The Environmental Legacy of Sugar Planting in St. Croix, US Virgin Islands

By

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Abstract

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Recent studies across the Caribbean have revealed unstable soils and distressed hydrological systems, with areas showing signs of significant erosion resulting in decreased agricultural productivity and the siltation and disturbance of tourist friendly coral reefs (Rawlins et al. 1998, Febles-González et al. 2012, Madramootoo et al. 1990, Madramootoo and Norville 1993, Metternicht et al. 2010). The inhabitants of St. Croix, US Virgin Islands, are acutely affected by the unstable conditions recorded in the Caribbean. Most present-day residents are descendants of enslaved Africans who were brought to the island to work sugar plantations in the eighteenth and nineteenth centuries. Today's population regularly endures droughts and lacks access to reliable, safe, and affordable drinking water. Moreover, several of the island's natural aquafers have become contaminated with salt water, and siltation from the island's eroding landmass continues to harm nearby coral reef ecosystems (VIWRRI 2012).

For nearly 100 years, historians, archaeologists, and natural scientists have speculated that centauries of sugar planting are to blame for the poor environmental conditions now documented throughout the Caribbean (Ragatz 1928, Crosby 1986, Mintz 1986, Watts 1990). Yet little empirical work has been done to support this hypothesis (Meniketti 2015, Fox 2016, Pratt 2015). As a result of collaborative anthropological research with contemporary Crucian farmers, the National Park Service, the Nature Conservancy, and the Society for Black Archaeologists, this dissertation expands our understanding of the impacts sugar planting has had on the environment of St. Croix. Through an ethnographic and ethnohistoric investigation of sugar planting and agricultural practices on island, the investigation of the hydrological landscape built on St. Croix to support the sugar industry, and a geoarchaeological investigation of the soils on the Estate Little Princess planation (in operation from 1740s through the early-twentieth century), this dissertation offers three studies on the extent to which contemporary conditions on the island might be linked to the adoption of sugarcane monoculture on island during the eighteenth, nineteenth, and twentieth centuries.

Dedication

This work is dedicated to my always encouraging parents Franklin Siegel and Debra Banon Siegel, and to my partner Brandy Espinola. They have offered their unwavering support throughout my dissertation planning, research, and writing. Thank you all so very much.

Table of Contents

Abstract 1

Dedication i

Table of Contents ii

List of Figures vi

List of Tables xi

Introduction: The *raison d'etre* - Why study the effects of Sugar Monoculture, why study it on St. Croix, and why study it on the Estate Little Princess? xii

Acknowledgements xv

Chapter 1. Collaborations and Histories: An Investigation into the Ethnography of Crucian Sugar Planting and its Environmental Legacy 1

Introduction: Exploring the Ethnographic/Ethnohistoric Record of Sugar Planting in St. Croix 1

Background: From What "We Know" About a Place, to Locals Understandings About Their Home 5

Chapter 2. Ethnographic and Ethnohistoric Methods: People, Places, Meetings, and Photographs 9

Ethnographic Interviews 9

Ethnohistoric Research 10

Chapter 3. Ethnographic Results: Information from Local Farmers, Experts, and Activists 12

Information Pertaining to Currently Perceived Environmental Concerns on the Island Today ... 15

Information Pertaining to Current Perceptions of Past or Present Human Actions, or Natural Events or Processes, that have Led to Today's Environmental Conditions 19

Information Pertaining to Current Perceptions on What is Being Done in the Present to Mitigate Current Environmental Concerns 21

Information Pertaining to Current Understandings of How Sugarcane Was and Still Is Planted on the Island 25

Chapter 4. Ethnohistoric Results: Information from the Jack Delano FSA Photograph Collection 27

The Maintenance of Cane on the Island in the 1940s 27

Depictions of Field Laborers and Agricultural Tools and Implements 41

Broader Understandings of Landscapes and Land Uses 45

Chapter 5. Discussion: The Space Between Science, Historical Wisdom, and Lived Experience 47

Chapter 6. The Hydrological Legacy of Sugar Planting on St. Croix and the Estate Little Princess Sugar Plantation 54

Introduction: The Study of the Hydrology of Sugarcane Planting in St. Croix 54

Background: The Survey of Colonial Era Water Management Features in the Caribbean 56

Chapter 7. The Archaeological Survey of Colonial Era Water Management Features on Plantations in St. Croix 59

Methods 59

Results 61

Estate Morning Star Water Tower 61
Built Water Management Features at the Estate St. George 67
Water Cistern at Estate Washington 80
Water Management Features at Butler Bay 83
Estate Whim Plantation Water Jugs 97
Built Water Management Features at Estate Little Princess 101

Chapter 8. The Characterization of Water Uses on Sugar Plantations in St. Croix 125

Category 1 Water Consumed by, or Otherwise Used by, Humans 126

Category 2 Draft Animals and Cattle 130

Category 3 Sugar Processing 131

Category 4 Sugar Agriculture 134

Chapter 9. The Estate Little Princess Sugar Plantation Water Balance Model 136

A Brief History of the Estate Little Princess 136

Inputs for the Estate Little Princess Water Balance Model 140

Estimates for Precipitation on Estate Little Princess 140
Estimates for Water Uses on Estate Little Princess 141

Running the Water Balance Model 144

Results from the Estate Little Princess Water Balance Model 145

Discussion: The Hydrological Legacy of Sugar Planting in St. Croix 148

Chapter 10. The Soilscape Legacies of Sugar Planting and other Land Uses at the Estate Little Princess 152

Introduction: The Reputation of Sugar Planting 152

Background: The Exploration of Soilscape Legacies in the Caribbean 157

The "Abandoning the Garden" Hypothesis 160
Examining the Soilscape Legacy of the Estate Little Princess 161

Methods 163

Desktop and Archival Research on the ELP's Land Use History 163
Shovel Test Excavations and Lab Tests: 166

Results 176

Chapter 11. Discussion: Unpacking The Soilscape Legacies at the Estate Little Princess 210

Interpreting the Results from Soils and Sediment Analysis from the ELP 210

Transect 1 210
Transect 2 226

Final Thoughts 230

Chapter 12. Conclusion: The Environmental Legacy of Sugar Planting in St. Croix, US Virgin Islands 237

What Investigations were Conducted? 237

What is the Environmental Legacy of Sugar Planting on the Island of St. Croix? 237

Future Directions and Opportunities for Further Investigation 242

References 244

Appendix A. Annual Water Balance Model for Estate Little Princess 265

Appendix B. Lab Test Procedures 271

Appendix C. Field Observations, Lab Results, Profile Wall Photographs, And Examined Geochemical and Geophysical Properties for the 14 Representative Shovel Tests 280

Appendix D. Radiocarbon Date Results 335

Appendix E. Comparative Table with Results from All Lab Tests Conducted for 14 Representative Shovel Tests 343

List of Figures

Figure 1. Locations of proprietors interviewed on the island of St. Croix.. 14

Figure 2. Women cultivating sugar cane on land owned by the Virgin Islands Company, Bethlehem. 28

Figure 3. Cultivating sugar cane on the Virgin Islands Company land, vicinity of Bethlehem. .. 29

Figure 4. Planting sugar cane on the sugar plantation along the northern coast of the island. 30

Figure 5. FSA (Farm Security Administration) borrower cultivating his sugar cane field. 31

Figure 6. FSA (Farm Security Administration) borrower's wife cultivating recently planted sugar cane. 32

Figure 7. FSA (Farm Security Administration) borrower's wife cultivating their farm. La Vallee vicinity. 33

Figure 8. Cultivating sugar cane of the Virgin Islands Company land, vicinity of Bethlehem. ... 34

Figure 9. Cultivating sugar cane on the Virgin Islands Company land, vicinity of Bethlehem. .. 35

Figure 10. FSA (Farm Security Administration) borrower and his wife cultivating sugar cane on their farm, Frederiksted vicinity. 36

Figure 11. FSA (Farm Security Administration) borrower plowing his garden with one of the few plows used on the island, Frederiksted vicinity. 37

Figure 12. Puerto Rican farm woman on her farm where she has planted sweet potatoes between rows of sugar cane, Christiansted vicinity. 38

Figure 13. Sugar cane fields on the north-west part of the island..... 39

Figure 14. Sugar cane fields on the north-west part of the island..... 40

Figure 15. Sugar farms along the northern coast. 41

Figure 16. FSA (Farm Security Administration) borrower who lives in one of the homestead houses..... 43

Figure 17. The Collins Company, Collinsville, Conn U.S.A. Brochure used in St. Croix in early 1900s. 44

Figure 18. FSA (Farm Security Administration) borrower going to town in his Sunday cart. 45

Figure 19. A cattle farm, vicinity of Christiansted. 46

Figure 20. Map of western St. Croix depicting the locations of surveyed plantations. 60

Figure 21. View of north side of the Water Tower at Salt River. 63

Figure 22. View of subsurface well, with all but top buried, within the interior of the Water Tower at Salt River. 64

Figure 23. View of southern doorway, taken from within the interior of the Water Tower at Salt River, facing southeast. 65

Figure 24. View of second tier of Water Tower at Salt River, showing archway used in tower's construction and maintenance, facing northeast.. 66

Figure 25. View of interior of the Water Tower at Salt River.. 67

Figure 26. View of Stone-lined Well at St. George's Botanical Gardens, facing north 68

Figure 27. View of St. George Water Mill sluice, on the east side of the millhouse, facing south.. 70

Figure 28. View of St. George Water Mill sluice, showing space in walls left for water wheel axle, facing southeast. 71

Figure 29. View of St. George Water Mill house, showing stretch of southern wall, facing south. 72

Figure 30. View of St. George Flume cistern, facing east.. 74

Figure 31. View of St. George Flume cistern, facing west.. 75

Figure 32. Overview of St. George Flume, facing northwest.. 76

Figure 33. View of St. George Flume splitter, facing north.. 77

Figure 34. View of archway at base of St. George Flume, facing northeast.. 78

Figure 35. View of Flume at St. George, facing north.. 79

Figure 36. View of dam on Mint Ghut within St. George Plantation, facing east. 80

Figure 37. View of Estate Washington Water Cistern, facing southwest. 81

Figure 38. View of Estate Washington Water Cistern, facing west. 82

Figure 39. View of Estate Washington Water Cistern, facing northwest.. 83

Figure 40. View of Butler Bay Planation's Cistern, facing southeast from the Cistern's northwestern corner. 84

Figure 41. View of Butler Bay Planation's Cistern, facing northwest, from the Cistern's southeastern corner. 85

Figure 42. View of Butler Bay Planation's Cistern's western buttresses, facing west (and down), from the top of the Cistern.. 86

Figure 43. View of Butler Bay Planation's Cistern's southern wall, taken from the top of the Cistern at its southernmost extent, facing south and down, showing the Cistern's southern buttress. 87

Figure 44. View of Butler Bay Planation's Cistern's northern wall, showing its arched top, facing southeast..... 88

Figure 45. View of Butler Bay Planation's Cistern's interior, showing the profile of its arched top as well as the plaster lining on the interior of the cistern, facing east. 89

Figure 46. View of Stone-lined Well found in the vicinity of Butler Bay Plantation, showing exterior, facing southeast. 90

Figure 47. View of exterior wall of Stone-lined Well found in the vicinity of Butler Bay Plantation, facing southeast. 90

Figure 48. View of interior and bottom of Stone-lined Well found in the vicinity of Butler Bay Plantation, facing southeast. 91

Figure 49. View of exterior of the staircase of the Stone-lined Well found in the vicinity of Butler Bay Plantation, facing south. 92

Figure 50. View of archway above the stairway within the Walk-in-Well found in the vicinity of Butler Bay Plantation, facing east..... 92

Figure 51. View of entry way/trough in the vicinity of Butler Bay Plantation, facing northeast..93

Figure 52. View of northern pillar of the entry way/trough in the vicinity of Butler Bay Plantation, facing west.. 94

Figure 53. View of southern pillar of the entry way/trough in the vicinity of Butler Bay Plantation, facing northeast..... 95

Figure 54. View of Stone-lined Well near the Sugar Factory at Butler Bay Plantation, facing south. 96

Figure 55. View of the interior of the Stone-lined Well near the Sugar Factory at Butler Bay Plantation, facing southeast. 96

Figure 56. View of coarse ceramic Water Jugs at Estate Whim Plantation Museum, facing south.. 98

Figure 57. Closeup of Jug 1 at Estate Whim Plantation Museum, facing south..... 99

Figure 58. Closeup of Jug 2 at Estate Whim Plantation Museum, facing south..... 100

Figure 59. Closeup of interior of Jug 2 at Estate Whim Plantation Museum. 101

Figure 60. Map of the Estate Little Princess depicting locations of its still extant historic era structures. 103

Figure 61. Views of the Water Tower at Estate Little Princess, facing east..... 105

Figure 62. View of upper portion of Water Tower at Estate Little Princess, facing east. 106

Figure 63. View of lower portion of Water Tower at Estate Little Princess, facing east. 107

Figure 64. Detail view of the entrance to Water Tower at Estate Little Princess, facing east.... 108

Figure 65. View of backside of Estate Little Princess Water Tower showing Well, facing north. 109

Figure 66. Closeup of "1745 RM" written in plaster on the northeast exterior of the Estate Little Princess Water Tower. 110

Figure 67. View of upper and lower portions of Water Tower at Estate Little Princess, facing east.. 111

Figure 68. View of interior of the second phase of the Estate Little Princess Water Tower..... 112

Figure 69. Photograph of Estate Little Princess Factory (center) and Water Mill (top left corner), from northwest of the Factory, facing southeast, from the ELP on site collection, entitled "Estate Little Princess STX #1958". 114

Figure 70. View of the Windmill Turned Cistern on Estate Little Princess, facing northeast. .. 116

Figure 71. View of the lip at the base of the Windmill Turned Cistern at Estate Little Princess, facing southwest..... 117

Figure 72. View of the south side of the Windmill Turned Cistern at Estate Little Princess, facing north. 118

Figure 73. View of the north side of the Windmill Turned Cistern at Estate Little Princess, facing south. 119

Figure 74. View of southern exterior wall of the ELP Sugar Factory Cistern, facing northeast. 120

Figure 75. View of western exterior wall of the ELP Sugar Factory Cistern, facing east..... 121

Figure 76. View of eastern side of the Pier to the south of the ELP Sugar Factory Cistern, facing west. 122

Figure 77. View of the Pond to the south of the ELP Sugar Factory Cistern, facing southeast. 122

Figure 78. View of the ruins of the ELP Dripstone Housing Structure, facing west..... 123

Figure 79. Detail view of the ELP Dripstone, facing west. 124

Figure 80. Examples of Carribbean water vessels, on left, Goglet, and on right, Biot Jar, both from plantations in Dominica.. 127

Figure 81. Limestone “Dripstones” for water purification.. 128

Figure 82. Interior view of a working boiling house, the Delap sugar factory on Antigua, ca. 1820..... 132

Figure 83. Location map of the Estate Little Princess, a sugar plantation in active use from the eighteenth through the twentieth centuries.. 154

Figure 84. Digital Elevation Model (DEM) for the Estate Little Princess, based on 2016 NOAA collected LiDAR data.. 164

Figure 85. Typical shovel test profile wall sampling strategy, showing locations of bulk samples taken from Shovel Test 9, west wall. 169

Figure 86. Locations of geoarchaeological shovel tests for the Summer 2022 field season and key features of the Estate Little Princess Plantation. 178

Figure 87. Shovel test unit locations, relative depths, Munsell color of encountered strata, and USDA soil characterization. 179

Figure 88. Eighteenth century depictions of St. Croix and the Estate Little Princess. 212

Figure 89. Photograph showing Emil Svitzer on a horse within a cane field ready for planting, (located to the southeast of the ELP’s Cane Factory), facing northwest. 214

Figure 90. Photograph showing the African laborer’s village located to the west of the ELP’s First Great House. 215

Figure 91. Photograph showing plantation laborers standing in front of the African laborer’s village (left), Lands Kept in Timber (center), and First Great House (right). 216

Figure 92. Photograph entitled “Emil Svitzer (On Horseback) and Guests in the Little Princess Palm Grove” facing east. 224

Figure 93. Photograph entitled “Estate Little Princess #1980 DEEP VII,” facing northeast, from southwest of ELP’s Sugar Factory. 229

Figure 94. Photograph entitled “Estate Little Princess #1981 DEEP VII,” facing northeast. 229

List of Tables

Table 1. Archival resources which inform the history of the Estate Little Princess..... 137

Table 2. Daily water requirements of humans on Estate Little Princess, estimates derived from Vivanti 2012..... 141

Table 3. Daily water requirements of animals on Estate Little Princess, estimates derived from Molina-Rivera 1998, Meehan et al. 2015, Ingram N.D. 142

Table 4. Estimates for the ratio of the number of enslaved or free Black laborers, White planters, managers or laborers, and livestock, for years when no data is available for the Estate Little Princess, derived from Thompson 2009. 142

Table 5. Water needed for sugar cultivation and lost to sugarcane, water absorption, and evapotranspiration on Estate Little Princess, estimates derived from Davis 2003, Deerr 1905, and Vicente et al. 2013. 143

Table 6. Water lost to evaporation in sugar manufacture on Estate Little Princess, understanding derived from Meide 2003, Deerr 1905, Craton and Walvin 1970. 143

Table 7. Attributes recorded in the field or selected for sampling within each shovel test and exposed soil profile 168

Table 8. Shovel test naming conventions, and descriptions of additional tests performed on bulk samples..... 180

Introduction: The *raison d'etre* - Why study the effects of Sugar Monoculture, why study it on St. Croix, and why study it on the Estate Little Princess?

