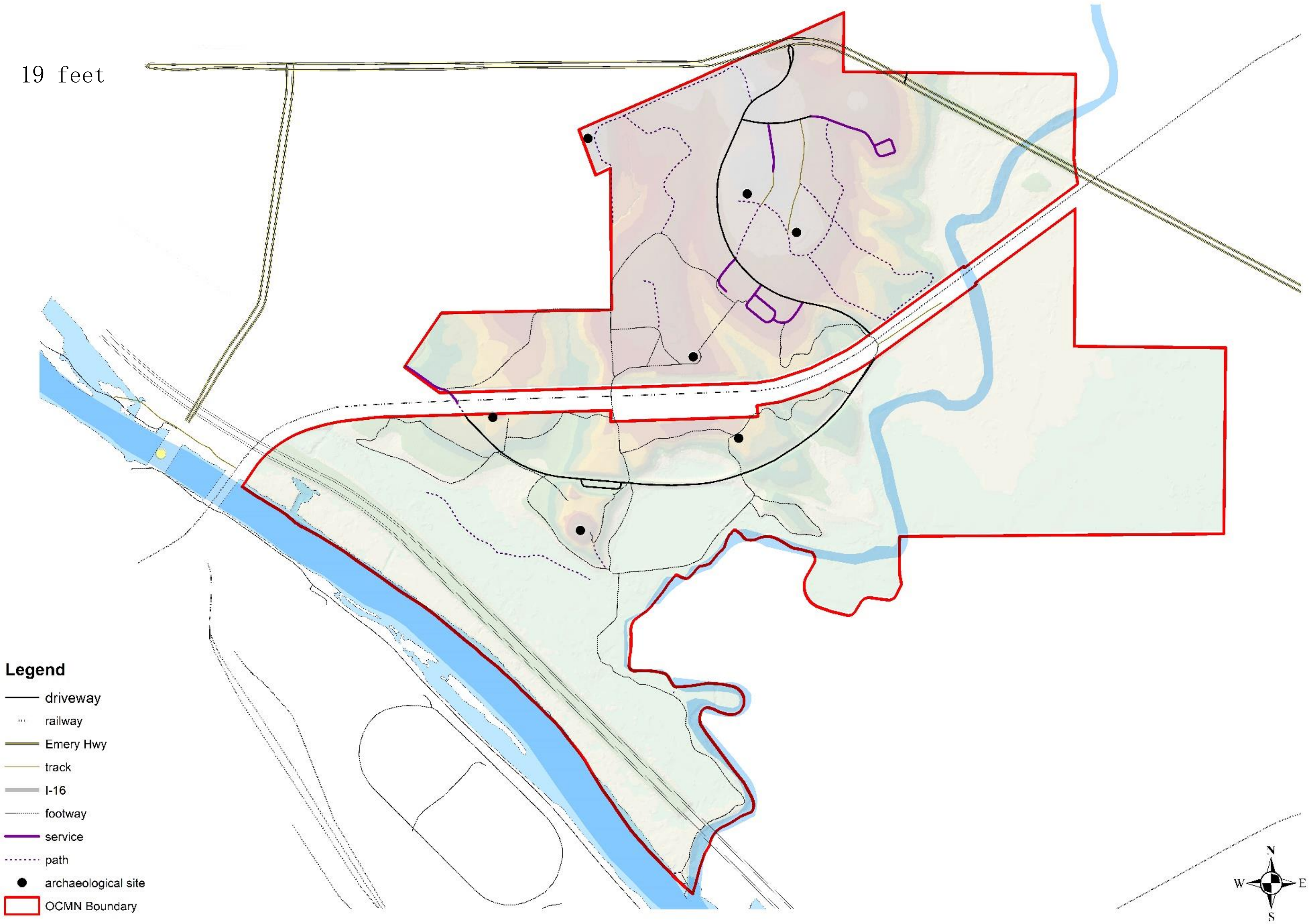
19 feet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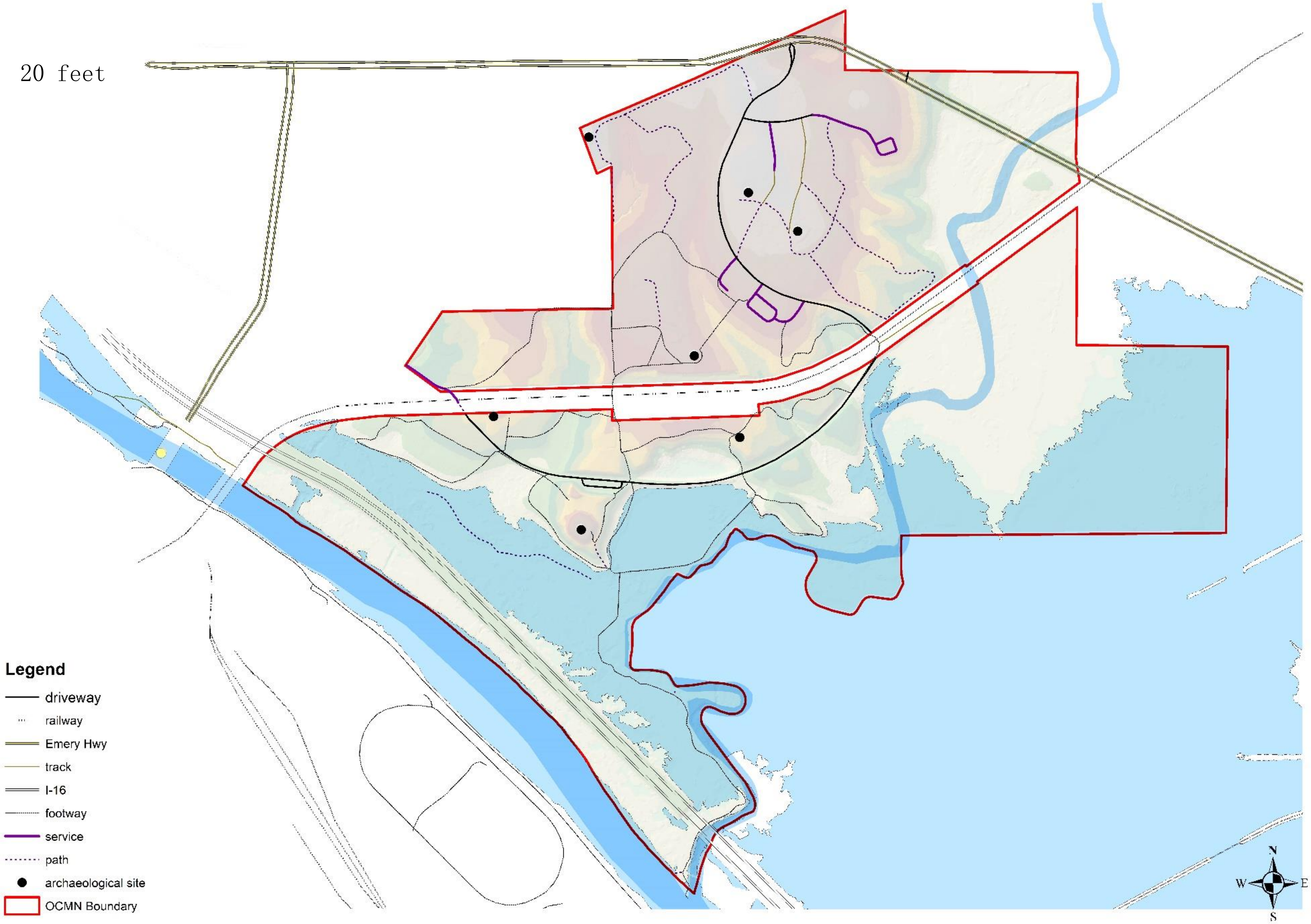
20 feet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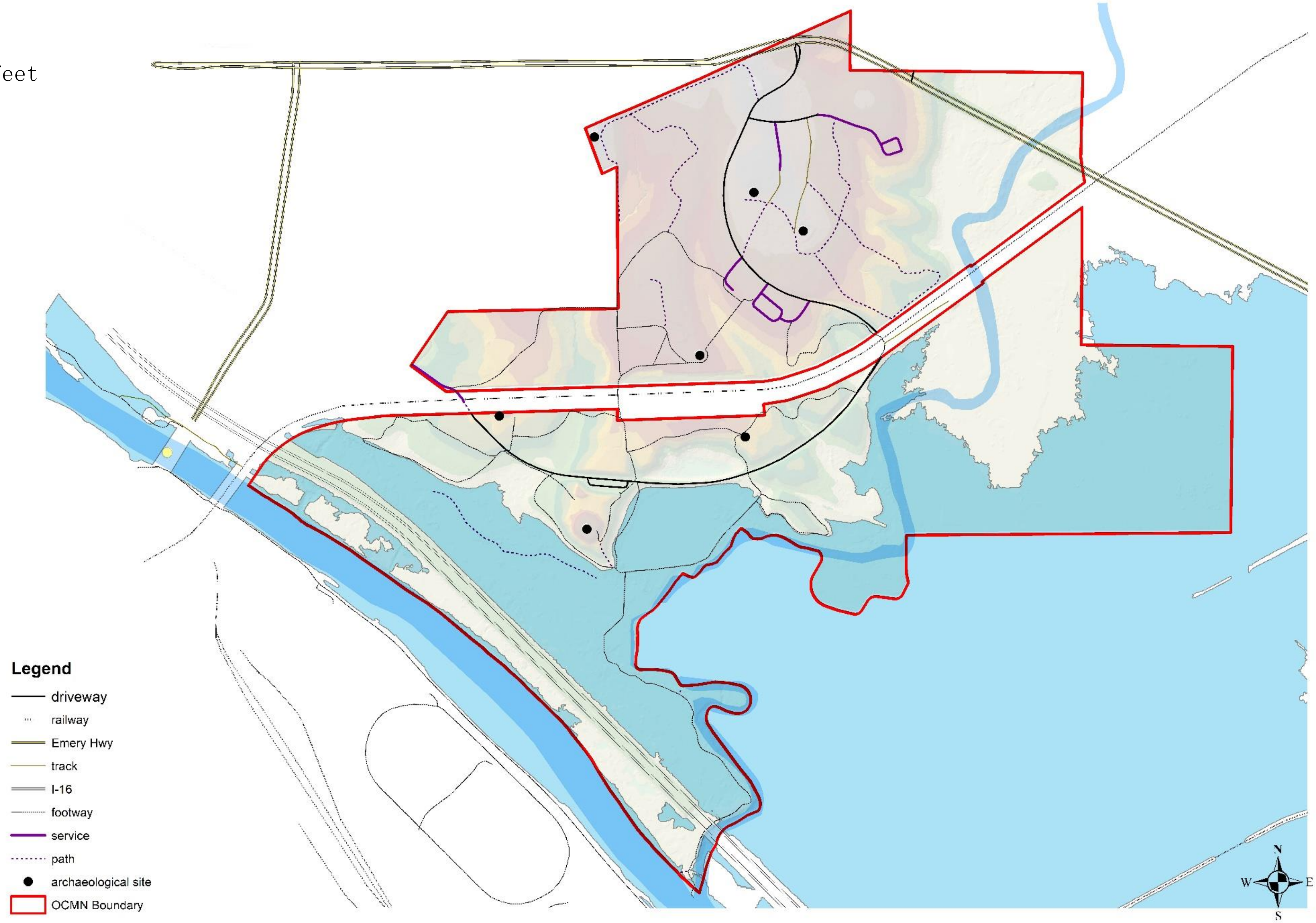
21 feet



Legend
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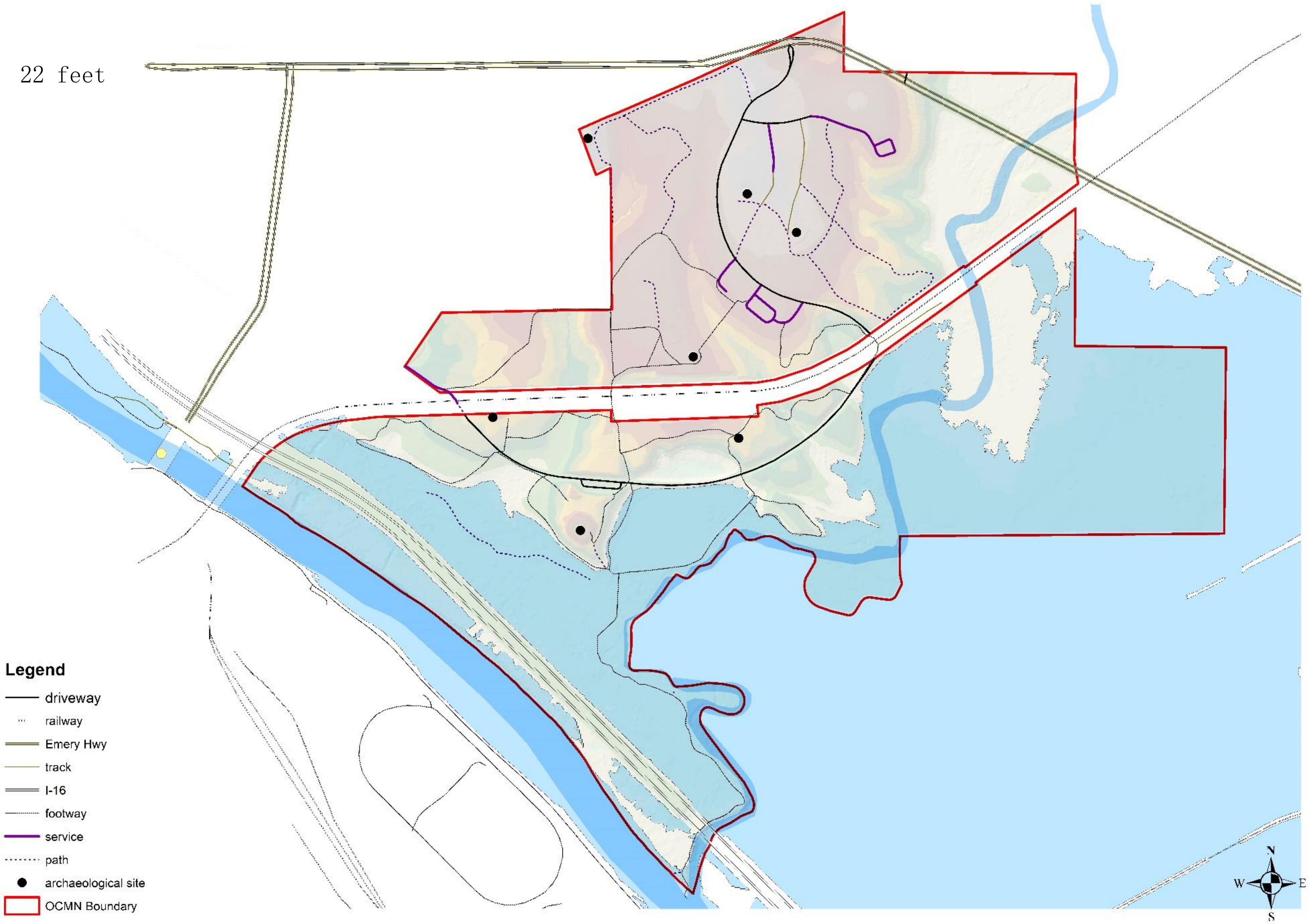
22 feet