Between 1500 and the early 1900s, European expansion through colonization, landscape alteration, long distance trade, and the extraction of natural resources took place at such an unprecedented rate and had such profound ecological effects that these behaviors fundamentally changed local environmental systems (Lightfoot et al. 2013). Plantation colonies established across the western hemisphere necessitated the clearing of wide tracks of land, the reduction of biodiversity (particularly that of local flora) and placed high nutrient and soil retention demands on local soil systems as managers only placed value on the hyper-focused production and processing of singular agricultural commodities including coffee, tobacco, cotton, cocoa, and sugar, often centralizing capital and enslaved (and Black) labor to do so (Richards 2003:414, Crosby 1986, Hare 1970, Carney 2001). Sugar plantations have a reputation for being among the most environmentally impactful type of colony to have appeared in the Americas during the sixteenth through twentieth centuries (Mintz 1986, Menikett 2015, Meide 2003, Ragatz 1928, Dunn 1973, Watts 1990).

Today, the residents of St. Croix, a United States (US) Territory, and US Virgin Island, regularly endure droughts and lack access to reliable, safe, and affordable drinking water. In addition, several of the island's aquifers are contaminated with saltwater and siltation from erosion continues to harm critical coral reef ecosystems. Moreover, locally recorded rises in surface temperatures, sea surface temperatures, ocean acidification, and reduced levels of precipitation, have been projected to worsen in the future, with devastating effects for those on island (USGCRP 2018). These hydrological conditions pose a serious and immediate threat to the wellbeing and water sovereignty of those living on island and create a moral imperative for eco-minded anthropologists to study past human activities that may have direct causal links to conditions we see today. Consequently, this dissertation examines the potential links between sugar planting and present environmental conditions.

While no previous works on St. Croix have investigated the environmental impacts of sugar planting, recent works of Caribbean archaeology have examined the environmental impacts of intensified sugar planting on other islands; identified chronological phases in the intensification of and technological advancements in sugar cultivation, pointed out the dependence of local environmental conditions on planter decisions and resulting plantation activities, anointed initial deforestation as among the most significant of plantation's impacts, and have made the analysis of plantations' landscape use, spatial layout, and access to natural resources common practice (Delle 1994, Meniketti 2015, Pulsipher and Goodwin 2001, Ryzewski and Cherry 2015).

The purpose of this dissertation is to examine the long-term environmental impacts of sugar planting on the island of St. Croix. More specifically, this interdisciplinary research is intended to explore the impacts sugarcane agriculture had on the hydrological and soil systems of the island. These goals are achieved through the pursuit of three distinct but interrelated investigations. The first investigation consists of an ethnographic and ethnohistoric investigation into colonial era sugar planting practices on island and their potential for, and perceived relationship to, long-term environmental impacts (Chapters 1 through 5). Seeking to emphasize the importance of human memory, oral tradition, and community perceptions in the development of local environmental histories, I conducted in-person oral interviews and dialogues with

Crucian farmers, activists, biologists, and historians, to strike at a deeper understanding of the long-term environmental impacts of particular planting practices, and the perceived relationship between sugar planting in the past and present environmental conditions. To supplement the information provided on the sugar planting practices of the island by interviewees, I also examined a photograph series collected by Jack Delano of the Farm Security Administration (FSA) in St. Croix during 1941 and 1942 for visual cues that might indicate how sugarcane fields were prepared, planted, maintained, and harvested, and what those practices might mean for the sugar industry's long-term impacts on the environment. Assigned to take pictures of local businesses, residences, public places, public gatherings, homesteads, and plantations on behalf of the US Federal Government, through his photographs, Jack Delano offers a glimpse of early twentieth century sugarcane planting practices in St. Croix.

The second investigation into the long-term environmental legacy of sugar planting in St. Croix consists of an archaeological survey of colonial era water management features on plantations across the island, and an assessment of what these water management features contributed to the water requirements of sugar planting in St. Croix, and what water resources were actually available to those living on island (Chapters 6 through 9). Making use of the findings from the archaeological investigation of the ruined remains of water management features on six plantations, including Estate Morning Star, Estate St. George, Estate Washington, Butler Bay, Estate Whim, and Estate Little Princess (ELP), I then characterize the four types of water uses evinced by these features, including water consumed or used by humans, water consumed by draft animals and cattle, water used in the processing of sugar, and lastly the water required by sugarcane plants throughout their lifecycle. Incorporating the findings of these efforts, I conclude the investigation into the hydrological impacts of sugar planting on St. Croix by making use of archival research, and historical rainfall data for the ELP, to develop a water balance model for the estate during its active use as a sugarcane plantation to demonstrate the tremendous water deficit which plantations on St. Croix likely incurred over the span of nearly two-hundred years of sugar planting.

The third investigation I pursued into the long-term environmental legacy of sugar planting in St. Croix consists of a geoarchaeological investigation into the connections between various forms of land use on ELP during the eighteenth, nineteenth, and twentieth centuries and the conditions of the soils found on the plantation today (Chapters 10 and 11). Drawing upon Christian Wells' concept of "soilscape legacies," or the idea that the soils of today represent an anthropogenically modified and examinable membrane on the earth's surface and can reflect the long-term consequences of human behaviors, this research makes use of historical, topographical, and geoarchaeological data collected on ELP to link known periods and locations of sugar cultivation and other activities with observable and datable changes in local soils (Wells 2013:28). Incorporating desktop and archival research on the ELP's land use history, digital elevation modeling of the plantation's environs, background research on the ELP's longer term geomorphological history, shovel test excavations, and the results from an array of soil test analyses on collected bulk samples from the stratigraphies observed across the plantation, this study identifies and interprets observable geochemical and geophysical attributes found in the soils across the ELP to find clear links between present soil conditions and specific types of human activities which are known to have taken place in various locations across the plantation during its active use.

Project efforts in St. Croix were strongly encouraged and influenced by the ongoing work on island by the Society for Black Archaeologists (SBA) and their Estate Little Princess Field School (ELPFS). Led by Dr. Justin Dunnavant (UCLA) and Dr. Ayana Flewellen (Stanford), and greatly assisted by Dr. William White III (Berkeley), the SBA has conducted archaeological investigations on the Estate Little Princess (ELP), a former plantation, since Summer 2017 in concert with the Nature Conservancy and the Slave Wrecks Project. The SBA's mission is to develop avenues of engagement and training that will prepare Black and African scholars and communities to become active participants in the documentation, excavation, preservation, and interpretation of Black and African heritage. At ELP the SBA's work has focused on the archaeological examination of the lifeways of enslaved and later emancipated Africans trapped within the Danish planter society that controlled the island during the eighteenth through twentieth centuries. This dissertation complemented the SBA's mission by working with and supporting Black students and agriculturalists in a collaborative effort to reveal the environmental outcomes of centuries of coerced African labor dedicated toward the production of sugarcane.

Designed to assess the long-term impacts of sugar planting on the hydrological and soils systems on the island of St. Croix, this body of research examines long-term environmental outcomes from past agricultural practices, and works with community collaborators to encourage dialogues with, and inputs from, local agriculturalists. By studying the enduring landscape of a proto-industrial society, this work invites eco-mined anthropologists to focus future studies on historical period societies who possessed the ability to cause environmental change that might still impact societies today (Rivera-Collazo 2015, Tsing 2011, Nelson et al. 2016, McGovern 2018).

Acknowledgements

A work of this magnitude could never be accomplished by just one person. For the research contained within this dissertation I am indebted to numerous individuals and groups without whom this work would not have been a success. I would first like to thank my academic advisers and fellow researchers at UC Berkeley. Beyond the broader sense of encouragement which these colleagues bestowed upon me, I would have surely been lost without their years of experience and at times their quite specific technical guidance as I pursued grants, intensive excavations in remote locations, and complex lab tests within the Archaeological Research Facility (ARF). I especially thank the members of my dissertation committee, including Dr. William White, Dr. Lisa Maher, Dr. Kent Lightfoot, and Dr. Peter Nelson, as well as Dr. Dave Wahl. These UC Berkeley faculty members were instrumental in the development of this project's research design, field methods, and laboratory protocols, and helped push me to achieve a higher level of academic rigor. I would also like to thank Dr. Nicholas Tripcevich (Nico) who helped oversee my use of ARF lab spaces and field equipment for over half a decade. Nico's patience for, and willingness to help trouble shoot, any issue, including the securing of a USDA soils permit for this project, proved absolutely critical to the achievement of the primary goals of this research.

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More than a thank you is also extended to Dr. Christian Wells, Professor and Director for the Center of Brownfields Research and Redevelopment at the University of South Florida, and his colleagues from the Betty's Hope Project in Antigua including Dr. Georgia Fox, Dr. Peter Siegel, Dr. Anthony Tricarico, and Suzanna Pratt. Their writings and groundbreaking geoarchaeological research at Betty's Hope inspired a great deal of the research presented in this dissertation. These thoughtful scholars happily replied to emails and phone calls when I sought out their advice. Dr. Wells, in particular, not only freely offered his counsel and expertise, but for years managed to find the time to talk me through methodological issues and research considerations as I attempted to get my own geoarchaeological research off the ground. His unselfish support and openhanded academic investment in this dissertation research is a generosity I will not forget.

I would also like to formally thank the students and volunteers who have supported this project either through their participation as geoarchaeological field assistants during excavations in St. Croix in the Summer of 2022 or as laboratory apprentices for the project through UC Berkeley's Undergraduate Research Apprenticeship Program (URAP). Excavations in St. Croix proved to be extremely challenging, taking place in unforgiving heat and humidity, and often in densely vegetated locations with little or no breeze. This is to say nothing of the physicality and raw

number of hours required to excavate the project's large, and at times quite deep, shovel tests. For her commendable effort in the field and unbridled enthusiasm for the overall project I offer a sincere and hearty thank you to Nicole Smith whose can do attitude made light work of what might appear to others as a daunting set of tasks. I also want to extend a special thank you to Xavier Albors who served as a senior URAP for the project for over three semesters between 2022 and 2024. Xavi's personal interest and time investment in the project directly led to the addition of more advanced laboratory testing than had been initially planned. Other field assistants and URAPs to whom I extend my thanks include: Kendall Archie, Jordan Griffin, Carly Schinhofen, Schyler Marvin, Kathleen Hulguin, Yiwen Mao, Ayesha Baig, and Danika Sanchez.

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Finally, I must also note that none of this work would have been possible without the generous support of several foundations and granting institutions. I am heavily indebted to The Nature Conservancy (TNC), who have served as the stewards of the Estate Little Princess since 1977. It is only through their welcoming collaboration that archaeological works could take place on the plantation, and I would personally like to thank TNC Program Director Celeste Jarvis who oversaw the archaeological permit under which this dissertation fieldwork was conducted. In a similar vein, I thank the Wenner-Gren Foundation for their generous Dissertation Field Work Grant, without which much of this research simply would not have had the means to take place. In parallel, many aspects of this project's ethnographic, archival, and geoarchaeological work could not have been conducted without generous funding from various departments across UC Berkeley's campus including the Scandinavian Department, the Archaeological Research Facility, the Anthropology Department, the Graduate Department, and the Global, International Areas Studies research hub. I thank these supporting organizations for taking a chance on what I hope turned out to be substantive and worthy research.

This dissertation represents years of hard work, sweat, and yes, even tears. It also represents my greatest academic research effort to date and is one of my most cherished achievements. I know that this summit was reached, not by a solo hike up the mountain, but by the grace of a supportive network of mentors, colleagues, collaborators, and friends consisting of both those I have mentioned above, and so many more who I have failed to name. Thank you all, from the bottom of my heart, for your help and support.

With much appreciation,

~Benjamin D. Siegel

Chapter 1. Collaborations and Histories: An Investigation into the Ethnography of Crucian Sugar Planting and its Environmental Legacy

Introduction: Exploring the Ethnographic/Ethnohistoric Record of Sugar Planting in St. Croix

The ethnography and ethnohistory of sugar planting is a particularly insightful way to learn about the precise agricultural practices undertaken by those who worked on sugar plantations on the island of St. Croix, presently a part of the United States Virgin Islands (USVI), and the environmental impacts these practices may have had on the island's water and soil systems. Archaeologists have an opportunity to gain insight into the short-, mid-, and long-term effects of sugar planting on local systems by talking to those who were involved in the sugarcane industry and by exploring photographic documentation of planting practices. This vernacular knowledge records and preserves past planting traditions on the island. It also documents cultural outlooks towards the sugar planting industry and its role in environmental change and present-day environmental conditions.

The initial goal of my research was to learn more about sugarcane planting practices and their environmental impacts on the island of St. Croix. In appreciation of Isabel Rivera-Collazo's work in Puerto Rico (2018) that made use of ethnographic data collected through interviews with local farmers, field laborers, and land mangers alongside other lines of evidence to strike at a deeper understanding of long-term human influences on the local environment, I sought to emphasize the importance of human memory, oral tradition, and community perceptions in the development of local plantation environmental histories (Rivera-Collazo et al. 2018). In this way, like Rivera-Collazo's work, a stated goal of this research was to highlight local understandings of past and present environmental conditions and memories regarding agricultural activities and landscape modifications so that they could be synthesized alongside ethnohistoric data sets to develop accurate and socially aware environmental assessments for an island-based community (Rivera-Collazo et al. 2018, Ezcurra and Rivera-Collazo 2018). Mirroring Rivera-Collazo's approach, my research set out to combine historical documents, the archaeological record, and testimonies and insights from local residents to learn about the ways the sugar plantation economy may have affected the hydrological and soil systems on the island.

To achieve these aims I pursued ongoing digital (email) and virtual (zoom) conversations with Crucian community members and participated in in-person oral interviews and dialogues with project partners on the island of St. Croix throughout Summer 2022. The goal was to better understand the particulars of the sugar industry in St. Croix and learn more about sugar's role in the island's environmental history. I had hoped that descriptions of the practices associated with pre-sugar planting forest clearance, soil preparation and amendment, and the construction of associated water management features would be vocalized by project participants and recorded. Another goal of these interviews was to learn more about the labor regimes of enslaved Africans and their later freed descendants on sugar plantations. Interviews were also intended to reveal local traditions involved in sugarcane crop planting, maintenance, harvesting, and crop rotation and or cover cropping between sugarcane harvests and planting seasons. By engaging in these dialogues about sugarcane planting, I sought to pinpoint and evaluate specific planting practices (or other cultural or natural factors) that could account for the island's present environmental conditions. It was also hoped that interviewees might share their opinions and understandings of the relationship(s) between sugarcane planting and the island's environment, as well as their

sentiments and attitudes towards the sugarcane industry. Such accounts and understandings of local sugar planting practices and their perceived effects on the environment recorded during these interviews would make for valuable contributions to the ethnographic record of sugarcane monoculture on St. Croix. Further, their accounts carry details of the island's environmental history, as the sugarcane planting era was a period where the majority of the island's landscape, and especially its hydrological and soils systems, were exposed to extensive clear cutting, mass deforestation, and sugarcane harvesting, tilling, and replanting between the 1730s and the 1960s. Worthy of preservation in their own right, the collected ethnographies have been digitally compiled. Consisting of audio recordings, transcriptions, and written notes from dialogues and meetings, the compiled interviews will live on as another form of the environmental legacy of sugarcane planting in St. Croix, one that endures within the hearts and minds of those that are connected to the soils and water systems on the island today.

In addition to collecting oral histories, in Spring 2022 I examined a photograph series collected by Jack Delano of the Farm Security Administration (FSA) who set out to the US Virgin Islands in 1941 and 1942 to take pictures of local businesses, residences, public places, public gatherings, homesteads, and plantations on behalf of the US Federal Government (United States Farm Security Administration 1941 and 1942). Kept at the US Library of Congress, this collection of 461 photographs offers researchers a glimpse of early twentieth century life and sugar cane planting practices in St. Croix. Through a visual analysis of these pictures, I looked for details regarding the farming implements used, past planting practices, and the depicted conditions of farmed sugarcane lands to add another dimension to the ethnohistoric examination of past sugarcane planting practices on St. Croix.