Legend
driveway
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archaeological site
OCMN Boundary
N
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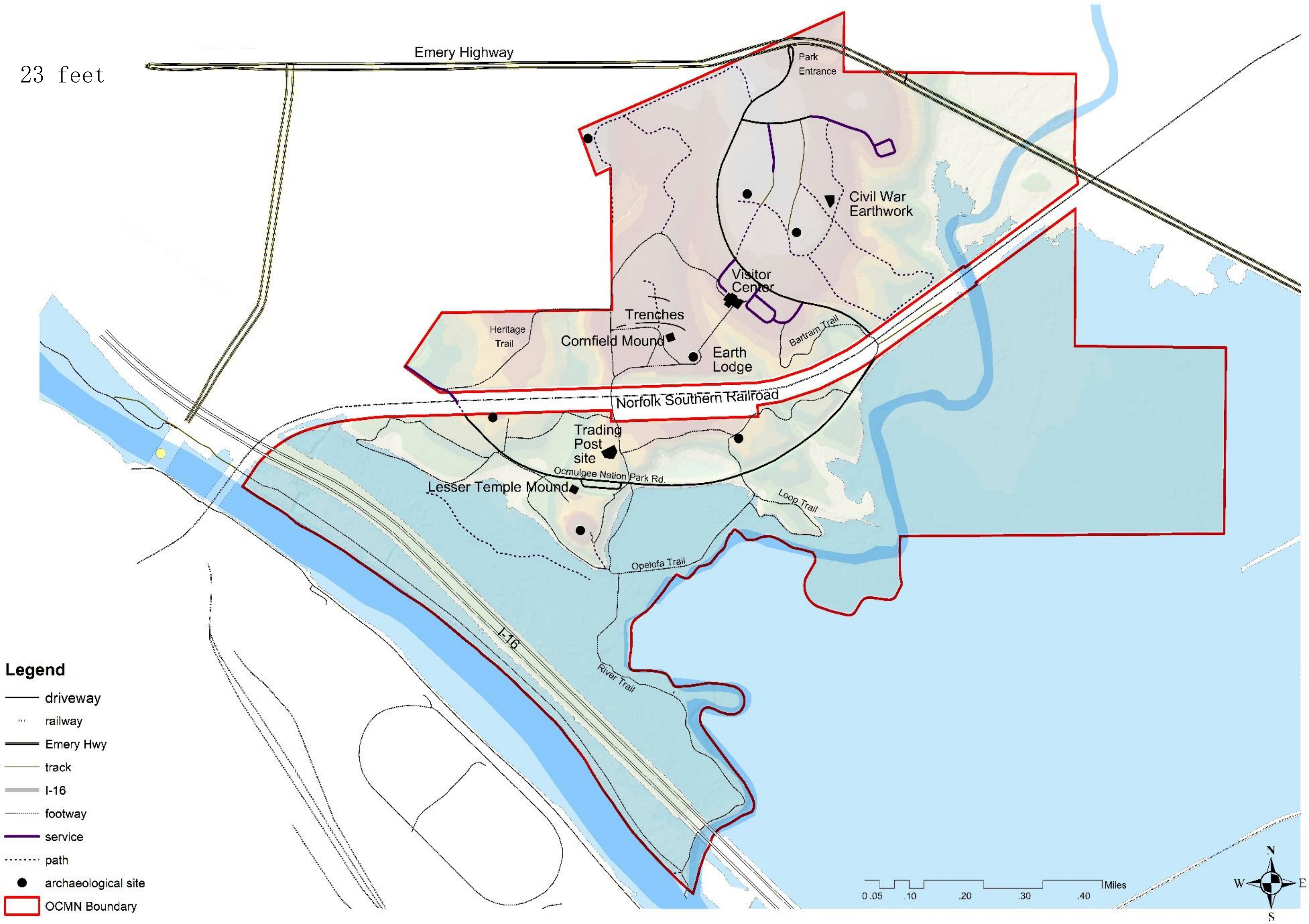
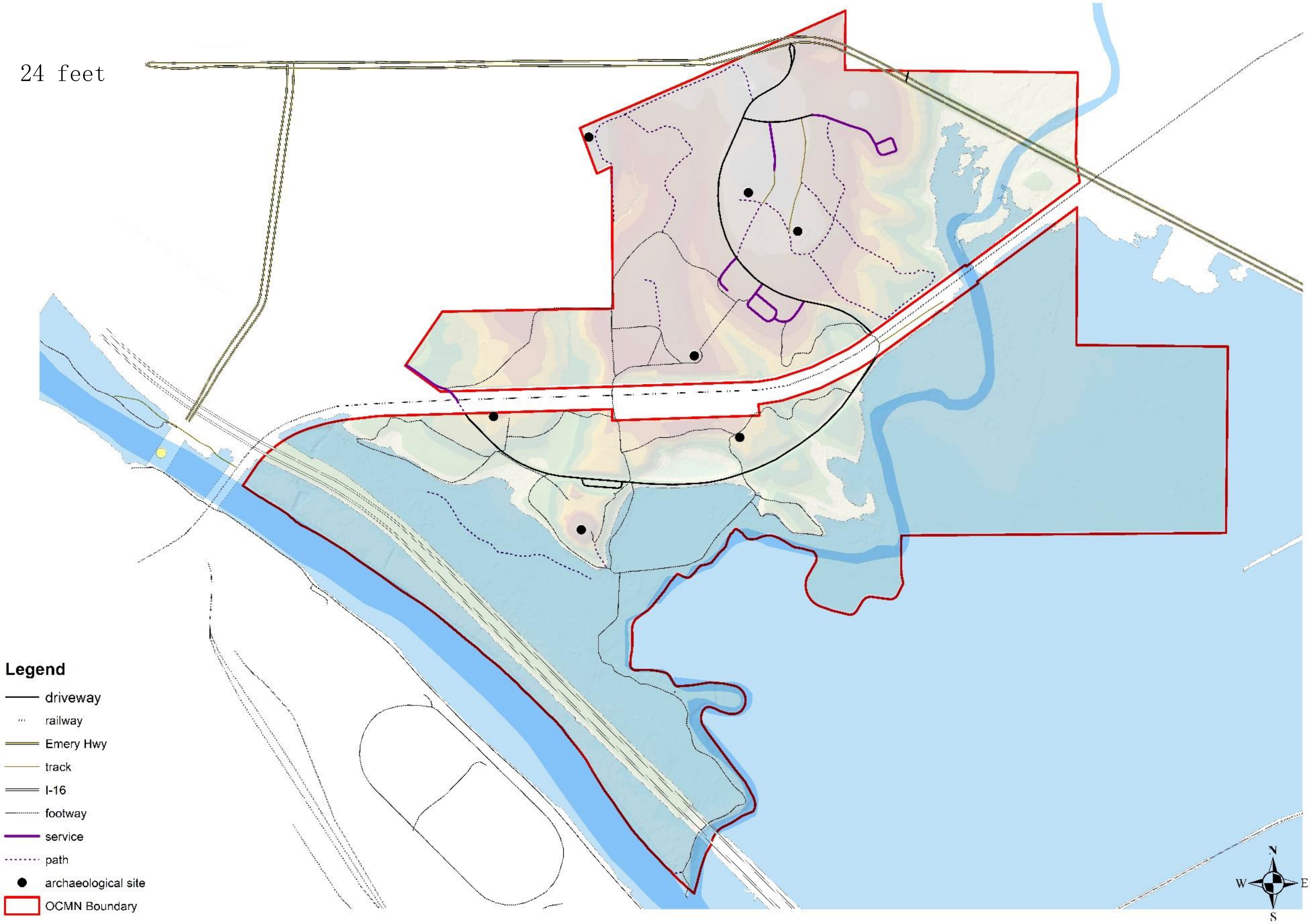
S

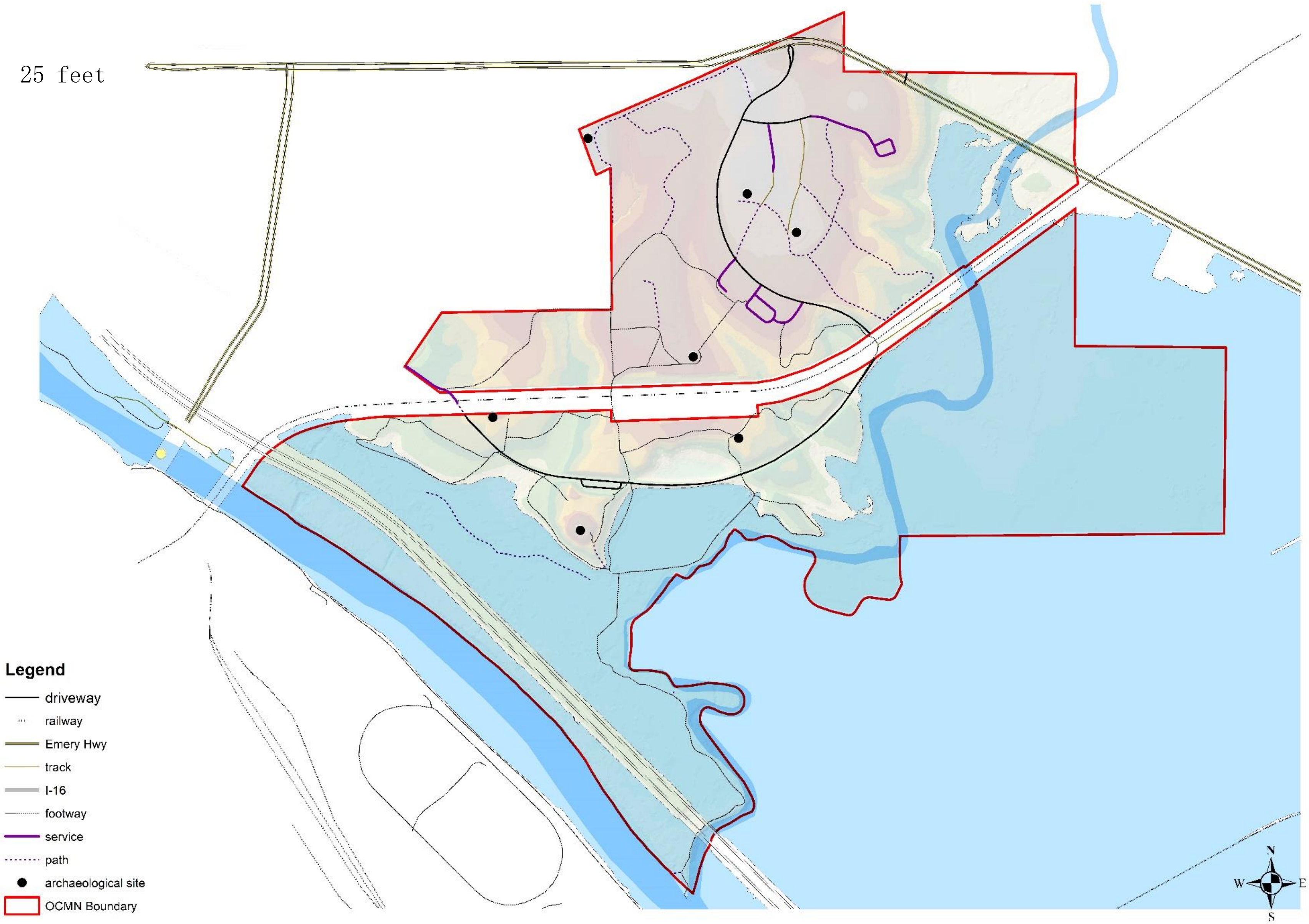
23 feet



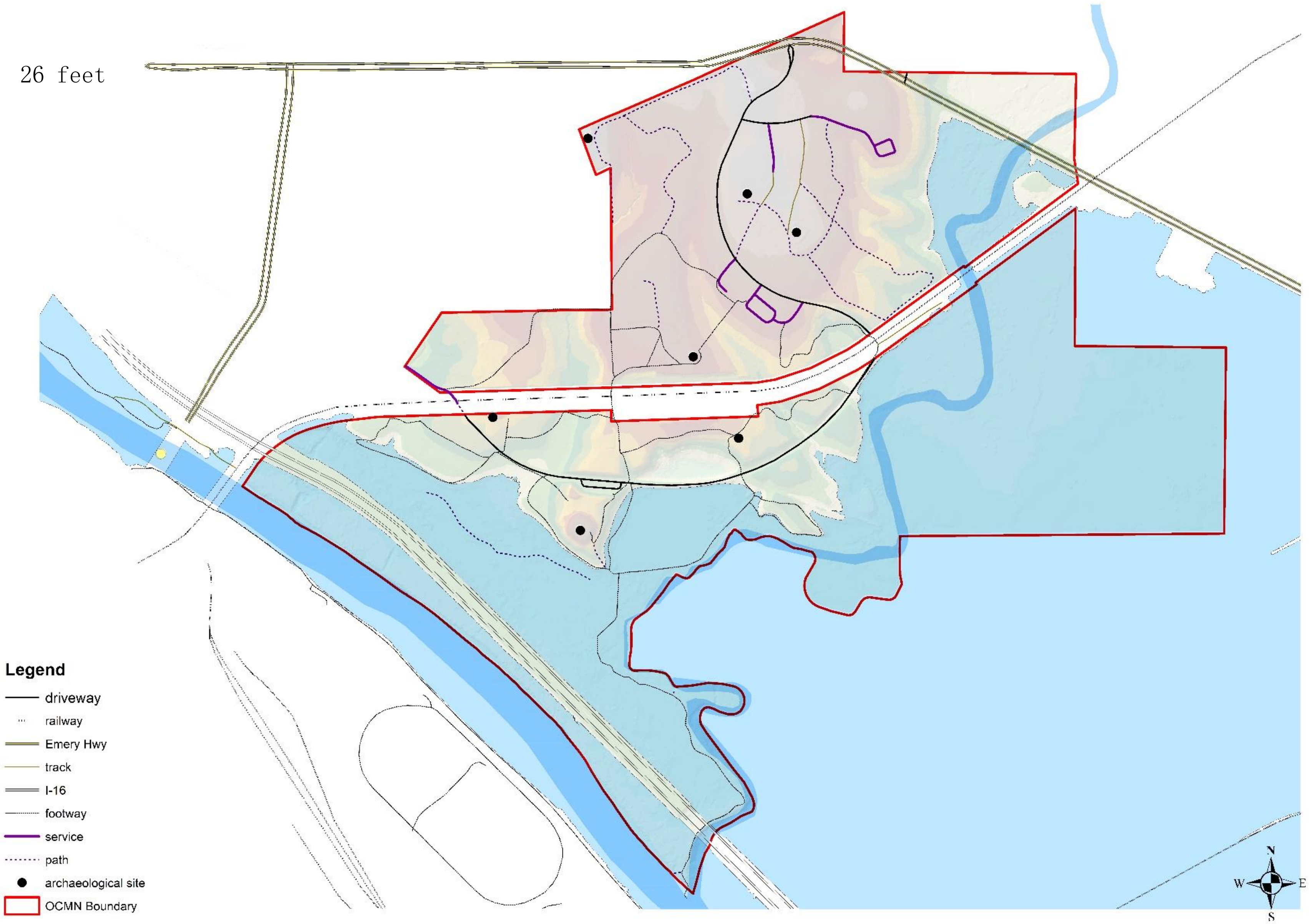
Emery Highway
Park Entrance
Civil War Earthwork
Visitor Center
Trenches
Heritage Trail
Cornfield Mound
Earth Lodge
Bartram Trail
Norfolk Southern Railroad
Trading Post site
Ocmulgee Nation Park Rd.
Lesser Temple Mound
Loop Trail
Opelofa Trail
I-16
River Trail
Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
0 .05 .10 .20 .30 .40 Miles
N
W
E
S