Initially it was anticipated that Crucian farmers, activists, biologists, and historians, would echo the conventionally maintained narrative conveyed within the island's historical, archaeological, and scientific literature, which strongly points towards connections between the ever-worsening environmental conditions on island and the area's centuries long adoption of sugarcane agriculture. The questions first developed for use in dialogues with locals were designed to hear accounts on how current hydrological and soils conditions on St. Croix were connected to past agricultural practices. But what began as an attempt to identify specific sugar planting practices that might account for current conditions evolved through project participants' responses and described interests. Interview conversations ultimately focused on presently experienced hardships pertaining to local declines in annual precipitation and a lack of sufficient laws, governmental representation, and appropriate levels of government maintenance and intervention regarding rainfall management, water conservation, and water distribution. As a result, the project's investigation into possible links between sugarcane agriculture and present-day environmental conditions in St. Croix transformed into an exploration of divergent local perspectives, and the space between conventional "scientific data," prevailing historical scholarship, and local understandings of, environmental conditions and their antecedents.

As Justin Hosbey and J. T. Roane demonstrated, within their studies on Black ecologies in the South and along the East Coast of the United States, underserved communities can hold different types of values for natural resources than those cherished by governmental agencies, agriculturalists, or developers. Their non-mainstream narratives may be all too often overlooked by historians and natural scientists (Hosbey and Roane 2021). Water is a natural resource which Hosbey and Roane revealed to be one that has been, and still is, thought about and appreciated

by Black communities in ways that are distinct from prevailing or mainstream cultural narratives. Taking details gathered during oral interviews and making using of historical data collected in Virigina, the Mississippi Delta, and the lower Chesapeake Bay (Maryland), Hosbey and Roane revealed how enslaved and later free African understandings and perceptions of water and the role this resource played in perceptions of overall environmental health, differed widely from white plantation and governmental narratives. Black individuals particularly valued accessibility of the resource to their communities, privacy and safety amongst these resources, and fish population health (ecosystems services) above governmentally or developer-held values that included large scale agricultural water rights, water navigability, and other conventional scientific metrics of ecosystem health (Hosbey and Roane 2021, Roane 2018, Roane and Hosbey 2019).

Though the current research was born out of an interest in collecting local accounts of the environmental history of St. Croix for comparative purposes with other sources of data, it evolved into an exploration of alternative figurations of water as held by Crucian farmers, agriculturalists, and activists through the responses heard and interests shared within dialogues with locals on the island. Ultimately adopting some of the core tenets of community based participatory research (CBPR) including a realignment of the project's research values with the community's research interests and pressing needs, an adjustment in the research questions asked of interviewees, and the development of meaningful bonds with community members and project partners, this project evolved in real time to be better aligned with the environmental circumstances and interests of Crucian project participants (Atalay 2007, Marshall 2002).

Acknowledging the negative effects that more traditional archaeological and ethnographic works have had on traditionally under-represented groups throughout the twentieth and early twenty-first centuries this study embraced a more community-based approach like those encouraged by Sonya Atalay (2006, 2012). Public engagement in projects and in the development of research questions, and open collaboration with affected communities whose history is being studied has never been more important (Atalay 2012:2). "Public involvement, heritage management, and collaboration with communities are now major concerns, and archaeologists are responding to the public with serious scholarly attention" (Atalay 2012:1). For far too long, groups studied by scholars have been excluded from participation in the research itself, and from the results and benefits of that knowledge collected (Colwell-Chanthaphonh 2009, Hammil and Cruz 1989). In many communities where archaeologists, anthropologists, and social scientists have conducted their research, locals have had limited access to the knowledge collection, creation, and dissemination processes, regularly excluded from project research designs and decisions (Atalay 2012:2). In light of these truths, many scholars have developed, advocated for, and continued to practice CBPR (Tax 1958, Robinson 1996, Atalay 2008, 2012, Marshall 2002, Stoecker and Tryon 2009, Sabloff 2008, McNaughton and Rock 2003, Vio Grossi 1980, McNiven and Russel 2005, Brady 2009, Rossen 2006, 2008, Smith et al. 2003, Flewellen et al. 2022). This CBPR movement stems from a critique of conventional research, and forms of social activism which identify and problematize the power imbalances between the visiting university or private institution scholar, and the local communities they study in remote and often disenfranchised and or impoverished areas. As a result, a core value of CBPR is that research must move "from 'on and for' to 'by and with," such that the very communities that are the subject of the research, or who are occupying the area(s) being studied, cannot be treated as merely the subject of the study, but instead must be seen and valued as partners in the design, execution, and dissemination of the

research itself (Atalay 2012:7, McNaughton and Rock 2003). Rather than an outright rejection of western modalities of research design and data collection, practitioners of CBPR look to bring self-awareness to the (at times vast) discrepancy of power inherent in dynamic of researcher and research subject, and to consciously bring the goals and values of a research project more into alignment with the desires and interests of the community being studied (Smith 1999:39, Atalay 2003, 2007, 2010, Hollowell and Nicholas 2009, Greer et al. 2002). In this way, CBPR looks to democratize the research process in order to resolve the tensions inherent in the processes of knowledge production and the use of that knowledge between the 'university scholar' and the real world (Vio Grossi 1980:70, Atalay 2012:11).

Through the democratization of knowledge production and the inclusion of community members in the design and execution of research the outcomes of CBPR projects are strengthened in a variety of ways. The practice of CBPR brings reciprocal benefits to both the scholar and the communities they study, by providing researchers with intimate access to normally concealed or difficult to reach types of information (i.e. living memory and oral history), while also allowing the community to steer the goals of the research, as well as the ways in which it is carried out, and to gain control of the way that information is shared and disseminated (Atalay 2003, 2007, 2008, 2010, Brady 2009, Budhwa 2005, Chirikure and Pwiti 2008, Chilton and Hart 2009, Harrison 2001, Murray et al. 2009, Silliman 2008, Bendremer and Richman 2006, Nicholas 2005, 2010, Robinson 1996) . In this way, the project ends up pursuing a research design that benefits both the scholar and the community in which the work is taking place (Atalay 2012:5, Bartu 1999, 2000, 2006, 2007). Further, through the sharing of control over project research questions, methodologies, and information, and the engendering of community trust, CBPR also enhances the outcomes of archaeological and anthropological research by enabling the research to draw upon, and be guided by, the distinct knowledge systems and local value systems unique to the area of study. By yielding control over the core values and goals of a research project to the local community, CBPR can result in the modification of projects such that the researchers involved are prompted to ask, and ultimately answer, questions about the past that they would not have otherwise considered (Marshall 2002:218). While it is true that this process means that some of the scholar's originally chosen research questions might fall by the wayside, it also ensures that the research pursued is better contextualized within the social and economic milieu of the community being studied, and that the knowledge collected is more meaningful for the community members who are participating. Through the sharing of control over the processes of research the practice of CBPR is thus capable of infusing a project with local values and understandings, ultimately guiding the project to more insightful research (Marshall 2002, Simpson 2010).

By more directly engaging with both descendant and non-descendant communities through the sharing of and democratization of the research process, the current study became a project where several tenets of CBPR were deployed. Ultimately, interviewees for the current study were invited to influence the project by: informing and adjusting the questions asked of collected data, advising on and questioning data sets collected, and infusing their environmental and historical understandings of sugar's role in environmental change on the island during the interpretation of project data (Atalay 2012, Marshall 2002). Borrowing from the praxis of CBPR this research engaged local Crucian interviewees on personal levels who would not only be asked to provide information to help answer the project's initial research questions, but who would also be given

the opportunity to sculpt the trajectory and focus of the research through their interests and particular concerns.

Presenting the results of these efforts, the Background section of Chapter 1 begins with an explanation of the conventional narratives regarding St. Croix's environmental present and future, and the traditionally deployed narratives that account for these conditions to understand the backdrop against which this investigation took place. Chapter 2 then provides a description of the methods undertaken to conduct oral interviews and the visual analysis of the Delano FSA ethnohistoric photographs to investigate current environmental conditions and their possible antecedents. Then, in Chapters 3 and 4 I present the results of these investigations. Lastly, in Chapter 5, I provide a discussion of the results obtained from both the oral interviews and ethnohistoric research presented and what the project's findings mean for our understanding of past sugarcane planting practices on St. Croix, the currently perceived environmental conditions on the island, and their possible causes and solutions.

While this ethnographic and ethnohistoric investigation was ultimately successful in identifying several details regarding local customs and practices pertaining to sugar planting on island, perhaps the most valuable insights were provided during ethnographic interviews, consisting of the nearly universal distancing of current environmental conditions from sugarcane's capacity for environmental degradation within the minds of those interviewed. In this way, the thoughts and perceptions shared by project interviewees would come to represent the distance between the classically and scientifically understood causes of contemporary conditions, and those understandings held by locals, who saw the present-day circumstances as far more preventable and actionable. These results reinforce the driving concerns of Hosbey and Roane who make clear that it is important to hear from local community members to better understand environmental realities and local perceptions of environmental conditions in each location, rather than to assume a total understanding based strictly on governmental or scientific research (Hosbey and Roane 2021, Roane 2018, Roane and Hosbey 2019).

Background: From What "We Know" About a Place, to Locals Understandings About Their Home

The Caribbean is a region currently experiencing what is believed to be human induced environmental concerns that are negatively impacting local agricultural and tourism industries, which are the two main pillars of Caribbean island economies. Recent studies across the region have revealed unstable soil conditions and distressed hydrological conditions, with study areas showing signs of significant erosion resulting in decreased agricultural productivity and the siltation and disturbance of tourist friendly coral reefs (Rawlins et al. 1998, Febles-González et al. 2012, Madramootoo et al. 1990, Madramootoo and Norville 1993, Metternicht et al. 2010). The inhabitants of St. Croix are among the communities heavily affected by the unstable conditions recorded in the Caribbean. Most present-day residents of the island are descendants of enslaved Africans who were brought to the island to work on sugar plantations in the eighteenth and nineteenth centuries. Today the population regularly endures droughts and lacks access to reliable, safe, and affordable drinking water. In addition, several of the island's natural aquifers have become contaminated with salt water, and siltation from the island's eroding landmass continues to harm nearby critical coral reef ecosystems (VIWRRI 2012). More recently, it has also been made clear that the island is also highly susceptible to tropical weather events as many Crucians suffered for years after the extensive water and wind damage caused by category 5

Hurricane Irma and category 4 Hurricane Maria, that hit the USVIs in the summer of 2017 (Craig 2018, Santiago 2017, Peters 2017, O'Brien 2017).

From a "scientific" perspective, the contemporary environmental concerns in St. Croix are "obvious." The U.S. Global Change Research Program (USGCRP) is charged by the Global Change Research Act of 1990 to deliver an environmental report regarding conditions observed throughout the U.S. to Congress and the President. On November 25, 2018, the USGCRP released its fourth National Climate Assessment (NCA) Report. Among its many goals was the analysis and synthesis of current trends in both human-induced and natural climate change, the projection of major trends for the subsequent 25 to 100 years, and the assessment of the effects of global climate change on the natural environment, and human uses of that environment, including land practices, energy production and use, and human health and welfare (USGCRP 2018). For the first time in its history, the NCA's 2018 report included a chapter specifically dedicated to the U.S. Caribbean.

The 2018 NCA report summarized and synthesized the findings of a vast collection of environmental studies conducted throughout the twentieth century and stated in "plain english" that rising temperatures, reduced precipitation, rising sea surface temperatures, ocean acidification, and rising sea levels, are trends that have already been consistently observed in St. Croix, and that the region can expect to see more of the same in the future (USGCRP 2018:819). According to the report, temperatures have risen in the US Caribbean since 1950 by 1.5°F and climate models project about another 1.5°F to 4°F increase in average regional temperature by 2050. Significant drying is also expected, with models predicting a decline of more than 10% in annual regional precipitation by mid-century. Finally, the report also lists a 0.43°F per decade rise in regional ocean temperature since 1996, and a regional sea level rise observed at the rate of 0.08 inches (2 mm) per year on average since the 1950s (USGCRP 2018:819 – 822). As one reactionary USVI newspaper headline commented the day of the NCA report's release, "Climate Change is Not 'Coming' to the Caribbean - It's Here" (Akin 2018).

Among the numerous impacts these climate changes will have on the region, one of the most severe (especially from a tourism perspective) is the impact rising temperatures, rising seas, rising sea temperatures, and increased ocean acidification will have on local coral health and reef growth potential. The findings of the NCA report suggested that "mass coral bleaching in the Caribbean may occur at least twice a year within the next decade" while increased "frequency of extreme heat events are likely to preclude reef recovery, considering that the region's reefs have yet to fully recover from [a] 2005 event" (USGCRP 2018:830). That 2005 "event" was a mass coral bleaching (or an expulsion of the symbiotic algae that live inside coral polyps), driven by just a single 12-week rise in temperature above the normal local seasonal maximum. Though not dead, corals in this state turn completely white, do not grow, and become more susceptible to disease. The 2005 event affected the entire Caribbean Sea, resulting in the bleaching of as much as 80 percent of the region's coral (USGCRP 2018:827).

Increased coral bleaching events and continued soil siltation of reefs by the island's eroding land mass would spell disaster for St. Croix's tourism industry and the island's economy. Aside from the protection that healthy coral reefs provide against severe storms (more of which are also anticipated by the NCA), local coral health is directly linked to the area's financial stability. "For the territory of USVI," the NCA report stated, "reef-related tourism was estimated as generating

$96 million per year, and coastal protection was estimated as providing $6 million annually to the local economy" (USGCRP 2018:829).

For nearly 100 years, historians, archaeologists, and natural scientists have speculated that centuries of European-driven sugar planting are to blame for the poor environmental conditions now documented throughout the Caribbean (Ragatz 1928, Crosby 1972, Mintz 1986, Grove 1996, Watts 1990, Dunn 1973, Richards 2003). Yet little empirical work has been done to directly test this hypothesis (Meniketti 2015, Fox 2016, Pratt 2015, Wells et al. 2017, Wells et al. 2018, Wallman et al. 2018). Recent scholars examining the environmental impacts of intensified sugar planting have: identified chronological phases in the intensification of and the technological advances in sugar cultivation, pointed out the dependence of local environmental conditions on planter decisions and resulting plantation activities, anointed initial deforestation as a particularly significant plantation impact, and have made the analysis of plantations' landscape use, spatial layout, and access to natural resources common practice (Delle 1994, Meniketti 2015, Pulsipher 1977, Pulsipher and Goodwin 2001, Ryzewski and Cherry 2015). Some scholars have even gone as far as to suggest that sugarcane factories, replete with kilns, mills, furnaces, boilers, cooling vats, and cooperages represented some of the first industrial landscapes, and their quick rise to prevalence across the Caribbean in the sixteenth, seventeenth, and eighteenth centuries contributed to modifications in local and global climate conditions. They have also identified the clearing of huge tracts of land as a leading cause in the reduction of local water retention and location precipitation, and have pointed toward the markedly increased levels of CO2 emissions which started to be produced during the industrial revolutions of the eighteenth and nineteenth centuries due to the development of factories and the increasing use of industrialized or mechanized processes of manufacturing like those used in Caribbean sugar factories (Crutzen 2007, Meide 2003, Meniketti 2015, Fox 2016).

A "scientifically driven" investigation into the anthropogenic antecedents of St. Croix's present day environmental conditions would seek to explore possible connections between the environmental circumstances of today with the possible impacts of sugarcane planting. This is logical given both the island's current environmental predicament, and the region's historically leading suspect of environmental degradation because the plantation-based sugar industry was an agricultural pursuit with a reputation for causing water and soil loss on the islands where it was practiced. I was prompted to interview Crucian farmers and other community members and local experts out of an imperative to involve in the project the people who might be most heavily impacted by those contemporary conditions. I was particularly interested in examining explicit connections between events and practices in the past that might still be impacting the environment today.

The choice to pursue oral interviews with local Crucians in addition to other forms of research was also inspired and shaped by the works of the Society of Black Archaeologists (SBA), which emphasize the importance of, and value added through, the inclusion of community members and their ideas into project research designs and the interpretation of collected data. Since 2018 the SBA's Estate Little Princess Field School (ELPFS) on St. Croix has achieved its goal of providing avenues of engagement and training for Black and African scholars and communities while highlighting the lived experiences of communities within the African Diaspora (Dunnavant et al. 2018a, 2018b). The SBA achieves this by practicing tenets of Black Archaeology, Indigenous Archaeology, and Community Archaeology; including, collaboration, employment

and training, public presentation, interviews and oral history documentation, and the production of educational resources (Flewellen et al. 2021, Atalay 2006, 2012, Moser et al. 2002). These community collaborations have steered the SBA's research goals toward the archaeological investigation of enslaved and later freed Africans' material possessions and daily practices on the Estate Little Princess (ELP) while fostering local capacity and interest in archaeological research.

Working alongside the SBA, I began to develop relationships with St. Croix based agriculturalists, scientists, historians, and other experts through meetings, conversations, and oral interviews. Over time, however, I found that those interviewed saw little if any connection between sugar planting practices during the eighteenth, nineteenth, and early twentieth centuries and current environmental conditions. Instead, they were particularly concerned with the acute water stress they were currently facing, as well as what they perceived to be the more immediate causes of this issue. Unable to ignore the interviewees concern for, and interest in, other topics pertaining to water management on St. Croix, I embraced a core tenet of CBPR and made changes to the project including a realignment of some of the project's core research values with the community's research interests and pressing concerns. What began as a series of interviews primarily designed to better understand sugarcane planting's potential to impact the island's environment shifted into ongoing dialogues about the environmental stressors currently being experienced and what their possible causes and solutions might be (Atalay 2012, McNaughton and Rock 2003). This was achieved through a significant adjustment in the research questions asked of interviewees (Marshall 2002). No longer purely a research project about sugarcane's possible environmental legacy, interview questions shifted to inquiries about current conditions and their perceived and more recent antecedents. This was done in an attempt to more meaningfully engage with community members and infuse community members' understandings of environmental issues on the island into the redesign of the project's research questions and ultimately the way in which the project's data would be interpreted (Atalay 2006, 2012, Moser et al. 2002, Marshall 2002). What began as a strictly top-down research project intended to collect data from a community on a specific topic, evolved into research with a new goal of better understanding the community's presently felt environmental stressors, and an attempt to reconcile the space between locals' perceptions of these stressors, and the traditionally held "scientific narratives" regarding the environmental history of the island. Anthropological works are "tool[s] for civic engagement," outreach, and capacity building (Little and Shackel 2007, Blakey 1997, Agbe-Davies 2010:172). Calling attention to this silenced ecological story, the incorporation of locals into the process of data collection through oral interviews provided not only valuable environmental information, but also democratized the project's research design by inviting local participation in the production of environmental knowledge (Hare 1970, Agbe-Davies 2010:173, Franklin et al. 2020, Atalay 2006, 2012, Marshall 2002).

Chapter 2. Ethnographic and Ethnohistoric Methods: People, Places, Meetings, and Photographs

Ethnographic Interviews

To learn the particulars of the sugar industry and to learn more about sugar's role in St. Croix's environment, I held oral interviews and conversations with Crucian biologists, historians, and agriculturalists in the Summer of 2022. Interviewees were embraced as research partners in identifying underlying causes of the island's current environmental conditions. The research set out as an attempt to understand short-, mid-, and long-term effects of sugar planting on local ecosystems, and to help develop local abilities to explore and express perceptions and concerns regarding St. Croix's environment.

Expecting to hear and document first and secondhand accounts on how sugarcane monoculture once ruled, and may have changed the island, I originally prepared four types of questions for interviewees:

1. Questions regarding consent to being interviewed, self-identification, and introductory details including name, age, connections to the community, place of residence, acres cultivated, and experience in agriculture.
2. Questions pertaining to current perceptions of environmental conditions (especially as pertains to soil and water systems), recalled environmental conditions from the past, and overt questions asking interviewees what they viewed as the causes of perceived environmental changes over time.
3. Questions pertaining to aspects of sugarcane planting/maintenance/harvesting that might have been particularly impactful to the environment.
4. Questions pertaining to current and past soil and water collection, retention, use, and loss on plantations and farms.

Initial interview participants were largely self-selected. Local community organizers, including Dr. Chenzira Kahina (Dr. Chen), a community educator and organizer, and Frandelle Gerard, the Executive Director of Crucian Heritage and Nature Tourism, Inc. (CHANT) a non-profit and heritage preservation institution, were already engaged participants in, and long standing partners of, the SBA's multi-year ELPFS. I was introduced to them by the Principal Investigators of the field school, Dr. Justin Dunnavant, Dr. Ayana Flewellen, Dr. William White, and Dr. Alexandra Jones. From then on, Dr. Chen and Frandelle Gerard continued to offer to share their knowledge on local environmental history and to introduce me to locals who might be interested in participating in interviews related to current environmental conditions and their possible causes. Additionally, Dr. George F. Tyson, local author and historian, former Executive Director of the St. Croix Landmarks Society, and past-President of the Society of Virgin Island Historians, and Mr. Olasee Davis, renowned naturalist and distinguished professor of Biology at the University of the Virgin Islands both availed themselves to not only participate in the oral interviews, but to offer their counsel and personal connections freely in introducing me to even more local farmers, government officials, land stewards, and activists. Beyond these four original project participants, the list of those interviewed (ultimately including the voices of 30 island residents) developed organically, and at times entirely incidentally over the course of the project.

All interviews followed U.C. Berkeley's Internal Review Board (IRB) Protocol, and this project was conducted with CPHS protocol ID number 2022-03-15178, as a research project involving the oral interview of locals on the Island of St. Croix to learn more about past sugar planting practices and changes in the environment over time. Potential interviewees were provided with the opportunity to not participate in the research, and for conversations which extended past introductions and one or two initial questions I was sure to obtain voluntary informed consent prior to continuing with any interview. Each conversation began with my introducing myself to prospective interviewees and explaining the purpose of my research and questions. Further, I specifically asked if interviewees wished to participate in these research dialogues. Contact information for follow-up questions from interviewees was also provided. Interviewees were also reminded that they were welcome to end the interview at any time.

Interviews lasted anywhere between a few minutes and a few hours, depending on the interviewee's interest in carrying on the conversation, and their knowledge about topics pertaining to past and present agricultural practices, land use history, and past and present environmental conditions. Follow-up interviews also took place on several occasions. These were only pursued based on the interviewee's interest in pursuing the conversation further. Other considerations included interviewees' availability, and their knowledge about topics that might help answer the project's evolving research questions. Interviews took place in public spaces including libraries, parks, restaurants, and even monuments, as well as private spaces including personal farms, homesteads, and places of work. Interviews in private spaces only took place when I was invited to visit these spaces after initial conversations in public locations. Two locations of interviews which perhaps straddled the line between public and private spaces which informed this ethnography include the Local Farmers Market held at the St. Croix Agricultural Fair Grounds every Saturday, and a meeting of the Territorial Agricultural Group's (TAG's) Information Exchange and Listening Session, co-sponsored by the Virgin Islands Good Food Coalition. This meeting was held at the Blue Bamboo Bar and Restaurant on July 26, 2022. At the farmers market I introduced myself and my research to farmers who were working their agricultural booths and chatted with those who cared to participate. At the activist group meeting, I attended as an invited guest of an event co-organizer, listened during public speeches and team building and community sharing exercises, and mingled with agriculturalists and pastoralists during the reception following the meeting.

Ethnohistoric Research

In Spring 2022 I conducted an analysis of photographs taken by Jack Delano of the Farm Security Administration (FSA) who set out to the U.S. Virgin Islands in 1941 to take pictures of local businesses, residences, public places, public gatherings, homesteads and plantations. Kept at the US Library of Congress, this collection of 461 photographs offers researchers a glimpse of early twentieth century life and sugarcane planting practices in St. Croix (Delano 1941). Through the visual analysis of these photographs, I learned much about the planting practices and state of conditions on the island during the early 1940s. The collection contained depictions of sugarcane cultivation and processing, cane field workers and homestead farmers, and other land uses and landscapes. Each photograph was examined for depictions of either large fields under cane cultivation and or smaller individual fields which could speak to the ways in which these fields were planted, managed, and worked. To gather further details on the nature of cane cultivation practices on the island, photographs were also examined for depictions of both individuals and groups of individuals working and or standing within cane fields, with special attention paid to

observable implements used in cane's cultivation. Furthermore, landscape photographs depicting larger sugarcane fields revealed broader patterns in St. Croix's land use during the 1940s.

Chapter 3. Ethnographic Results: Information from Local Farmers, Experts, and Activists

Among the first interview participants were local organizers, educators, and government officials known to the author through either the SBA or other professional connections, including Frandelle Gerard, the Executive Director of Crucian Heritage and Nature Tourism, Inc. (CHANT), Dr. Chenzira Kahina (Dr. Chen) the former founding and inaugural director of the Virgin Islands Caribbean Cultural Center, Dr. George Tyson, historian with the St. Croix Historical Society, Professor Olasee Davis, a biologist teaching at the University of the Virgin Islands' St. Croix Campus, Mr. John Farchette of the USVI Department of Fish and Wildlife, and Dr. Meredith Hardy, archaeologist with the National Park Service's (NPS's) Southeast Archaeological Center who had archaeological jurisdiction over the NPS's holdings on St. Croix. Through these early discussions, I heard the conventional history of St. Croix's sugar-based monoculture in the eighteenth, nineteenth, and twentieth centuries. I also heard elements of the widely held scientific and historic understandings of the environmental impacts sugarcane has had on Caribbean islands more broadly, and St. Croix specifically. It was also during these initial conversations that I was introduced to, or encouraged to contact, a wide range of local farmers, ranchers, and activists to learn more about these topics. Subsequent conversations with these first project participants and later conversations with their recommended points of contact opened additional lines of communication with interested and concerned members of the island's community.

After making initial introductions with interview participants, and after hearing a willingness to participate from each interviewee, the first talking points I brought up in conversation pertained to current environmental conditions on the island, indices used to determine environmental health, the identification of acute concerns, local understanding of the causes of present conditions, and local mechanisms or interactions by which news of conditions or concerns are spread throughout the community. Designed before any of these interviews took place, the initial questions were deliberately intended to extract honest answers from interviewees, without revealing the preconceived notions of the interviewer. Moreover, my original set of questions were intended to allow the interviewees to steer the conversation towards the types of land uses they were most familiar with, as well as any particular set of environmental conditions, and or changes over time in environmental conditions, with which they might have direct or secondhand experience. I expected to hear locals echo the narrative described in scientific publications and articles on Caribbean history and archaeology. I imagined that those interviewed would readily and independently draw an abundance of connections between current environmental concerns regarding water scarcity and soil loss to the island's long history of sugarcane planting, if not explicitly identify specific locations where past sugarcane activities are known to have impacted the environment directly. Conversations with locals however, quickly shifted the dialogue in other directions that were based on the responses, belief systems, and sentiments shared by project participants.

A total of 30 interview participants were included in this ethnographic investigation. In categories that are not necessarily mutually exclusive, 17 of the participants were self-identified farm owners, gardeners, or pastoralists, five participants were self-identified environmental activists, and four participants were government officials. Other categories participants could be said to fall into would include historians (3), educators (4), and self-identified community

organizers (3). Of the 17 self-identified farm owners, gardeners, or pastoralists, two had cultivated sugarcane within their lifetime, and one held acreage in sugarcane at the time of interview. Of these same 17 agriculturalists eight managed small sized operations (one acre or less), seven were found to manage medium sized operations (ranging from two to 15 acres in size), and two were found to manage large scale operations (15 acres or more). At the time of interview these agriculturalists were aged between 30 and 86 years old, and collectively held farms across the central and northwestern portions of the island. Five of the 17 farm owners, gardeners, or pastoralists were also proprietors of their own established companies or corporations, including the proprietors of the Feather Leaf Inn, The Honey Man Inc., Annaly Farms, Inc., Sejah Farms of the Virgin Islands, and Art Farm LLC (Figure 1). Each of these individuals were interviewed on their own properties so they could point out particular features or concerns on their managed land. Six farmers were interviewed at their farmer's stands at the island's weekly farmers market held at the US Agricultural Station's Agricultural Fair Grounds, which is located in the central western portion of the island (Figure 1). One-on-one interviews with locals were also complemented by observations made during the TAG Information Exchange and Listening Session, where I heard a wide variety of sentiments expressed about current environmental conditions, challenges to agricultural production on the island, and causes of, and future mitigations against, pressing environmental concerns. The event, held on July 26, at the Blue Bamboo Bar and Restaurant and was attended by over 100 farmers, pastoralists, activists, educators, land stewards, and elected government officials.

Figure 1. Locations of proprietors interviewed on the island of St. Croix. Map created by author, 9/29/24, using Google Earth software and imagery.

While revealing the specific answers given by specific interviewees might seem to be the most direct route to the sharing of information, it is also perhaps the most direct path towards the intrusion into the privacy of those interviewed. Instead, I present the results of these ethnographic interviews in an amalgamation of relevant sentiments and responses expressed by project participants during conversations regarding specific topics. This format was chosen not only to protect the privacy of the individuals who freely gave their responses during these conversations, but also to add some level of synthesis to the answers received, rather than merely reprinting transcripts of lengthy conversations. Moreover, and much to my surprise, most of those interviewed expressed strikingly similar sentiments regarding environmental concerns, their causes, and the ways they might be remedied. Perhaps even more interesting were the moments in collective memory which seemed to hold critical spaces in local environmental history and the milieu among the island's agriculturalists and environmentalists.

Despite the value in the aggregated information shared during interviews with local partners, I still identify three proprietors in this work pertaining to the information they shared— Hans Lawaetz, life-long conservationist, rancher, and founder and owner of Annaly Farms Inc., and the owners of ArtFarm LLC, Luca and Christina Gasperi. These three interviewees are mentioned by name, because during interviews they made it clear to me that they were dedicated toward the sharing of information with the public to try and improve these conditions.

For the purposes of this research, aggregated information gathered during interviews have been compiled into four main categories:

1. Information pertaining to currently perceived environmental concerns on the island today.
2. Information pertaining to current perceptions of past or present human actions or behaviors, or natural events or processes, that have led to today's environmental conditions.
3. Information pertaining to current perceptions on what is being done in the present to mitigate current environmental concerns.
4. Information pertaining to current understandings of how sugarcane was and still is planted on the island.

Information gathered from the 30 local project participants pertaining to each of these four categories is synthesized below.

Information Pertaining to Currently Perceived Environmental Concerns on the Island Today

When asked questions like "What are the leading environmental concerns on the island today?" universally, interview participants responded with concerns about a lack of sufficient water. Farmers consistently reported insufficient rainfall to support their crops, and often, interviewees also expressed concerns over an island wide lack of sufficient water catchment, water management, and water conservation. These responses were undoubtedly informed and influenced by, if not at least underscored by, the drought which hit the island between December 2021 and July 2022. During this meteorological episode, the island was recorded as receiving a

mere eighth of its annually expected rains over the past seven months which included the traditionally rainiest months of the year. By the time of the interviews which took place in June and July of 2022 the island was experiencing what was understood locally as a severe drought, one which, according to farmers, was on par with the drought of 2015, the worst drought anyone could remember. “Back in 2015” said one farmer, “even the coconut trees [the most drought tolerant plant on the island] were drooping, things were really bad”. Such sentiments were in fact, echoed by several other agriculturalists and activists who were interviewed, each independently offering similar comparisons between the current drought and the drought of 2015, referring to 2015 as a benchmark year, and identifying the withering of coconut trees as a sure sign of severe drought.

Follow up questions aimed at asking interviewees to identify other pressing environmental concerns, or even to identify any other environmental concerns which interviewees were aware of revealed little else. Those interviewed did not express concerns regarding local (or global); rising temperatures, rising sea temperatures, invasive floral or faunal species, pests, plant or animal disease, deforestation, encroachment of secondary growth, coral health, nor any of the other environmental concerns mentioned within the NCA 2018 report. Natural disasters were, however, mentioned by several of those interviewed, with the 2017 hurricanes, including Irma (category 5) and Maria (category 4) still fresh in participants’ minds. Several participants mentioned that as a result of these disasters, and especially Maria, there was a widespread loss of public services. Roadways were blocked, powerlines were down, and needed assistance for fence repair and crop maintenance from the USDA’s Agricultural Department was unavailable.

Perhaps most concerning for St. Croix’s long-term wellbeing were hurricane Maria’s compounded impacts to the island’s agricultural systems and economy, as it made landfall just days after category 5 hurricane Irma had already destabilized farmers and farms as it passed by the island. Between the two storms, growers lost livestock, trees, crops and infrastructure, while the Virgin Islands Department of Agriculture stations on St. Croix and its two neighboring US Virgin Islands (St. Thomas and St. John) were severely damaged rendering their offices and structures unusable (Ellis 2017). “During the two weeks between Hurricanes Irma and Maria, St. Croix farmers gathered 8,000 pounds of fresh produce [to send]… to St. Thomas. After Hurricane Maria struck, that was no longer possible” (Ellis 2017). Beyond immediate impacts to growers’ capacity to produce goods for local and foreign markets, these storms also destroyed seedlings and covered large swaths of agricultural fields in unmanageable debris. The rains that came with the storms, which persisted through November 2017, also made it difficult if not impossible for farmers to plough for and plant new crops through the end of the month, diminishing the island’s ability produce fresh produce in the short to mid-term thereafter (Ellis 2017). Efforts to clear debris, harvest crops, and plant new ones were all compromised by the storm’s destruction of field equipment, especially tractors and other vehicles that might have otherwise enabled farmers to handle the unanticipated heavy workload.