24 feet

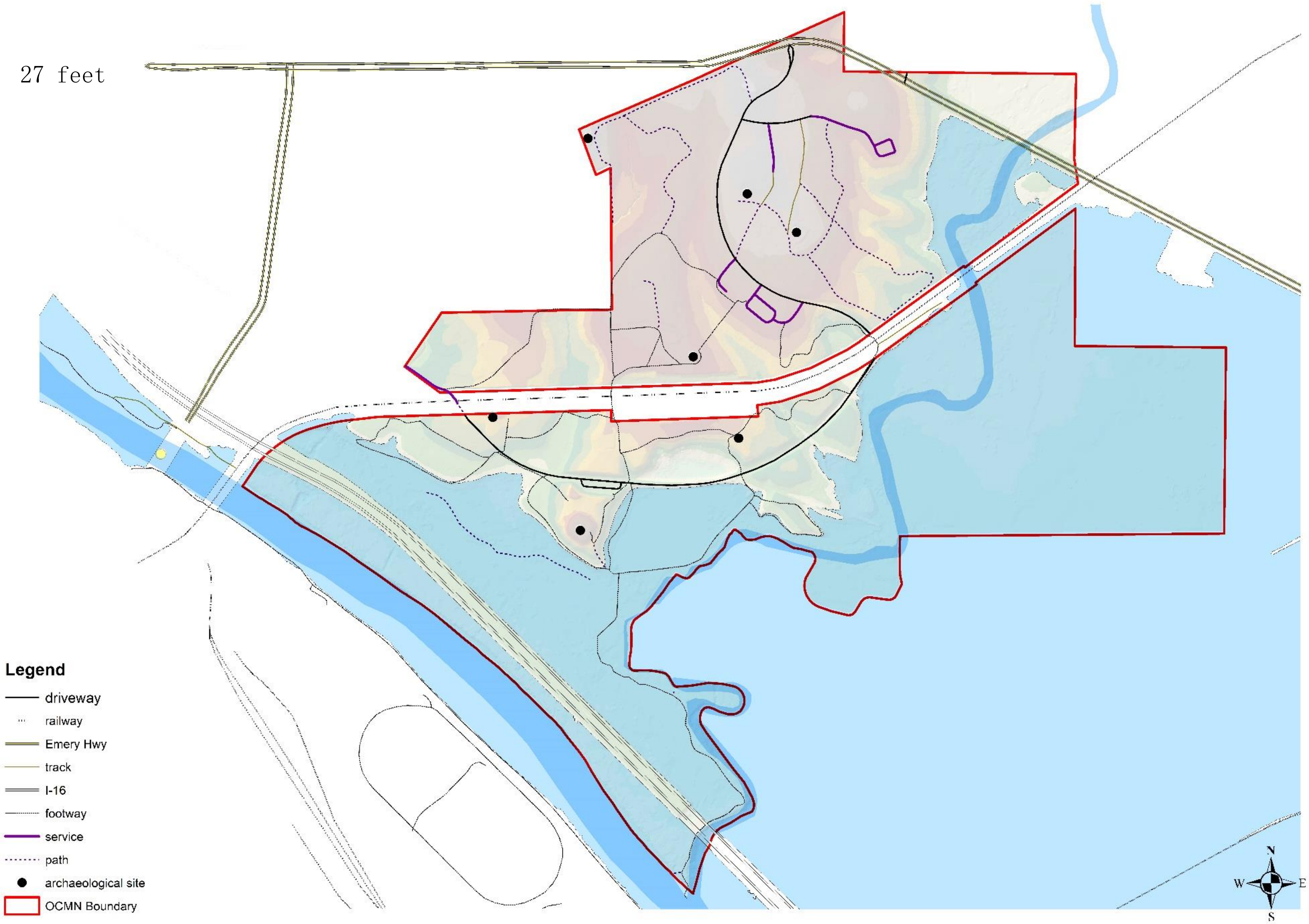

Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S


25 feet
Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S

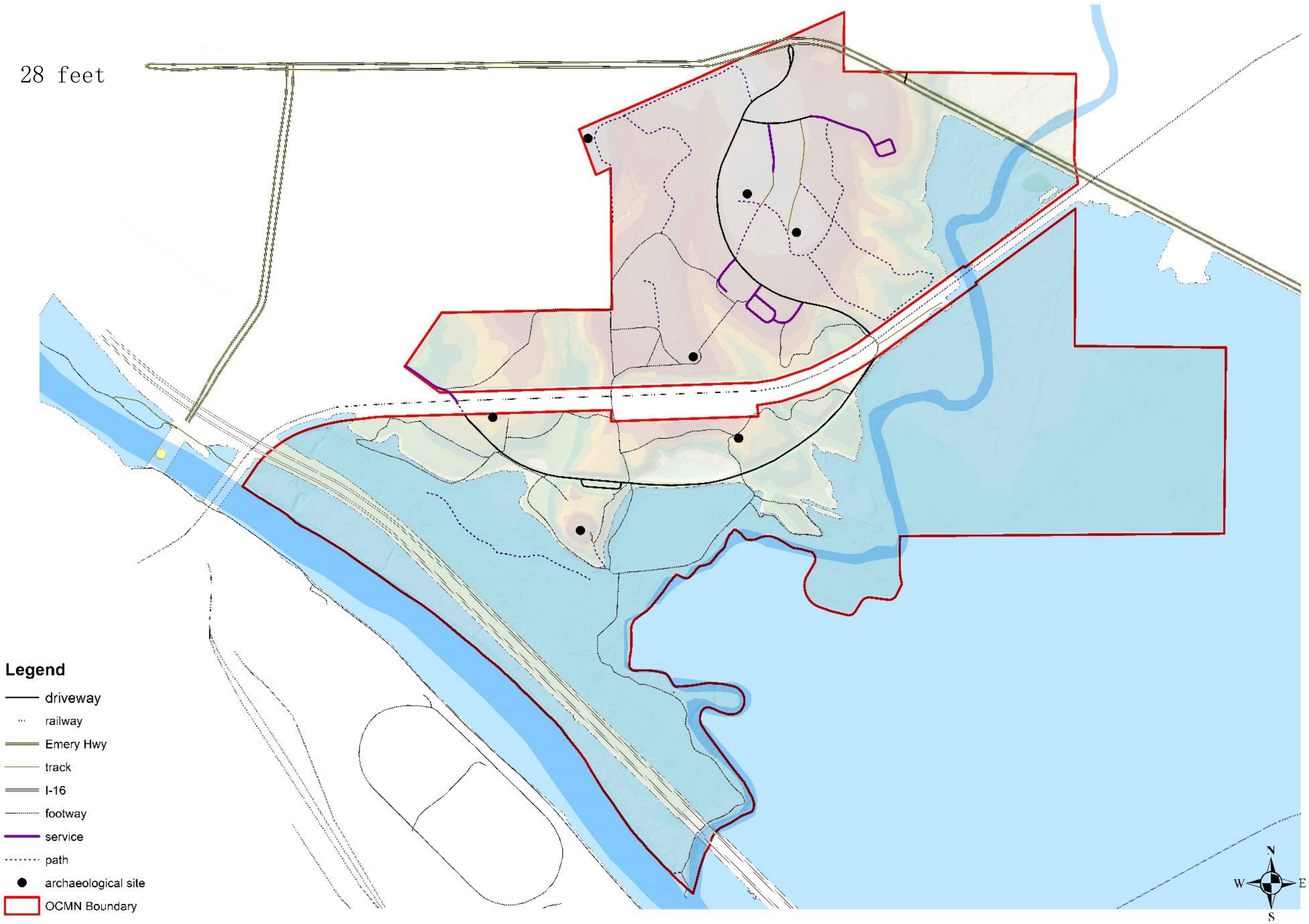