The long-term agricultural ramifications of these hurricanes are also severe. During the back-to-back storms “farmers lost most of their mango, breadfruit and soursop trees” which are plants that take years to reach commercial scale fruit yielding maturity, but in November began replacing them with “quick crops such as bok choy and cucumbers, [just] to create an interim revenue stream” (Benita Martin cited in Ellis 2017). Farmers’ livestock were also hit hard by the hurricanes, with many goats, sheep, chickens, and hogs dying in the storms and then later from

diseases and malnourishment, due to lack of sufficient grain on the island, in the weeks and months after the storms. The destruction of the island's (and even the region's) bee population is also a major longer-term concern. "About half of the Virgin Islands beehives were destroyed by the hurricanes and Puerto Rico's population suffered even more," said Crucian beekeeper Toni Downs (Toni Downs cited in Ellis 2017). Downs lost 16 of her 20 hives in the two storms, and they will not be easy to replace. Starting from scratch, it can take 6 to 12 months for a beehive to reach a size and population capable of producing surplus honey that can be taken to market, while in the interim, the absence of a large bee population (pollinators) will make it difficult for plants to pollenate and produce fruit (Organic Grow 2013).

More than just Crucian farmer's capacity to produce food, the storms have also taken away their ability to bring produce to markets. In addition to difficulties associated with debris filled roadways, market spaces were also devastated by hurricane Maria. As of December 2017, the grounds that traditionally host the island's annual agriculture fair were in terrible disrepair. "The hangar like buildings, usually filled with locally grown crops, no longer have roofs [and] the yellow, wooden booths where vendors sold dishes lie crumpled" wrote CNN's Cassandra Santiago (Santiago 2017). The level of destruction prompted Virgin Island's Department of Agriculture (VIDOS) Commissioner, Carlos Robles, to cancel the February 2018 event, for the first time in 46 years (Santiago 2017, Ellis 2017). Though the community and event sponsors eventually rallied and rescheduled a somewhat smaller scale event for May 2018, other nearby markets and produce stands were not so lucky, with the storms wrecking stages, merchant frontage, and public spaces (Staff Writer 2018, Ellis 2017).

Interviewees who were old enough to recall also made frequent call backs to hurricane Hugo, a category 5 hurricane which struck the island directly and with terrible force in 1980. Virtually every interviewee who was alive during the storm, (making them at least 41 or 42 at the time of survey, and in many cases far older) referred to this historic hurricane with either firsthand observation or through the sharing of secondhand accounts. Collectively these interview partners recalled the island wide destruction it caused, including downed trees, demolished houses and roofs, the loss of life during and after the storm, and the painstaking aftermath as the communities on the island attempted to recover.

Beyond water stress and hurricanes, only a few of those interviewed shared concerns over the health and preservation of St. Croix's soil systems. Though each interviewee was asked about their perceptions of soil conditions, and environmental concerns related to soil such as erosion (soil loss), or overall soil fertility, only three of those interviewed (one environmental activist, one government official, and one farmer/proprietor) responded with concerns pertaining to soil systems on the island. The activist mentioned soils in the context that she encouraged, and sometimes helped farmers who particularly needed it, to have their soils tested at a lab. This was in cases she said, where an area's possible contamination with heavy metals may be necessary, or where there is value to checking in on nitrogen and phosphate levels in soils to identify appropriate soil amendments. The activist opted not to discuss specific locations to help keep the identities of the owners of those areas private.

The interviewed government official who spoke of soils did so with regard for the Natural Resources Conservation Service (NRCS), an agency which serves under the United States Department of Agriculture (USDA), managed programs which relate to soil and water

conservation. “The NRCS cost share program” stated the government official, “is a territory wide cost share program with a screening and an application process, whereby they provide support to land managers with the installation of irrigation systems, the laying of pipelines, and mulching, and cover cropping of their lands, mostly with sun hemp”. Mentioned, in a proactive sense, this official promoted the available government program on St. Croix, which offered financial, technical, and physical aid towards the modification of agricultural fields, so long as they were focused on conservation practices, including the adoption and practice of contour farming.

Lastly, Hans Lawaetz, owner of Annaly Farms Inc. and longtime rancher, agriculturalist, and conservationist, volunteered a tremendous amount of concern for the soils on the island, having played a particularly large role in the stewardship of the island’s soils between 1965 and 2002 when he served as a chairman and or board member of St. Croix’s Conservation District. “After 1972” said Hans, “anyone who wanted something [groundworks] done [on the island] had to submit a permit to us, and a federally paid technician [from the Soil Conservation Service] would review the project, and then [conservation] district volunteers would sign the permit, and the person could go ahead with the project, along with any mitigative measures [i.e. cover cropping or contouring] that were required”. Hans said he signed hundreds of permits between 1972 and 1986, until the federal government’s Coastal Zone Management (CZM) agency came into the picture on the island, with a mandate to protect land sloping to the sea. With the coming of CZM to St. Croix, Lawaetz saw no need for two agencies to oversee the permitting process, so he yielded the duty to the CZM. “But while the district of conservation’s review included a federal round of review and oversite” said Hans, “you didn’t see that happen through CZM reviews of applications, instead it went through local review only, which was great, but not necessarily putting the reviews in the hands of those technically trained in the fields of erosion and or preservation.” Ultimately Hans said that soil conservation is “a matter of how it’s being done and enforced, because you can pass all the laws you want, but it’s a matter of enforcement”. He pointed out that “the technicians that evaluate [permit applications] need to be well trained, because when you evaluate these permits … we… recommend improvements to your plan. We’re gonna try and make your plan better than what was submitted to us, so if you don’t have that technical input or the education to provide that information then you know its [the protection] just isn’t there”.

Beyond his description of management efforts in the past, at the time of our interview Mr. Lawaetz also mentioned an extremely acute and immediate concern regarding soil erosion on a property adjacent to his own. Evidently, Mr. Lawaetz’s neighbors to the north were mechanically clearing ground on a slope leading down to his property and were apparently doing so without a permit. “Right now something is going on where the hill outside, that hill is being cleared and roads are being put in and all that land is being cleared since the 1st of May, and I live right across the road and no one ever showed me a permit” said Hans. “As a neighbor I should be able to have some input… but we haven’t seen the plan … there’s a group of individuals who are supposed to review the permit, review the plan and how these roads are going to be built, and where the waters going to run to, and that should be that.” But at the time of the interview, and after five full weeks of ground disturbance, only now, was there a permit number visible on the property. “You are concerned about conservation during the cane days” said Hans during our interview, “and what I’m concerned about is about conservation today.”

Information Pertaining to Current Perceptions of Past or Present Human Actions, or Natural Events or Processes, that have Led to Today's Environmental Conditions

With interviewees consistently identifying the acutely felt water scarcity as the top environmental concern on the island today, but failing to identify a connection between these conditions and sugar planting in the past, I was compelled to revise the project's research trajectory. This prompted a shift in the interview questions, with a move towards a series of inquiries pertaining to currently held beliefs and understandings regarding more recent causes of the island's 2022 drought (Marshall 2002, Atalay 2012). Bringing the project's research questions more into alignment with the community's contemporary concerns, these efforts resulted in an outpouring of community member's environmental perceptions, fears, and frustrations (Simpson 2010). In response to this revised set of questions interviewee responses ranged a wide gamut spanning from "chem trails," "global warming," and "God's mysterious plan". "You can call it climate change" said Mr. Lawaetz, "but I moved cattle out of the Creque dam area in 1999, so what you see now is a lot of bush, so you have trees that have roots going down 20 ft [(6.1 m)], before it was grass with roots going down a foot. So, some of that could be part of the problem, as far as the water table" he said.

A more often repeated line of reasoning shared by several of those interviewed, however, consisted of a combination between an increasingly common reduction in annual precipitation, and a lack of sufficient governmental oversight of the catchment, conservation, and management of any water that does manage to fall from the sky. By way of unsolicited description, five of the farmers interviewed for this project, one of whom was Mr. Hans Lawaetz, and an additional interviewed government official, all referred to the inadequate maintenance of the island wide series of water detention ponds which had been constructed by the Virgin Islands Department of Agriculture throughout the mid-twentieth century as part of the present-day problem of water stress. "The island's primary catchments," said Hans Lawaetz, were/are "the farm ponds." He continued, "in the 50s, 60s, 70s we were building ponds to restore the water, to increase the water table, and at the time, SCS, the soil conservation service technicians, would design the pond and VI Agricultural Department would build the pond at no expense to the farmers." Hans then told the story of how his father and uncle oversaw the construction of two large ponds in the early 1950s which he pointed out was, "when the government provided assistance, because," he said, "making a pond isn't a cheap deal. It needs to be able to handle the amount of water from the spillway and watershed it sits within." During our conversation Hans also mentioned that there were over 150 manmade ponds on St. Croix. "We've had 7 inches of rain in 7 hours" he said, "so lots of flooding, and we had those problems going from no rain to flooded [in short order]." The key, he contended, was to develop detention ponds so that these sudden and heavy rain waters could be captured and kept in place long enough to recharge local aquifers. But now, says Hans, these ponds were filled with silt. "Federal technicians would design the pond" said Hans, "and would build the pond at no expense to the farmers. Unfortunately," said Hans, "none of that exists anymore, and unfortunately not all of those ponds were appropriately maintained and are not serving in the real capacity they should be now. Many of them have filled with silt and not been properly maintained."

Indeed, these ponds, along with their developed catchments, and water delivery systems that connect catchments to these detention ponds proved to be public resources. Almost all of the farmers interviewed reported using these public water resources on farms across the island in years past. These resources, noted project interviewees, were of particular value during times of

drought, to help farmers and ranchers secure sufficient water for their crops and flocks. At the time of interview, these pond systems were universally reported as "having been allowed to fail," filling up with silt and other natural and manmade debris including modern garbage. Locally understood to be the responsibility of the Virgin Islands Department of Agriculture to build and maintain, it is perceived that through a lack of oversite these water management features have been rendered incapable of capturing and transporting collected rainwater. When asked why the Department of Agriculture would simply abandon these vital resources, interviewees suggested that the department has not acted for two reasons: first, they believed that the agency was not receiving either government pressure or support from local legislatures, governors, or environmental agencies to maintain the ponds, and second, interviewees understood the department to be short staffed, and seeking to systematically wean the local population from the agency's public services.

Alluding to additional governmental inefficiencies in the realm of environmental services, Hans Lawaetz also pointed out how ineffective the conservation district of the Virgin Islands had become in recent years. "The problem with the Virgin Islands conservation district, is we have 3 islands, but one district… and the district board hasn't convened since I left [the board] in 2002". The "board has not existed" said Hans, "and they're working on it…but the nominated individuals serving on the board are supposed to go to the legislature for a hearing, so the legislature can interview those individuals to see if they are interested and sufficiently knowledgeable about those subjects." When asked why the conservation district might be struggling to organize, Hans responded, "I don't know what's changed because at that time [the 60s, 70s, 80s, and 90s] we had active people who wanted to participate and would come to meetings, and we had a quorum. Now we can't even get a quorum, and there's where it hangs up, is finding people that can afford the time and devotion to do it, because it's not a paid job, it will take you eight hours of time but you could be having to come [to conservation district board meetings] from the other island, and it's an eight hour job".

Several of those interviewed also blamed more recent urbanization on the island (which was identified as having been an issue from about 1970 onward), and the subsequent overuse of St. Croix's aquifers through unregulated private well drilling as the cause of the island's acute drought conditions. When asked about the possible causes of current water stress on the island, one government official responded, "drought on the island has lasted for the past several years, and also over the past 30 years, more houses have been built and lots more ground water has been tapped for the purposes of supporting that housing." One of the interviewees also relayed a story about a company on the island that had drilled water wells to excess depths, to enable them to draw more than their fair share of water. This was only possible, claimed the interviewee, due to the lack of sufficient regulation and enforcement regarding the development of new wells.

What was not on the minds of those interviewed was some form of cause-and-effect relationships between the sugarcane industry of the past, and presently experienced water stress. At the suggestion that centuries of sugarcane planting, accompanied by mass land clearings (which might be responsible for changes in precipitation patterns through deforestation) and/or that the sugarcane crop and sugar refining industry's tremendous thirst for water might be responsible for a disruption of the water table and the dryer conditions noted on the island over the last few decades, interviewees responded with sentiments ranging from a neutral stance, to skepticism, to all-out disbelief and disagreement. Four of the famers interviewed who were old enough to recall

the days when cane was still being planted on an island wide scale (during the 1950s and 60s), recalled that at that time, the ghuts (the local word used for creeks and streams) ran high, and that as children they would play in the waters of creeks and ponds near their homes. “We didn’t have these problems back then” said one interviewee. “The problems with water is because of the mismanagement of these [detention] ponds, sugar had nothing to do with it” said another. “In the 40s, there was water in the creek going to Creque Dam” said Mr. Lawaetz, “yea, that dam used to run with water.”

Originally constructed in 1926 by the U.S. Navy, Creque Dam has 45-foot-(13.7 m)-tall walls and can hold upwards of nine million gallons of water. Examined by the author in Summer 2019 and 2022, the creek leading up to Creque Dam was observed both before and during the drought. On both occasions, the creek was found to be nearly entirely dry, with little more than a trickle passing through a check dam some hundred meters upstream of the dam and reservoir, with a completely exposed and heat-cracked creek bed.

Information Pertaining to Current Perceptions on What is Being Done in the Present to Mitigate Current Environmental Concerns

Having unequivocally vocalized a sentiment that water shortage was the leading environmental concern on the island, not just presently, but for the last 20 years or so, farmers that were interviewed regarding mitigation measures to current environmental concerns focused their answers entirely on the steps being taken to combat drought. Several farmers shared (sometimes in person) the counter measures they were taking presently and had taken in the past to steel themselves and their farms against times of water scarcity. Many interviewed had expended time, effort, and funds sorely needed elsewhere on their farms to build cisterns and storage tanks, dig private wells, and develop Hügelkultur (or mounded crop beds) and or drip irrigation systems to efficiently extract, store, and deliver water to support growing produce. While private plastic cisterns proved to be a common sight on the island, and an item possessed by virtually all those interviewed, I found that several of the farmers I spoke to also possessed additional water storage tanks and that several farmers had been forced to invest in private wells that also required the installation of electric pumps. In years past, these pumps could have instead simply been tapped into local detention ponds to bring water to private residences, but as the public ponds have since dried up, private drilling has become more of a necessity. Speaking to two midsized farmers who had invested in electrical pumping systems to work private wells excavated on their property, I learned that even those with the capacity to install these counter measures were still not collecting enough water. “I purchased the well and pump system to draw 800 gallons a day, I’m lucky if I see half that” said one farmer. “Despite these pumps I still find myself frequently without enough water to water all of my crops,” said another. When such expensive mitigation measures still fall short, Crucian farmers have few options.

One farm in particular, ArtFarm LLC, located in the southern plain of the island and not far from the island’s southern coast, has gone to great measures to protect their farm and crops from the effects of drought. Owned by Luca and Christian Gasperi, ArtFarm is an organic commercial vegetable and fruit production farm on land at Longford. On July 30, 2022, I had the opportunity to visit Luca on his farm and to engage in conversation about the history of the farm and local weather, as well as discuss his forms of land use and water management strategies. Luca was born in 1973, to an Italian father. For 60 years his family has owned this farm, though his father also kept a large number of cattle on their lands. When I asked Luca about what he knew of local

precipitation patterns, Luca recalled family "pictures from the 1970s which show pastures, fields, kasha and dirt". It was "very dry" he said, sharing that his father always told him "big rains in May" throughout his youth. Corroborating this memory, Luca also recalled that "there used to be a triathlon on the island in the spring, and that was right before a 4 inch [rain] event". He also mentioned remembering sizeable rainfall events that would come in February which came from the south and "covered the farm, raining 2.5" inches in an hour." The storm "then went over to Judith's Fancy (a region of the island near the northern tip) and then out to the sea [where] it caused a bumper crop in the short term but proved to be a very isolated shower". These kinds of rains mentioned Luca, "only have a month or two-month effect," as did "[Hurricane] Maria" he said. In the twentieth and early twenty-first centuries though, Luca shared that whereas there was once usually enough rain in fall such that he doesn't have to water for a month, "this hasn't happened" he said, "for the last two years… it's when the central part of the island that starts to dry up, that panic sets in [on the island]" said Luca, "and that's how it was just recently before the late June showers". This most recent drought forced Luca to make the unpleasant decision of allowing several of his mango trees to die which take a lot of resources to replant. He also lost a lot of citrus trees and coconut trees in the drought and pointed out that fig trees were unable to survive in a drought. Conjuring memories of similar stories in his past, he shared, that "the 2015 drought was really bad" as he pointed out the areas where he lost 20-foot-(6.1 m)-tall established mango trees that did not receive enough rainfall to survive.

Such fruit trees can take years to mature, and represent significant investments in startup costs, time, and water resources, not to mention the opportunity cost expended to dedicate the land and water resources to fruiting trees rather than shorter term leafy crops which ripen and can be brought to market sooner and more frequently. Indeed, the costliness, startup time, and challenges in losing trees to drought and or severe storms in the pursuit of fruit tree farming, was mentioned by two more of the farmers interviewed who lost fruiting trees, or who had family members who had lost significant numbers of fruiting trees, causing them to give up that line of agriculture for good. This harsh reality was also made quite clear in the aftermath of Hurricane Maria in 2017, when local farmers were obliged to resort to growing leafy greens, and quick growing but annual or semi-annual ground crops, after the storm ravaged many of the fruit trees on the island (Ellis 2017).

"So, what do you do to conserve water?" I asked Luca, "what do you do to keep your crops alive when it simply refuses to rain?" These questions prompted Luca to show me the three water detention ponds he has overseen the development of over the years, each designed to temporarily store rainwater when it actually does fall. It turns out that Luca has a permit from the Department of Parks and Natural Resources (DPNR) to keep three ponds, which can hold a combined total of some 460,000 gallons of water. The oldest of his ponds holds 250,000 gallons on its own. Luca explained that this pond was built through a partnership with the Department of Agriculture. Back during his father's era of running the farm, engineers from the department would come out and dig these ponds. At that time, said Luca, "the department would provide the design expertise, the excavator, and the manpower necessary to construct the pond…but this is no longer the case". A second more modern 150,000-gallon pond, which was installed at the expense of ArtFarm, is covered with an ethylene-propylene-diene-monomer (EPDM) liner, and as a result can very efficiently collect roughly 5,000 gallons during a 0.5" rain event. Lastly, the smallest of his ponds was developed with funds obtained from a grant from the World Central Kitchen, a nonprofit organization which in the past has provided support for Caribbean farmers, fishers, and

food producers to help secure local capacities food security, sustainability, and resilience against future disasters (World Central Kitchen 2022). This grant funded an unlined detention pond that "can hold about 60,000 gallons when full" Luca said. "We are also seeking to build up towards 80,000 gallons in cisterns storage capacity" said Luca, "but we aren't quite there yet".

These ponds need maintenance, Luca explained, with the large one "needing to be cleaned out every 12 years or so". To get this done, the farm is "reliant on the Department of Agriculture" he said, while pointing out that this could be tough, as the department worked on "their own timetable". Short staffed, under equipped, and facing a large and needing public, department support will get here when it gets here. "One month before and during the agricultural fair" said Luca, "they don't do any work," likely because they simply do not have the capacity to perform this kind of maintenance across the island. Realizing he's on his own, Luca has maximized the efficiency of ArtFarm's three ponds to preserve water well after the rains have subsided. To do so he's developed and installed a custom-built electrical pump system, which drain these ponds shortly after rain events, and transport the water into large cisterns for later use. This two-step process actively protects fallen rainwater from evaporation, ultimately ensuring that even more water is conserved.

A second element to ArtFarm's water management strategy lies in the use of roofs that have been designed to function as water catchments. All the roofs on the property, including the main house, side house, and collection of sheds and other ancillary structures on ArtFarm are equipped with these roofs, with runoff directed into rain barrels and, in some cases, directly into larger cisterns or storage tanks. These roofs were installed across the farm at the proprietor's personal expense, but now help Luca, his wife, children, and father, collect and preserve even more precious water when rains come.

A third component of ArtFarm's water management strategy is the implementation of Hügelkultur, or "mound culture," which is the use of raised plant beds that are built on top of decaying wood debris and other compostable biomass (Luo et al. 2020). A farming practice used by German and European farmers for centuries, Luca went out of his way to learn and try out this European practice on his own farm (Luo et al. 2020). Well-built Hügelkulturs form a self-watering and self-composting raised garden. Essentially, the deeper, but somewhat porous subterranean component containing midsized to larger logs, the hügelkultur leaves room for both the collection of rainwater, and then the means to slowly absorb and retain that rainwater for future use by the raised bed. Using hügelkultur beds and wicking beds (built on the same principal as hügelkultur beds but using plastic instead of reused wood on the inside) on the central part of their farm, the owners of ArtFarm have had years of success raising healthy and profitable produce with this method. Luca said that during and after the losses of the 2015 drought he adopted this water management tactic.

Finally, a fourth component of ArtFarm's water management strategy is making deliberate choices in the crops he farms, making sure they match the harsh realities of St. Croix's now drier environment. Having lost so many trees in the 2015 drought, he no longer plants mangos, citrus, or coconuts, but has found more success with pineapples and dragon fruit. "Pineapple is fairly drought tolerant" he said, "though it needs more water when fruiting" and that is when the water tanks and cisterns come in. Luca also said he makes use of sunn hemp (*Crotalaria juncea*) and sword bean (*Canavalia gladiata*) as cover crops, which are relatively drought tolerant, not water

hogs themselves, and are easily removed when it is time to plant the next round of crops. In this way, by being planful about the crops planted, the farm places a strong emphasis on water conservation, ensuring that preserved rainwater is put to the most efficient use possible; serving drought tolerant (or at least drought-minded) plants.

Beyond merely choosing what crops to grow, Artfarm also places plants strategically and with intentionality on the landscape. This allows them to draw from a usually dry creek that runs through a segment of the property, and often means they avoid the placement of plants in areas with steep elevation and or poorly drained soils. To this effect Luca has planted fruit trees and grasses along either side of a ghut which runs from north to south through his property to support its development and to help retain the water it occasionally carries downhill. However, the ghut is also problematic for him as when it occasionally floods water pours over onto the flat plain which forms the western half of his farm. As a result, Luca has dredged sands from the riverbed of the ghut and has used them to build berms along the west side of the ghut to protect against flooding. To further ensure against this flooding becoming a problem Luca also keeps his fields in grass when they are not actively being cultivated.

Not every farmer on the island is as fortunate or as crafty as those who own Artfarm however, and many on St. Croix cannot afford, construct, and or implement equivalent water conservation measures on their farms. Detention ponds like those at ArtFarm can cost up to and over $10,000 simply to install, and that includes assumed assistance from the Department of Agriculture and does not include the costs associated with the construction of and maintenance of the water tank storage and piping systems necessary to harness and properly manage the water these ponds can collect.

Despite their advantages, the proprietors of ArtFarm are still not beyond the reach of the effects of a severe drought. In times when Crucian farmers run out of water, they have two options. First, they have the option to collect up to 5,000 gallons per week from the U.S. Agricultural Station (USAS) located in the middle of the island at no cost. Second, they can purchase water delivery from the local municipal water company (WAPA). Neither option, however, is realistic. While the water at the USAS is “free” to anyone who would claim it, to obtain this water farmers must have their own containers to hold it and their own capacity to transport it back to their farms. According to Luca “when things got really tough,” like a temporary or extended drought, the Department of Agriculture water supply was “not reliable,” which led him to start collecting and storing water from the service in advance so that he could be certain of having some water on hand in an actual crisis. The purchase and maintenance of such containers, let alone the vehicle(s) needed to haul them, are also costs that many strapped farmers on the island are not able to take on. Similarly, taking private sector water deliveries from WAPA on a weekly or monthly basis is not a financially viable solution for agriculturalists on the island. As of the summer of 2022, each delivery costs $250, and provides only 5,000 gallons of water. With weekly water needs in the tens of thousands of gallons on even five-acre parcels, such costs for water delivery would make it impossible to turn a profit on agricultural efforts.

On June 25th, 2022, I was speaking with several farmers at their booths at the island’s Saturday Weekly Farmers market located at the St. Croix Agricultural Fairgrounds. On this day the first rain of the summer hit the island, and I had a chance to hear from a few project participants as the rain was still falling. There was no question that those interviewed were more at ease, and

they spoke with smiles on their faces as rain carried by a light wind wetted wooden tables and carefully placed produce lying under the overhangs of their stalls. “How are you feeling today?” I asked some of the farmers. “During really big storms, or when we get steady rains” said one participant, “this ghut here, flows,” referring to the creek just behind his stall at the market, which was approximately six meters wide and over two meters deep. “It’s going to take a lot more than this morning’s rains to put us right,” he said.

Information Pertaining to Current Understandings of How Sugarcane Was and Still Is Planted on the Island

Two of the farmers/proprietors interviewed had direct experience planting, maintaining, harvesting, and selling sugarcane. The first of these farmers was encountered at the weekly farmers market, actively selling freshly squeezed cane juice (and a few other juices) to paying customers. When asked about his juice business, and the origin of the sugarcane, he shared that he kept “a few cane plants” on his approximately 0.25-acre farm. These cane stocks were strictly grown and used for immediate sale, either as pressed juice, or as a sliver of raw (but skinned) cane, a sweet treat sometimes enjoyed by children and tourists. Though he owned a small, portable, commercial press which he used at the farmers market, he never pursued the production of muscovado sugar. When asked about the methods by which he planted his sugarcane, the farmer confirmed that he planted the cane in furrows but did not comment as to the use of contours in the selection of planting locations, the use or removal of “cane trash” from the crop, and the means by which the cane field was prepared or maintained during intercrop periods. When asked how long he had planted cane, he said that he picked it up in his 20s or 30s out of an interest to sell the juice but did not specify from whom.

The second farmer/proprietor who managed sugarcane that I interviewed was Mr. Hans Lawaetz, lifelong rancher and farmer, and owner of Annaly Farms Inc. In response to questions regarding his familiarity with sugarcane planting on the island, Mr. Lawaetz volunteered that he and his family kept 300 acres in sugarcane on their farm close to the highest point on Mahogany Road (in the northcentral portion of the island) in the 1930s, 40s, 50s, and early 60s. “We had sugarcane up there in the 40s,” Hans reminisced. “We had oxen carts taking the sugarcane to a hoist that’s operated by a mule that would bundle the cane and put it on trucks.” When asked about the particulars of planting, maintaining, and harvesting cane, Hans had quite a bit to say. “During my dad’s time,” he stated, “everything needed to be done in contour [contour farmed] and in fact we made use of the subsoil using a tractor and subsoiling every 20 feet [(6.1 m)] or so to retain water on the hillside because we were realizing poorness of water in that time… [and] the plants were mounded, with a valley in between” (taken to mean planted in furrows). In terms of other notes on planting techniques Hans mentioned that he and his farther “planted [sugarcane] by the sprigs. The cane has knots, so you cut it where it has two knots, and then you plant that, and then by the knot leaves with spring up and you’ll get cane, so it had to be harvested, cut, and then planted that way”. When asked about how the crops were watered, Hans replied that there was “no irrigation, [it was] straight rain, and I think we usually harvested between February and March”. This was apparently based on the annual precipitation he and his father came to depend on in those decades. “We’d expect…always that it would be dry in January/February, we’d get rain in April and May, and its usually dry in June and July, and then it’d rain between August and December” making February and early March a great time to harvest. “Did you ever ratoon the plant?” I asked, “as in allow it to produce runners from a mature plant to produce the next generation? Or did you always plant from sprigs?” “Every five

to seven years" he said, "there was a replant." "And what about 'cane trash' management?" I asked, "would you leave it in the fields, collect it, or burn it?" "I think he [Hans's father] left it," said Hans. "It'd keep the weeds down to some extent; weeding is always a problem… we left the trash in the fields and to keep the weeds down."

Mr. Lawaetz also went into some level of detail regarding who worked in the cane fields on his property. "When I came back [from the Air Force in 1964] we had at least 300 acres of sugarcane here on Annaly farms, and my father and I needed to bond 40 employees from British islands like Nevis and Anguilla, that's where my people were coming from, and others were hiring from French islands, and other farms had them coming from St. Kitts and St. Lucia and other places, and we had to bond these people, which meant that I was responsible for them when they were here, and I would have one of my guys go by sailboat and pick up these people to Christiansted and I would meet them at the immigration, health department, and customs, and all this, and I had housing here on the ranch to house all these people, barracks actually, and I had to provide electricity and water. They were here for three months to harvest the cane. And then they were going back to their island, but then about this time, the courts passed a law that at some point they required a green card and then they were allowed to bring their wives in and then they were allowed to bring their kids in."

Two of the other farmers interviewed for this project also shared secondhand knowledge about sugarcane cultivation on the island by telling stories about their parents who worked at least part time in cane fields. One farmer shared that his mother and father who worked the cane fields, were born in St. Kitts, and for years, would travel to St. Croix only during cane harvest seasons to work in the fields on the island cutting cane, and bringing it to the cart. Another farmer, when asked about what she recalled, shared that she remembered that her father had originally jumped around various islands looking for work, and moved here from St. Kitts after working for some seasons on cane fields here. In both cases, current farmers recollections about their parents work in cane fields, included reports in the planting of cane in furrows, the use of machetes in the cleaning of cane stocks of debris, and the chopping of cane at its base. Once cut, the cane was reportedly put on horse drawn carts or trucks, to be taken to the Bethlehem Sugar Mill and refinery, located in the center of the island. Further queries into what these farmers recalled about their parents work in the sugarcane industry did not yield any additional information.

Chapter 4. Ethnohistoric Results: Information from the Jack Delano FSA Photograph Collection

Intended to supplement the information gathered from conversations with locals pertaining to St. Croix's historic sugar planting practices, I examined the Jack Delano FSA photograph collection from St. Croix, held at the U.S. National Archives, in spring 2023. During this analysis I visually inspected each of the 461 photographs in the Delano collection for traces of sugarcane cultivation and processing, as well as depictions of cane farmers, and related land uses and conditions. These efforts provided several insights into the ways in which sugarcane was planted, maintained, and harvested, and revealed the conditions of landscapes on which cane was planted across the island during the early 1940s. The results from this visual analysis are presented below and organized by category of information provided. The categories include: the maintenance of cane on the island in the 1940s, depictions of field laborers and agricultural implements, broader understandings of landscapes and land uses, and the apparent scale of sugarcane processing. While all 461 photographs within the Delano collection were examined, those photographs explicitly referenced in this research have been included following the paragraphs in which they are first referenced.

The Maintenance of Cane on the Island in the 1940s

Within the photograph collection, no fewer than 15 distinct scenes of sugarcane cultivation were captured via either black and white or color photograph. While not always the intended focal point of the photograph, these depictions reveal several aspects of sugarcane cultivation on the island, including planting, cane maintenance, and harvesting practices. The cane fields captured in these images depicted sugarcane fields in various stages of development including freshly planted, sprouting, and ready for harvest, as well as cane fields actively being harvested, tilled, and planted. "Cane trash" (or the trimmed/pruned leaves of sugarcane that are discarded during harvest) was notably absent within each photograph showing cane fields in sufficient detail to reveal ground surface inclusions (Figure 2 through Figure 11). Large piles of ash or charcoal, or even significant discolorations hinting at such, were also markedly absent from the same group of photos depicting the ground surface of cane fields, suggesting that "cane trash" in St. Croix was neither burned off prior to cane harvesting, nor cut off in situ during the harvest and set afire after the cane stocks were removed. These two details taken together strongly suggest that the local practice consisted of the physical removal of "cane trash" by field laborers during Crucian cane harvests. In this case the removal of leaves and other debris from the cane stock might have been completed in situ but cleaned up by hand during the harvest, or the separation of stock from leaves might have been deferred until the cane was either about to be loaded onto the cart, or once the cane had arrived at the location where it would be juiced. The absence of "cane trash" on the fields suggests that at least early to mid-twentieth century sugarcane planters on the island did not take advantage of a low tech but potent natural tool that helps against rainsplash damage to their cane field soils, and which might have also helped protect water within cane field soils from evaporation in the island's severe heat. Moreover, the absence of charcoal and ash from the depicted fields also suggests that fire was not a tool frequently used by cane planters on the island, and that local cane fields were not likely to be frequently replenished by nutrients commonly found in plant ashes including magnesium, calcium, potassium, and phosphorus.

Figure 2. Women cultivating sugar cane on land owned by the Virgin Islands Company, Bethlehem. Saint Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797440. Accessed at https://www.loc.gov/item/2017797440/.

Figure 3. Cultivating sugar cane on the Virgin Islands Company land, vicinity of Bethlehem. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017878942. Accessed at https://www.loc.gov/item/2017878942/. Note the absence of "cane trash" in the field and use of hand hoe.

Figure 4. Planting sugar cane on the sugar plantation along the northern coast of the island. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797327. Accessed at https://www.loc.gov/item/2017797327/.

Figure 5. FSA (Farm Security Administration) borrower cultivating his sugar cane field. He lives in one of the homestead houses. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797403. Accessed at https://www.loc.gov/item/2017797403/. Note the absence of trash on the field, dry soils, and farmer's use of a hand hoe to till the fields and create furrows.

Figure 6. FSA (Farm Security Administration) borrower's wife cultivating recently planted sugar cane. St. Croix, US Virgin Islands. Library of Congress, Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797235. Accessed at https://www.loc.gov/item/2017797235/.

Figure 7. FSA (Farm Security Administration) borrower's wife cultivating their farm. La Vallee vicinity. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 201779325. Accessed at https://www.loc.gov/item/2017797325/.

Figure 8. Cultivating sugar cane of the Virgin Islands Company land, vicinity of Bethlehem. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017877852. Accessed at https://www.loc.gov/item/2017877852/. Note absence of "cane trash" in field and use of hand hoes.

Figure 9. Cultivating sugar cane on the Virgin Islands Company land, vicinity of Bethlehem. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017877857. Accessed at https://www.loc.gov/item/2017877857/.