26 feet


Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S

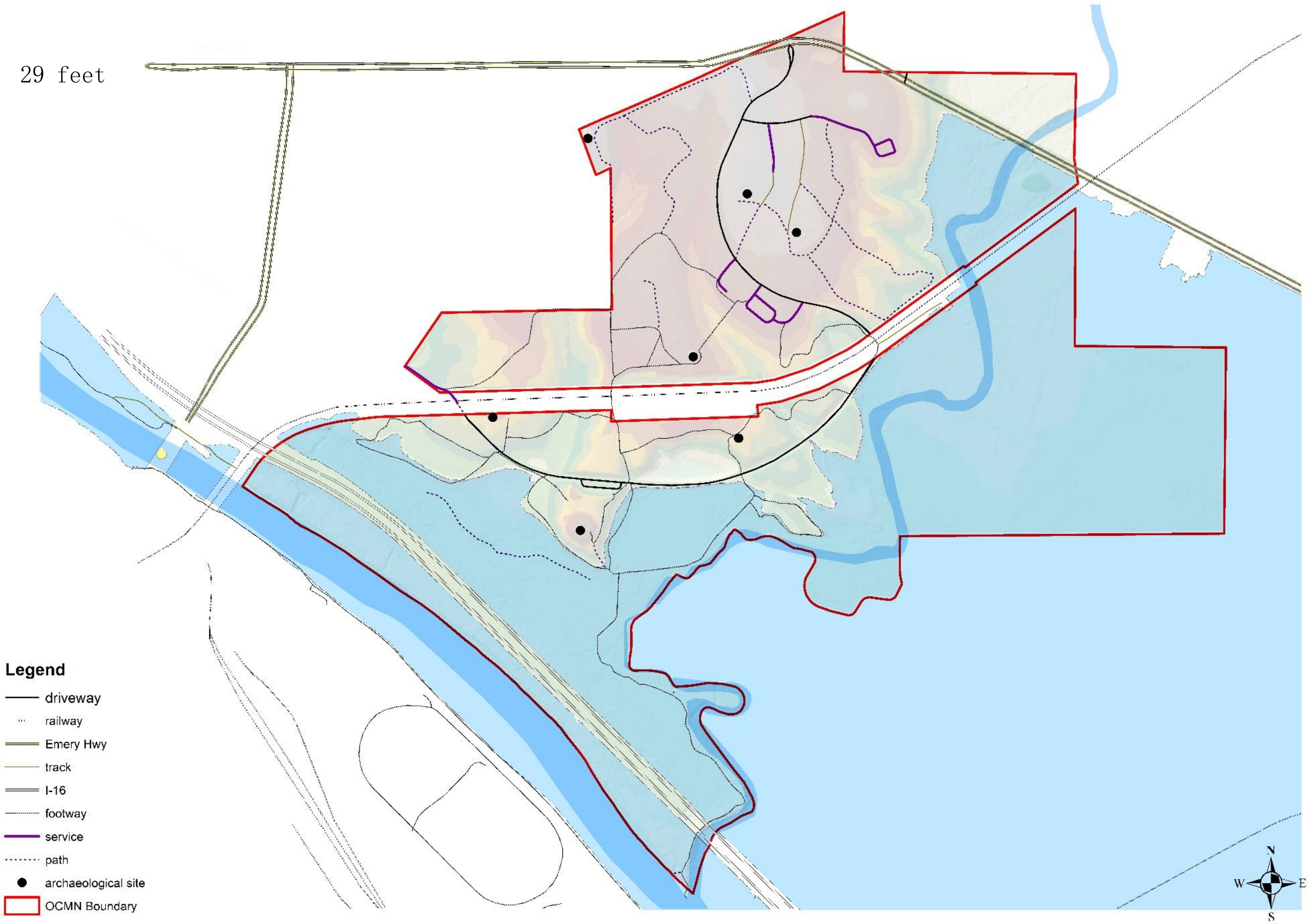
27 feet


Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S

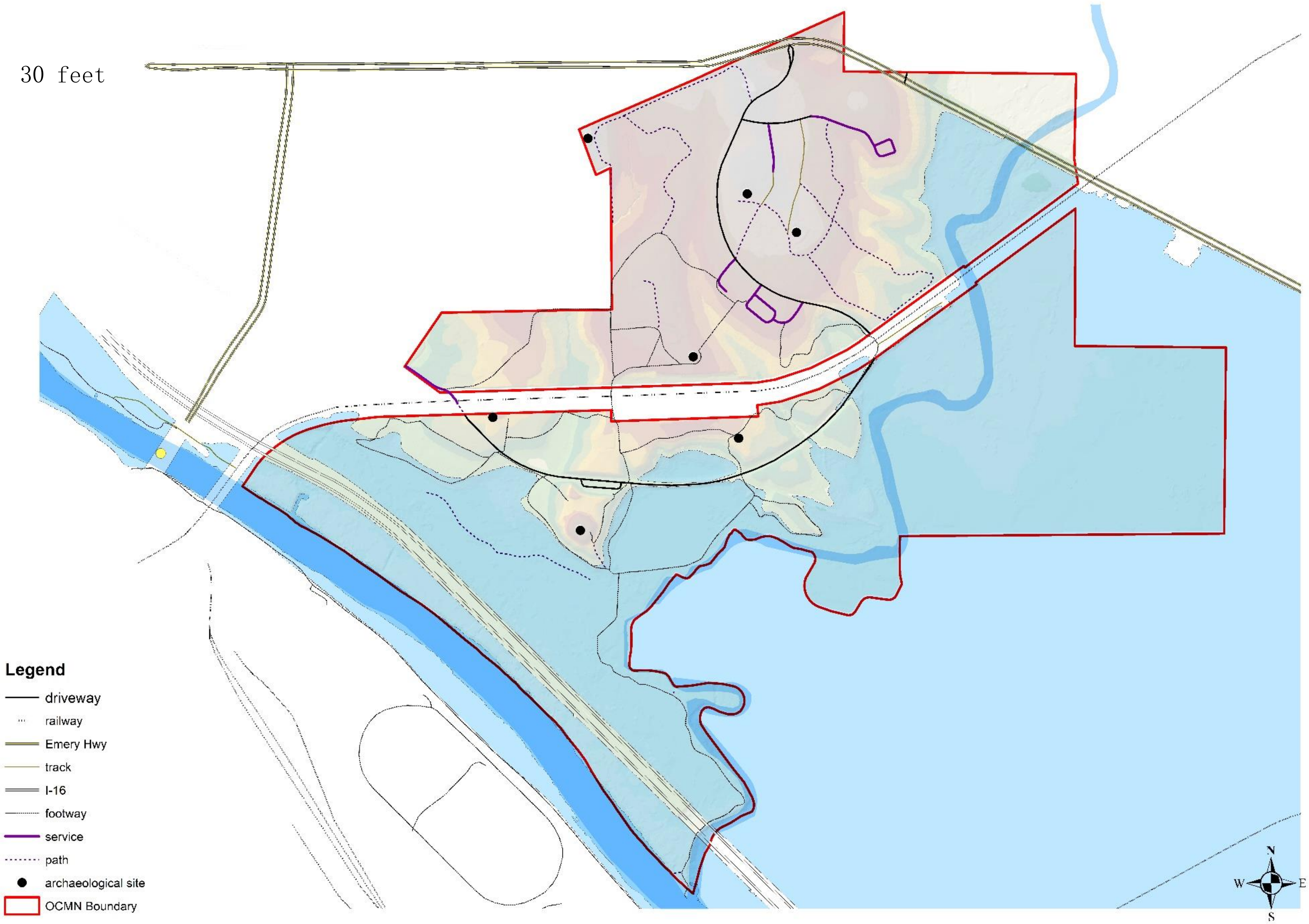
28 feet


Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S

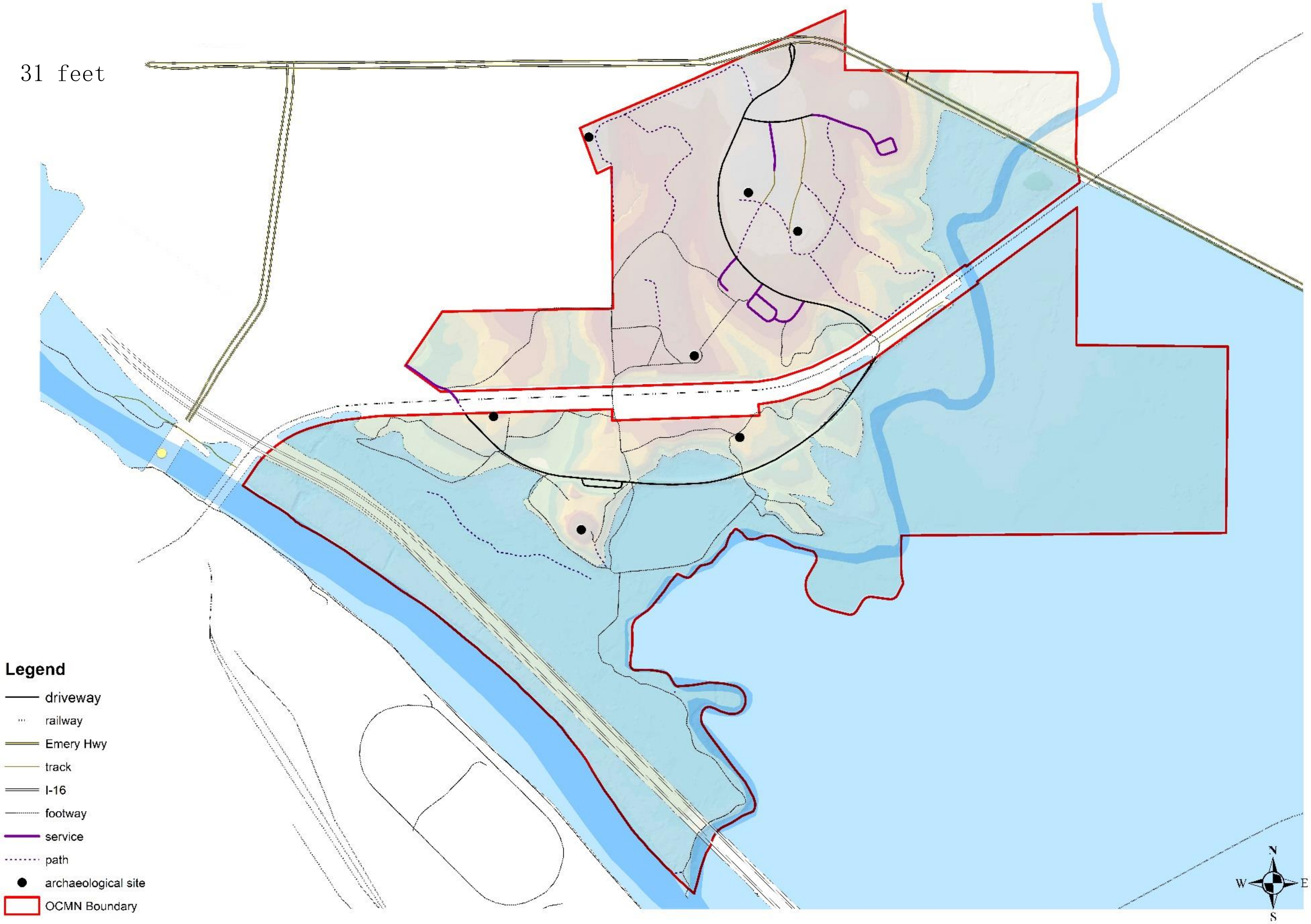
29 feet



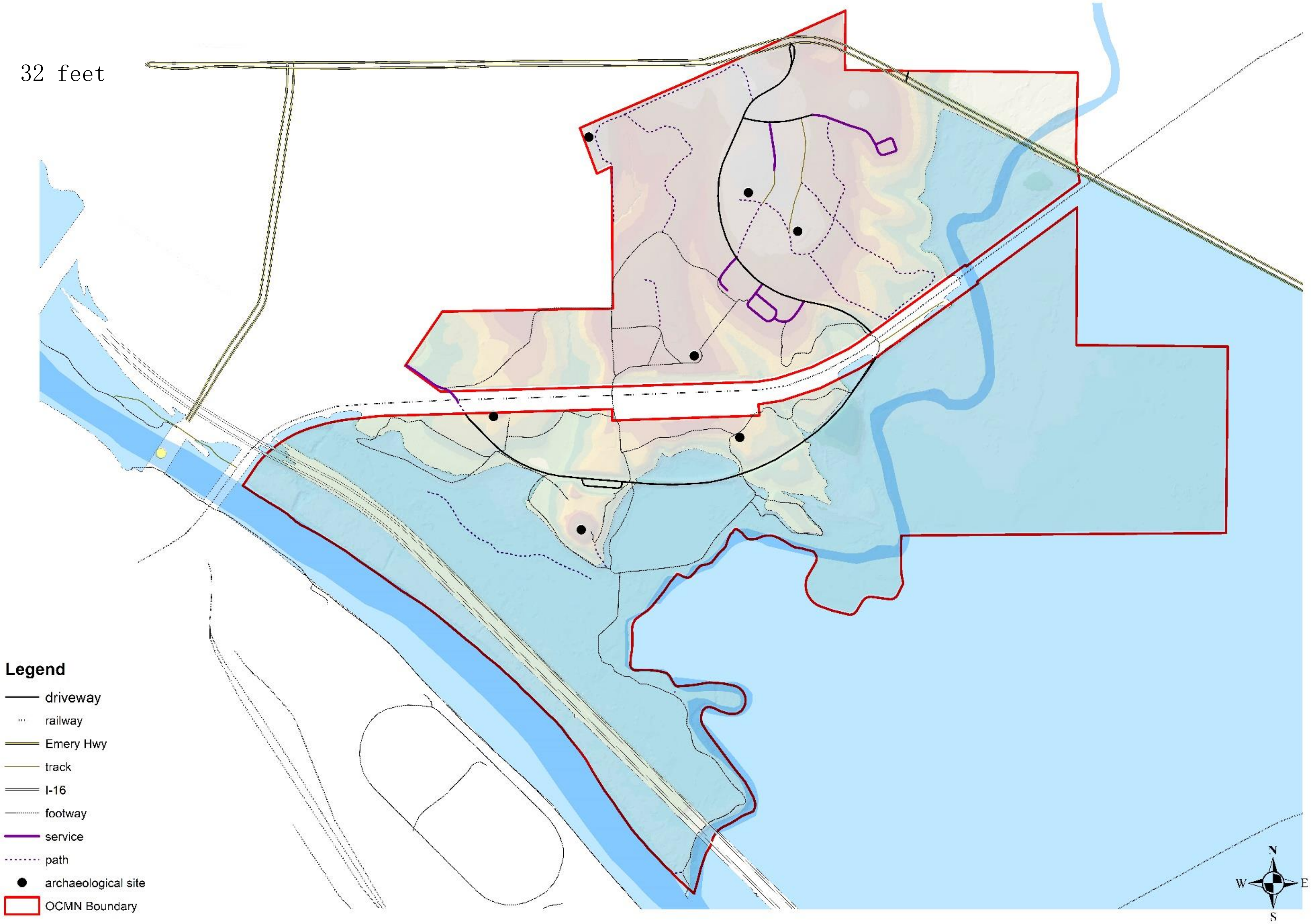
Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S