Figure 10. FSA (Farm Security Administration) borrower and his wife cultivating sugar cane on their farm, Frederiksted vicinity. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797364. Accessed at https://www.loc.gov/item/2017797364/.

Figure 11. FSA (Farm Security Administration) borrower plowing his garden with one of the few plows used on the island, Frederiksted vicinity. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797401. Accessed at https://www.loc.gov/item/2017797401/.

In terms of the management of the sugarcane plant itself, seven photographs depicted either fields that were soon to be, or currently in the processing of being planted, or fields containing young cane plants, suggesting the fields were planted no more than four months prior (Figure 2 through Figure 9). Though perhaps not Delano's intent, these photographs revealed that the cane he photographed was planted from trimmed, and perhaps cured or cultivated segments of previously harvested sugarcane, rather than either planted from seed, or "ratooned" from a previously harvested cane root allowed to stay *in situ*. The presence of visible cane plants within even recently planted fields, as well as the excavation of pits in which trimmed cane segments could be planted, strongly suggest this was the observed planting practice on St. Croix. In one instance a farmer is even photographed in the act of planting a trimmed cane segment on his recently plowed field (Figure 4).

Several photographs in the series also depicted deliberately constructed furrows, suggesting the widespread use of furrows for sugarcane agriculture on island (Figure 2 through Figure 12). While it is difficult to know for sure as there were no scales in the images, by estimating the field laborers depicted in the photographs as between 5 and 6.5 ft (1.5 – 1.98 m) tall, the furrows depicted in these photos could measure between approximately one foot (0.30 m) and two feet (0.61 m) wide by one half foot (0.46 m) to two feet (0.61 m) tall at maximum. In all but one of the pictures depicting sugarcane fields, the cane stalks are shown as being planted between approximately two (0.61 m) to three feet (0.91 m) apart. Another important detail of field management gleaned from the visual analysis is that sugarcane fields are never depicted within

the photographs as being irrigated. Instead, the sugarcane appears to be strictly rainfed. Nowhere in the collection are there depictions of irrigation ditches, locks, dams, gates, hoses, pipes, water works, water buckets, or carts carrying water. This would suggest that sugarcane on the island relied on the ebb and flow of St. Croix's annual rainfall to grow to profitable size. The lack of irrigation depicted also helps explain the use of furrows as depicted within Delano's images of the cane fields. These furrows were designed to retain naturally deposited water and could be placed to support the crop. By placing them along contours of a landscape these furrows could act to both channel rainwater to plant roots, and to encourage soil retention from the natural movement of rainwater.

Figure 12. Puerto Rican farm woman on her farm where she has planted sweet potatoes between rows of sugar cane, Christiansted vicinity. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797249. Accessed at https://www.loc.gov/item/2017797249/.

In terms of overall field management, cultivated fields depicted are relatively level, with only one photograph depicting even a slight slope. In addition, fields adjacent to those shown in cane cultivation are frequently seen with cane plants in different stages of growth, suggesting the rotation of plantings, and potentially even alluding to different fields being given rest in between harvests, or after a certain numbers of harvests. This appeared to be especially true in Figure 3 and Figure 4, and Figure 6 through Figure 15. In these images multiple fields are depicted in a single frame and in some cases cane fields in the foreground and background appear to be in different stages of growth. Similarly telling, was that no evidence could be found within depictions of cane fields that would suggest the use of cover crops in between harvests and plantings (Figure 2 through Figure 15). Cover crop usage would have been evinced through the presence of small leafy green plants, potentially including but not limited to, clovers and or guinea grass, or their churned up remains within recently plowed, or planted fields, or recently harvested, but not yet tilled fields would have been depicted, but no such evidence was

encountered. This might suggest that cane fields were either left fallow and exposed to rains and sun based drying throughout the fallow portion of the crop cycle, or quickly tilled and replanted shortly after harvest. In either case, the nutrient fixing and soil protecting practice of cover cropping is not depicted within the Delano collection.

Figure 13. Sugar cane fields on the north-west part of the island. St. Croix, US Virgin Islands, Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017877861. Accessed at https://www.loc.gov/item/2017877861/.

Figure 14. Sugar cane fields on the north-west part of the island. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017877862. Accessed at https://www.loc.gov/item/2017877862/.

Figure 15. Sugar farms along the northern coast. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017877839. Accessed at https://www.loc.gov/item/2017877839/.

Depictions of Field Laborers and Agricultural Tools and Implements

Unfortunately, none of the names of the field laborers photographed by Delano are known. What little descriptions and captions Delano provides with each of his photos are relegated to brief, somewhat vague, geographic descriptions such as "vicinity of Frederiksted," "vicinity of Christiansted," or "plantation along the north shore," and perhaps a few words about what the photo shows as pertains to his FSA based mission on the island, i.e. "FSA borrower's wife cultivating recently planted sugar cane" (Figure 6). As a result, efforts to identify and learn more about the individual laborers in these photographs have thus far proven fruitless (Frandelle Gerard, personal communication, 2022). Nonetheless, there is still information that visual analysis of the Delano photograph series provides regarding the depicted field laborers and the field implements they used in the tending of sugarcane.

A review of each photograph within the Delano collection that contains depictions of sugarcane on St. Croix revealed that with only one possible exception (the woman described in Figure 12 as Puerto Rican), all the cane field laborers appear to be Black (e.g. of African descent), adolescent to middle-aged adults, including biological men and women, seemingly of nearly equal number. Nothing within the photos depicting field laborers within the Delano collection suggests that specific tasks were designated to members of a specific gender, with both biological males and females (as suggested by garb of pants for men, and a dress for women) participating in the full range of activities depicted. The photographs showed laborers tilling cane fields (Figure 2 and

Figure 3, Figure 6 through Figure 9, and Figure 11), planting sugarcane (Figure 4), weeding and maintaining cane furrows (Figure 5 and Figure 10), and harvesting crops (Figure 12).

In all but one of the photographs depicting the activities of tilling and or weeding and maintenance work laborers are seen universally using handheld hoes to carry out their work. These hoes appear to be made of cylinders of wood, some of which are seemingly pruned and cured branches, others of polished and milled wood, approximately one inch or smaller in diameter, and were found to be of varied length, though generally they appeared to be longer than the height of the laborer using it, suggesting they might have been six feet (1.83 m) or longer (Figure 2 through Figure 10 and Figure 16). The hoes appear to possess fastened, and presumably imported, metal blades or heads which affixed to one end. Such imports were readily available on the island in the late nineteenth and twentieth century with implements advertised on the island via pamphlets or brochures depicting a variety of farming implements for sale (Figure 17). Other tools observed include: a small knife, a horse drawn plough, and a horse drawn cart (Figure 4, Figure 11, and Figure 18 respectively). The horse drawn plough (depicted in Figure 11) appeared rare enough to photographer Jack Delano that he included in the description of the photograph “Farm Security Administration borrower plowing [sic] his garden with one of the few plows [sic] used on the island”.

Figure 16. FSA (Farm Security Administration) borrower who lives in one of the homestead houses. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797367. Accessed at https://www.loc.gov/item/2017797367/.

Figure 17. The Collins Company, Collinsville, Conn U.S.A. Brochure used in St. Croix in early 1900s. Reproduced courtesy of St. Croix Landmarks Society Archive at Estate Whim Plantation.

Figure 18. FSA (Farm Security Administration) borrower going to town in his Sunday cart. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017797289. Accessed at https://www.loc.gov/item/2017797289/.

Broader Understandings of Landscapes and Land Uses

Several of the photographs taken in the vicinity of the Bethlehem Sugar Works, (one of the largest plantations on island) help depict the scale of sugar planting on island during the early 1940s (*Figure 2*, Figure 3, Figure 8, and Figure 9). The Delano photographs also provide a good sense of the type and extent of ground cover that the sugarcane plant's canopy might have afforded cultivated tracts of land once the cane plant reached its mid-growth stage, and even more so as it approached, reached, and exceeded its harvest age and size (Figure 10 through Figure 15). By contrast, other images reveal just how barren and uncovered the fields would have been in times following harvests, in between harvest and tilling, between tilling and fresh plantings, and or between plantings and when the cane reached at least its mid-growth stage (Figure 2 through Figure 9). It is also clear from these photographs that the extent of clear cutting for the sake of cane development cannot be overstated, with the western half of the island having been nearly entirely covered in dense temperate forests prior to European arrival yet depicted in the 1940s as a landscape virtually devoid of trees in order to make way for thousands of acres of sugarcane and cattle ranching (Figure 13 through Figure 15 and Figure 19).

Figure 19. A cattle farm, vicinity of Christiansted. St. Croix, US Virgin Islands. Photograph by Jack Delano, December 1941. Image from Library of Congress Prints and Photographs Division Washington, D.C. Control number 2017877854. Accessed at https://www.loc.gov/item/2017877854/.

Chapter 5. Discussion: The Space Between Science, Historical Wisdom, and Lived Experience

Environmental research over the last 50 years has demonstrated that St. Croix, and many other Caribbean islands, face a difficult future. Based on measurements taken throughout the twentieth and twenty-first centuries from collection points across the region, the 2018 US Global Change Research Program's (USGCRP) National Climate Assessment (NCA) 2018 Report projects heightened sea temperatures, higher sea levels, ocean acidification, and significant atmospheric drying over the next 25 to 50 years. These projections, however, are being reported during an already environmentally volatile present. Since 1980 St. Croix has been ravaged by two category 5 hurricanes, one category 4 hurricane, and dozens of tropical storms. It has also experienced two severe droughts (one in 2022 and one in 2015) within the last nine years. In addition, federal and territorial coastal managers consider erosion off St. Croix to be a priority for protection and restoration, with eight of the 19 ambient monitoring sites managed by the Department of Planning and Natural Resources reading as "impaired" mainly due to land-based sources of sedimentation (VIWRRI 2012). In a batch of related studies on the island it was also revealed that several of the island's natural aquafers have become contaminated with salt water (VIWRRI 2012). Studies across the region have demonstrated that Caribbean island environments are the scenes of unstable soil conditions and distressed hydrological conditions, with concerns over erosion, decreased agricultural productivity, and the siltation of critical nearby coral reefs (Rawlins et al. 1998, Febles-González et al. 2012, Madramootoo et al. 1990, Madramootoo and Norville 1993, Metternicht et al. 2010).

While not all of these conditions are entirely anthropogenically induced, these documented physical conditions have been frequently explained by twentieth and twenty-first century historians, archaeologists, and natural scientists as impacts of centuries of European-driven sugar planting on Caribbean Islands (Ragatz 1928, Crosby 1972, Mintz 1986, Grove 1996, Watts 1990, Dunn 1973, Richards 2003, Lightfoot et al. 2013, Pratt 2015, Wells et al. 2017, Wells et al. 2018, Wallman et al. 2018). To seek out and document stories and firsthand accounts of potential connections between sugar planting and present conditions on St. Croix, I sought to learn more about Crucian traditions and practices in sugar planting, and to record local understandings of environmental history. A question I looked to answer was, do Crucians draw connections between the island's history of sugarcane planting and present-day environmental concerns?

Initially, I sought to collect information through oral interviews and dialogues with local farmers, activists, community organizers, and scholars who lived and worked across the island in a manner modeled after that of Rivera-Collazo elsewhere in the Caribbean. In Puerto Rico Rivera-Collazo's pro-actively engaged with and spoke to local landowners, property managers, farmers, and field hands to learn more about fist hand understandings of local environmental conditions and their possible antecedents (Rivera-Collazo et al. 2018). Through the deployment of a similar framework and methodology, my work in St. Croix sought to highlight the importance of local human memory, oral tradition, and community perceptions in the development of plantation environmental histories. Attempting to build upon the existing body of historical, archaeological, and scientific literature on the environmental history of St. Croix this project's interview questions were initially intended to collect information on Crucian sugar planting traditions and to help identify locations on the island which might show signs of connections between past sugarcane planting activities and present environmental conditions.

Very early on in the interview process, patterns began to emerge in the interviews I collected. It became clear that locals did not draw any particular correlations between sugar planting and local environmental conditions. Even when directly asked about the possibility of a link between the theoretically high impact of sugarcane on local hydrological and soils systems, with impacts that might be represented in contemporary issues of water stress and the siltation of nearby coral reefs, those interviewed did not share sentiments or beliefs that sugarcane agriculture caused these conditions. In fact, the results of interviews sometimes revealed quite the opposite. Four of those interviewed, each of which were experienced farmers on the island, and three of which had firsthand memories of when cane was still grown on the island commercially, expressed that they thought the widespread practice of sugarcane cropping likely helped the flow of local water. They expressed beliefs that clear cutting the land of what they considered to be "water hogging" trees for the purpose of sugar planting showed more respect for the natural systems of the island and thought that such clearances reduced overall siltation and pollution contributions to local rain-based runoff.

Surprised to hear these responses to questions about direct links between sugarcane and environmental conditions, but cognizant of the value of human memory and local understandings of the environment, I embraced some of the key elements of CBPR. This consisted of the realignment of some of the project's core research values with what were quite clearly the community's most pressing environmental concerns (Atalay 2012, Marshall 2002). Aware of the negative effects that more traditional archaeological and ethnographic works have had on traditionally under-represented groups throughout the twentieth and early twenty-first centuries, and seeking to help produce research that was more reflective of the needs and interests of local agriculturalists, activists, and environmentalists on St. Croix, I shifted the goals of the project from an investigation into sugarcane planting's potential for environmental impact to a series of inquiries into the community participants' environmental concerns in the present and local understandings of their causes (Atalay 2006, 2012, Marshall 2002, Moser et al. 2002). This shifted the priority of project conversations and interviews from learning about sugar planting's environmental legacy to learning more about locally held perceptions of contemporary environmental issues and their perceived and likely far more recent antecedents. What was revealed through this process, were local concerns and perceptions about a far narrower range of environmental concerns than those described in contemporary scientific literature, and a belief that the currently and acutely experienced environmental stressors on the island were human induced and quite distinct from the widespread adoption of sugarcane agriculture. Universally, all of those interviewed were focused on, if not profoundly preoccupied with, presently experienced water stress, and all but three of the project interviews and conversations included at least some mention of connections between currently experienced water stress and improper governmental oversight, regulation, maintenance, funding, or representation as pertains to water resource management.

Reminiscent of the narratives revealed by Justin Hosbey and J. T. Roane in their investigation of Black ecologies in the U.S. South and Chesapeake Bay region, I also realized that while the information shared by project partners may not corroborate nor entirely refute historically suggested connections between past sugarcane planting and current environmental conditions, the understandings being shared by project participants represented, if not outright furtive understandings of local environmental conditions and their causes, then at the very least expressions of values and concerns regarding water resources and their management which run

counter to those held by governmental agencies, developers, and contemporary scientific researchers (Hosbey and Roane 2021, Roane 2018, Roane and Hosbey 2019). Valuing the potential to hear more about these narratives which might run counter to the to those presented in historical, archaeological, and scientific literature focused on Crucian and Caribbean environmental conditions and their antecedents, I continued to work with local farmers, activists, and scholars from traditionally disenfranchised communities on St. Croix, to reveal divergent narratives regarding concerns over local climatic, environmental, and natural resource concerns (Roane 2018).

As a result, what began as an investigation into the sugarcane-based causes of present-day environmental conditions on St. Croix was transformed into an exploration of the space between the narratives presented in prevailing historical literature and contemporary scientific studies, and local understandings of environmental conditions. Whereas soil loss, soil nutrient loss, rising sea and surface temperatures, and the siltation of local coral reefs comprise the scientifically and historically "understood" environmental concerns of the island, these environmental concerns were notably absent from the narratives shared by project participants. Though soil loss (e.g., erosion), was expressed as a concern of Mr. Hans Lawaetz, soil was only mentioned by one other interviewed individual, who was herself, a soil conservationist and promoter of soil chemical testing to better understand phosphates and nitrogen levels to optimize horticultural pursuits. Instead, then, of the environmental concerns stressed within the pages of the 2018 NCA Report, those interviewed for this project universally shared that a lack of access to fresh and affordable water was not only their agricultural problem, but *the* environmental problem of the twenty-first century for St. Croix. Further, when asked what might have caused the currently experienced water shortage, those interviewed did not draw any connection between sugarcane's tremendous thirst for water, the islands' centuries long dedication towards the extensive planting of sugarcane, and the currently experienced water stress. Even when I outright suggested the potential relationship between sugarcane and water to local interviewees, many still did not agree that there was an explicit connection. A few respondents, in defiance of the connection, even offered memories from their youth and short stories shared by their parents, where readily flowing water in local ghuts, was common, right up to and, even after, the end of the cane era on the island (the 1950s and 60s). Instead, project participants shared alternative narratives about the causes and conditions of the island's current water stress.