30 feet
Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S

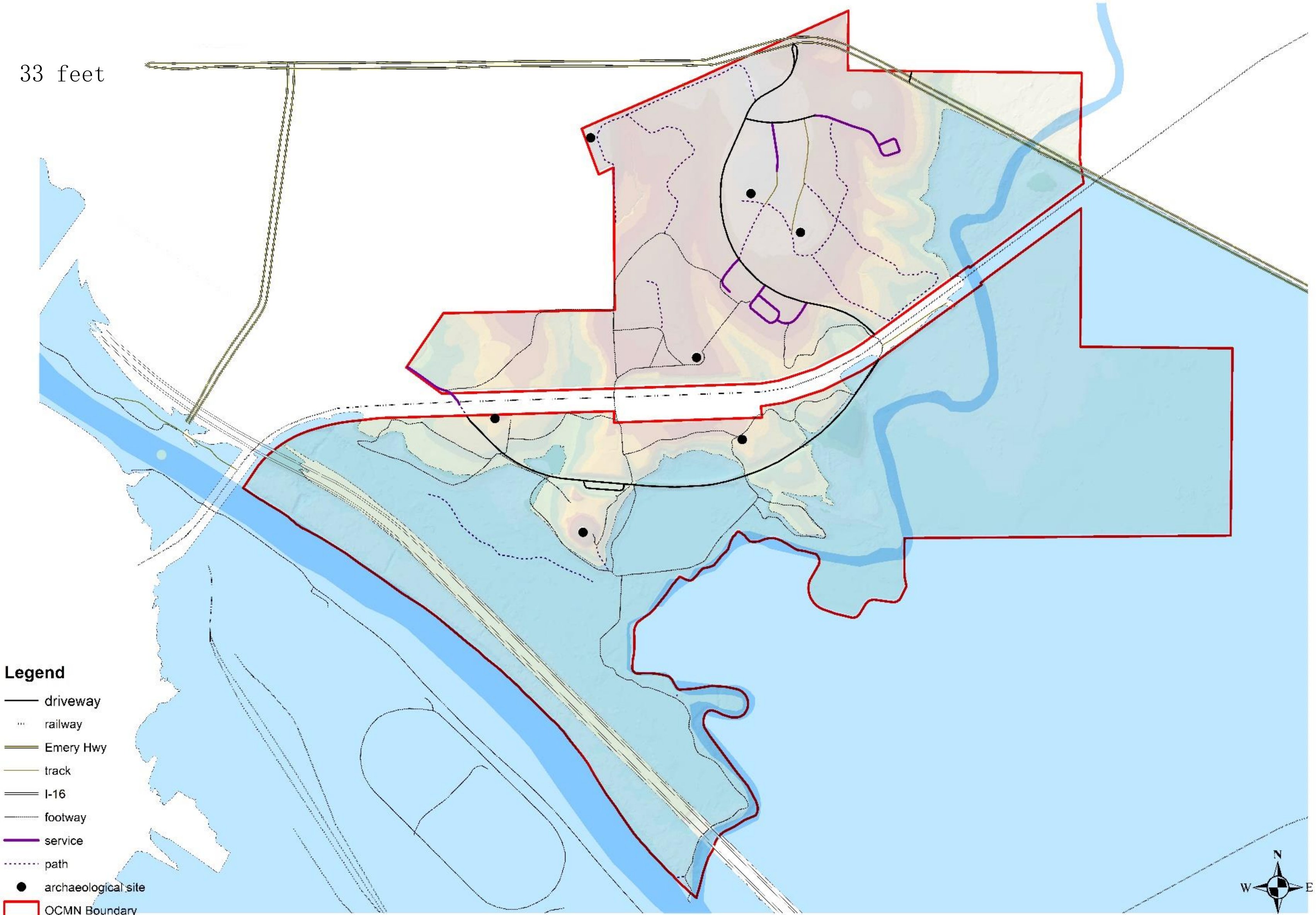
31 feet


Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S

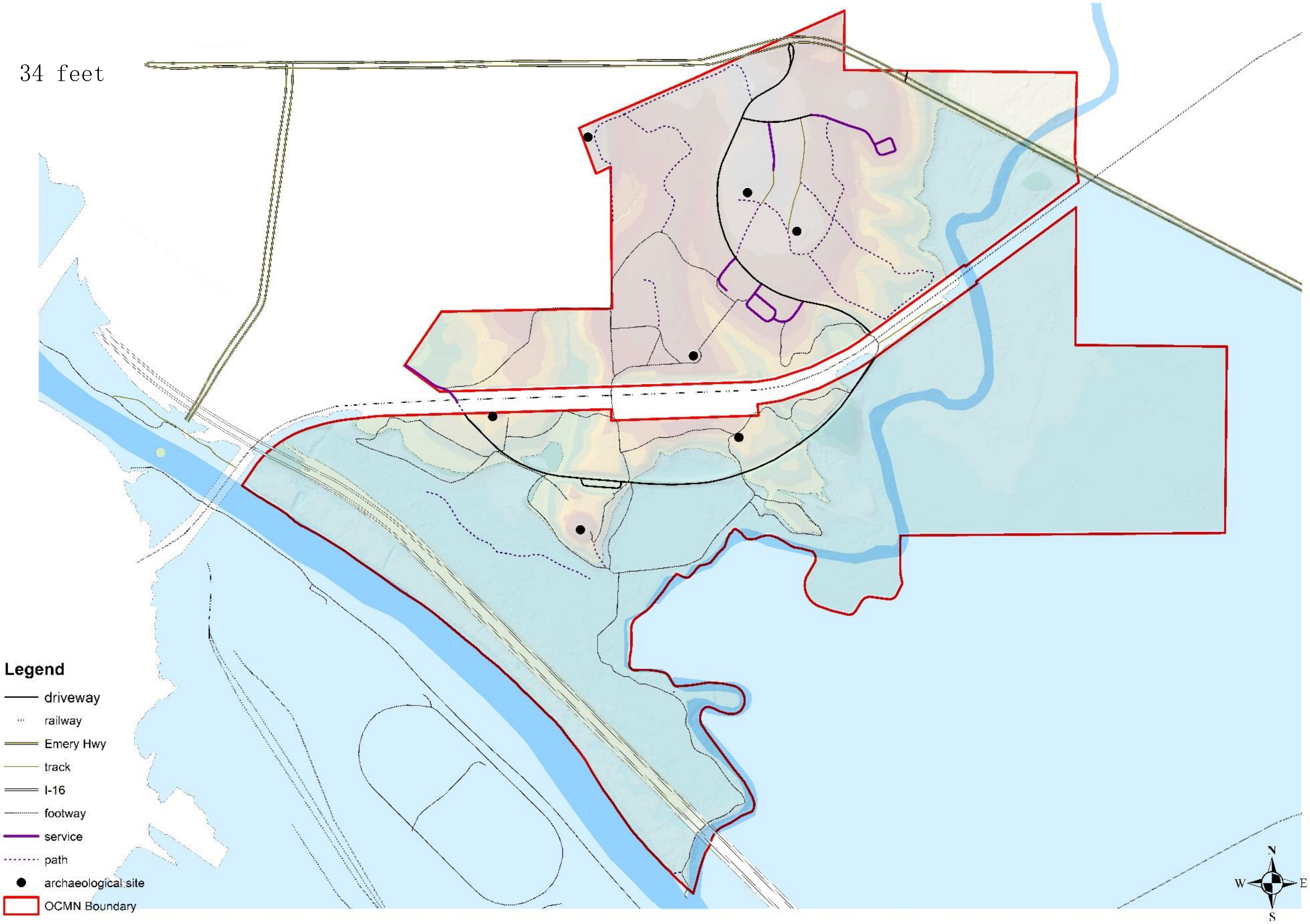
32 feet


Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S

33 feet


Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
E
S

34 feet


Legend
driveway
railway
Emery Hwy
track
I-16
footway
service
path
archaeological site
OCMN Boundary
N
W
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S