Project participants were particularly vocal about more recent anthropogenic causes of the current water shortage. By far, the most frequently expressed belief was that the acutely felt water stress was the result of a lack of appropriate levels of government funding and support to service St. Croix's already extant water management and conservation infrastructure which includes an elaborate system of US Agricultural Service built water retention ponds (constructed in the 1950s, and 60s), cement water catchments, aqueducts, and piping-based water delivery systems, which according to many have been insufficiently maintained since as early as the 1970s. Several of those interviewed also attributed the island's drought to more recent leaps in local population growth during the 1970s, 80s, 90s, and 2000s followed by the installation of insufficiently planned, and or over zealously exploited wells, which now draw too heavily on St. Croix's freshwater aquafers and give them inadequate time to recharge.

Without necessarily contradicting scientifically supported explanations of St. Croix's environmental conditions, these shared narratives reveal something that is missing from the

conventionally held historical and scientific understandings of Crucian environmental history. While sugarcane may have played a role in the shaping of the island's environment, heretofore neglected perspectives on acutely felt water stresses demonstrate that from local perspectives increased funding of, and increased governmental oversight over, the maintenance of already extent water management infrastructure including retention ponds and water catchments is a readily applicable solution to at least part of the island's pressing water concerns. Additionally, oversight and regulation pertaining to on island water well drilling would appear to be a viable course of action to further protect St. Croix's already stressed aquifers.

Taken as a whole, the results of these interviews reveal how the gap between the narratives held by scientists and government agency researchers and what locals perceive to be the causes of, and potential solutions for, contemporary environmental issues represents an effective disenfranchisement of contemporary Crucian farmers, scholars, and activists from local governance and public services. Through interviewees' eyes, their need for water and water services, as well as the needs of *everyone* on the island are not being met, and notably, from their perspective, these problems are not the result of some long-ago practiced agricultural pursuit (i.e. sugarcane) for which nothing can be done, but instead, a contemporary issue with solutions that could be achieved through more thoughtful and better attuned local governance in the present. While scientific reports and conventional wisdom presented in governmental grey literature and scholarly works point towards a direct link between sugar planting and environmental degradation, a strict focus on these types of sources of information would prompt an understanding that ignores what are considered by locals to be clear and obvious connections between the shortcomings of public planning efforts, and in the construction and maintenance of public services, and the contemporary environmental stressors being experienced on the island.

Reconsidering the message shared by the 2018 USGCRP against the background of the local understandings gained through these interviews is telling. Though crystal clear on the certainty of the findings of various scientific studies collected throughout the twentieth and twenty-first centuries, and perfectly prepared to predict a worsening future for St. Croix and the rest of the region, the report includes surprisingly little in terms of what the inhabitants and governments of the affected islands can do to help mitigate against the current and future effects of human induced climate change and environmental degradation. The report recommends that affected cities deploy projects of urban planning that emphasize adaptable flood retaining cityscapes and green infrastructure (USGCRP 2018:839). It also encourages local farmers to use "the internet" to find adaptive practices for water management and heat stress in crops and livestock (USGCRP 2018:839). Finally, it strongly encourages more collaborative climate research, more regional risk and vulnerability assessments, and the development of early warning systems to support emergency decision making (USGCRP 2018:846).

What the report does not do, is identify sources of funding that can be used to encourage these changes, make clear which government organizations ought to be overseeing the adoption of these adaptive practices, or locate the nexuses through which these technologies and practices can be shared with local agriculturalists and developers. Even more troubling, is that this top/down style report, prognosis, and list of recommendations, leaves no room for those living on St. Croix, who are navigating and experiencing in real time the environmental conditions on the island. Within the report there is no acknowledgement of the lack of connection between St. Croix's governance and public services management and the people who need these services.

There are also no suggested remedies on how to bridge this divide or how to bring about meaningful change that will manage and refurbish already existing resources. Instead, the document prescribes independent research and recommends that actions be taken by small scale farmers to incorporate possible adaptive strategies. On St. Croix however, these prescriptions appear as though they would likely prove prohibitively costly or in-actionable due to a lack of available construction materials, access to the required construction equipment (including excavators and tractors), and labor. While the causes of and solutions to pressing environmental concerns might seem obvious to the scientific and academic communities, the juxtaposition between the messages of the 2018 USGCRP report and the stories shared by project interviewees reveals the space between science and lived experience, and demonstrates just how important it is that studies investigating the causes of present environmental conditions continue to include the communities which occupy the environments being studied. They, far more than others, are the most acutely aware of local environmental concerns of the day and are also quite likely to have opinions and ideas on what might have caused these conditions and how they might be fixed.

In addition to revealing the space between science, historical wisdom, and lived experience on St. Croix this project's ethnographic and ethnohistoric investigation also succeeded in revealing details about local sugarcane planting practices in the early to mid-twentieth century, and at least hinted at local traditions that might have been in practice as early as the nineteenth or even eighteenth centuries. Two of the project participants interviewed had firsthand experience planting, maintaining, and harvesting. These interviewees shared that their cane was grown in furrows. One farmer, Mr. Hans Lawaetz specifically recalled having kept more than 300 acres in cane over several seasons in the 1940s, 50s, and 60s, and suggested that his sugarcane was strictly rain fed (not irrigated), planted in furrows that were placed along the contour lines of local topography, and that he and his father had deliberately left "cane trash" on the fields for a time after harvesting to suppress weeds. Mr. Lawaetz also suggested that his sugarcane was allowed to ratoon (a form of runner-based procreation) between harvests, for periods of five to seven years, and then when the cane had to be freshly planted, it was planted from sprigs, consisting of a single cane segment, with the top and bottom knots still attached. Perhaps most interestingly, Mr. Lawaetz described details from the hiring of, and temporary housing of, off island field hands, from neighboring Caribbean islands such as Nevis, Anguilla, St. Kitts, and St. Lucia, to assist during cane harvesting season. In some detail Mr. Lawaetz recalled "bonding," feeding, boarding, and working with these field laborers, who were allowed to bring with them children and wives and would come to the island to work for up to three months at a time to harvest the cane. Similar details were also shared by two other interviewed farmers who shared memories of their parents who once worked in cane fields during their youths. One farmer mentioned that his mother and father who once worked the cane fields were originally from St. Kitts and had traveled and worked on other sugarcane plantations across the region before finally settling down on St. Croix. Another simply recalled that her father, who worked in the cane fields, was originally from St. Kitts.

Beyond the information provided about sugarcane planting practices on St. Croix the ethnohistoric examination of the John Delano photograph collection also contributed a great deal to our understanding of cane planting traditions on the island. In these images, cane is depicted as universally planted in furrows measuring between one and two feet (0.30 – 0.61 m) wide by 0.5 to two feet (0.15 – 0.61 m) in height, and "cane trash" was notably absent within any

depiction of cane fields. Though seemingly running contrary to Mr. Hans Lawaetz's description of the use of "cane trash", it is quite possible that the practice of leaving "cane trash" on the fields was either: a) only for a duration, and thus absent from photographs of fields that had been harvested more than a few weeks or month ago, and, or; b) not practiced by all sugarcane planters on the island. Furthermore, the absence of large piles of ash or charcoal, and or soil discolorations suggesting the presence of ash or charcoal, suggest that "cane trash" was neither burned off while still on the plant, nor burned in the field once removed from the cane stalks in the cane fields of St. Croix.

In the Delano photographs it also appears that the sugarcane plant itself was planted from trimmed, and perhaps cured or cultivated segments of previously harvested sugarcane, rather than either planted from seed, or "ratooned" from previously harvested cane plants. Moreover, though sugarcane fields were shown in various stages of development (e.g. soon to be planted, freshly planted, first sprouting, mid-growth stage, and mature) no evidence of the use of cover crops could be found in examined photographs, suggesting that the fields might have been left fallow in the intercrop period, or possibly that these fields were quickly tilled and replanted shortly after harvesting. Further, not even one of the Delano photographs depicts Crucian sugarcane as being irrigation fed, instead suggesting that the crop was rainfed across the island.

Some information was also gleaned regarding those who conducted the field labor, and the ways in which sugarcane fields were maintained on the island. With only one possible exception, all the cane field laborers in the photographs were black, adolescent to middle-aged adults, including biological men and women in equal number. From the depictions, no specific field task seemed to be relegated to members of either gender, with individuals presumed to be biological men and biological women participating in tilling the fields, planting sugarcane, weeding, maintaining cane furrows, and harvesting crops. As for the implements employed in this labor, the overwhelming majority of photographs depicting the activities of tilling and or weeding show field laborers wielding handheld hoes to carry out their work. These hoe handles were made from cylinders of wood, some made of pruned and cured branches, others of polished and milled wood, roughly one inch (2.54 cm) in diameter, and generally six feet (1.83 m) or so in length, while the metal heads of these hoes were manufactured off island, and imported for use. Though a horse drawn plough was depicted in one of the photographs analyzed it was described by Delano as "one of the few plows [sic] used on the island," suggesting that handheld hoes were the primary implements of cane field maintenance.

These insights from the Delano collection make valuable contributions to the understanding of how sugarcane was planted, maintained, and harvested on the island, while also offering depictions of the scale and magnitude of landscape level changes that the adoption of sugarcane monoculture represented for the island. The recordation of and preservation of these planting traditions are worthy in their own right as they help to increase our understanding of local customs and the pan-Caribbean labor regimes and practices which enabled the perpetuation of sugarcane planting well into the twentieth century. In addition, these findings also help inform the study of some of the possible environmental impacts these practices may have had in the short-, mid-, and long-terms. The presence of "cane trash" on the fields would represent the use of a low tech, but ultimately extremely effective soil and water retention treatment for their cane fields with trash litter affording a tremendous amount of ground cover and protection against rainsplash damage, as well as capturing and preserving moisture in soils after rain events. By

confirming that the “cane trash” was either collected by hand or allowed to stay on the cane fields indefinitely rather than burned off, we know that the acreage kept in sugarcane was spared the drying event of deliberately placed fires, but also left devoid of the reintroduction of potentially valuable nutrients back into the soils in the form of incinerated charcoal and ash. Such specific data points have the capacity to help inform the interpretation of the diachronic water balance model developed and discussed in Chapter 9 of this dissertation, as part of an assessment of the environmental impacts of sugar planting on St. Croix during the eighteenth, nineteenth, and twentieth centuries.

Chapter 6. The Hydrological Legacy of Sugar Planting on St. Croix and the Estate Little Princess Sugar Plantation

Introduction: The Study of the Hydrology of Sugarcane Planting in St. Croix

Today the island of St. Croix is a difficult place to live. Present-day Crucians, many of whom are descendants of enslaved Africans who were brought to the island to work on sugar plantations, regularly endure droughts and lack access to reliable, safe, and affordable drinking water. Contemporary farmers on the island who have installed wells have also struggled to find sufficient water to sustain their crops. Moreover, several of the island's natural aquafers have become contaminated with saltwater (VIWRRI 2012). The island is also highly susceptible to increasingly larger and more severe tropical storm events brought on through global climate change over the last several decades (USGCRP 2018). Many Crucians suffered from extensive water damage caused by the two category 5 Hurricanes, Irma and Maria, that hit the United States Virgin Islands (USVI) in the summer of 2017 (Craig 2018, Peters 2017). Together, drought and increased storm activity and severity, have resulted in acute freshwater shortages. The acutely felt hydrological conditions on the island, both the lack of access to drinking water, and the threats of saltwater contamination of underground aquifers and severe flooding during storms, pose a serious and immediate threat to the well-being and water sovereignty of those living on the island.

While the specific causes and impacts of these conditions are debatable, attributable to both environmental change and human activity, there is no debating that the island's hydrological systems have been greatly altered by over two hundred years of intensive sugarcane planting. Purportedly one of the thirstiest crops in the world, sugarcane planting has been cited by many as a primary cause of environmental degradation on landscapes across the Caribbean (Fachinelli and Pereira 2015), with scientifically conservative estimates of the water needed for the profitable cultivation of un-irrigated sugarcane reaching sums of 13,997 gallons (52,984 liters) of water per day per acre (Davis 2003). On St. Croix, sugarcane was grown, harvested, refined, and exported from the seventeenth century through the early 1900s. Thus, sugarcane plantation-based modalities of water use and water management is thought to have shaped the island's hydrological systems for centuries. Sugar's intense level of water requirements lies in stark contrast to the average annual rainfall on the island which has historically ranged between 45 and 55 inches (114 – 140 cm) of precipitation per year. This amounts to roughly between 3,347 and 4,092 gallons (12,670 – 15,490 liters) per day per acre (GDWII 1892, 1905, Shaw 1933, FES 1967). Moreover, the required clearing of land, and the practices involved in sugarcane planting, maintenance, and harvesting, artificially encouraged soil loss and soil compaction, diminishing local soils' capacity to allow rainwater infiltration and percolation and preventing the recharge of local water tables and nearby aquifers (Ritter 2012, Hartemink 1998, Turner et al. 2004).

To better understand the relationship between sugar planting in St. Croix and its short- and long-term effects on local hydrological systems this research explores the ways in which water was used on sugarcane plantations across the island during St. Croix's sugar growing era (1733 through the mid-twentieth century). Further, it develops a plantation specific water balance model for the Estate Little Princess, a sugar producing plantation during those years, to estimate and assess the amounts of water required (and available) to support sugarcane agriculture for nearly two hundred years. To achieve these aims, this research presents the findings from the survey of archaeological remains of water management features from sugar plantations in

operation during the eighteenth, nineteenth, and twentieth centuries. During this survey, conducted in Summer 2019, Winter 2021, and Summer 2022, water management features were recorded within the ruins of nine former sugar plantations in locations across the western half of the island.

This research also contextualizes the data collected during the survey against St. Croix's historical record and considers these findings against the backdrop of additional historical, ethnographic, and archaeological data collected from sugar plantations on other Caribbean islands to characterize the different types and forms of water uses that were commonly seen on the historic-era sugar plantations on St. Croix. Finally, I develop and present the outputs produced by a water balance model for the ELP between the years of 1739 and 1925 (the last year for which sugar production records are available). Compiling data from the archaeological survey discussed within Chapter 7 with available historical and precipitation records for the island, as well as estimates for the water requirements of sugarcane cultivation, sugar production, and the water needed to sustain humans and animals living on plantation to support sugar's cultivation and manufacture, this water balance model provides archaeologists and other scholars with a tangible glimpse of the hydrological effects sugarcane planting and processing may have had on the island of St. Croix and other locations throughout the Circum-Caribbean (Fox 2016, Meniketti 2006, 2015, Wells et al. 2017, Pratt 2015, Ezcurra and Rivera-Collazo 2018).

The results of these investigations reveal a great deal about water use in colonial era sugar plantation settings. Interpreted as the responses and adaptations of the planters who owned and managed sugar plantations, as well as those of enslaved and later free Africans who worked the sugarcane fields and factories, the recorded water management features reveal that the securing of sufficient water for the needs of these sugar plantations was a constant challenge. Effectively, the recorded water management features from St. Croix's sugar planting era "represent a colonial coming-to-terms with unfamiliar physical environments, the recognition of possibilities and limitations to settlement [and sugar planting], and the adaptation of technologies to local circumstances" (Lawrence and Davies 2012:47). Through this lens, the features' size, requirements of labor for construction, and consistent utilization of ad-hoc and utilitarian construction materials (including locally cut and broken limestone, locally produced plaster, and Danish brick, once used as ballast on ships traveling to the island from the home country), betray the lengths that plantation managers on St. Croix would go to obtain water access and storage capacity.

In turn, the results from the water balance model created for the Estate Little Princess provides us with a glimpse at the vast water deficit incurred through the adoption of sugarcane monoculture on St. Croix and ultimately speak toward the lasting hydrological legacy of sugar planting on a given environment. Estimating that the Estate Little Princess would have usually operated at an annual deficit in the hundreds of thousands to millions of gallons of water per acre planted in sugarcane per year, the water balance model suggests that the sugarcane industry likely played a significant role in the diminishment of the island's primary aquifer, which remains responsible for providing water access for much of the island's residential, industrial, commercial, and agricultural uses. These findings more concretely link historic narratives of sugarcane's capacity for environmental degradation with the hydrological conditions seen on the island today, and call attention to the importance of the pursuit of agricultural endeavors that are sustainable for the environments in which they are established, not just for the short term and the

sake of human profit, but for centuries to come, with considerations given to the human populations that will inherent these agricultural lands after they are abandoned (Grove 1996, Ragatz 1928, Wilkie and Bartoy 2000, McGovern 2018).

Background: The Survey of Colonial Era Water Management Features in the Caribbean

Much has been written about the cultural, economic, political, and social legacies of the sugar plantation industry in the Caribbean and the Americas (Mintz 1986, Dunn 1972, Craton and Walvin 1970, Wilkie 2005, Singleton 1985, Armstrong 1990, and Farnsworth 2001). But more recently, some scholars working in the Caribbean region have begun to examine the tremendous extent of landscape modification brought on by the sugar industry and the effects this might have had on aspects of local environments, including hydrological systems. While no previous works on St. Croix have investigated the built hydro-scape, or cultural landscape focused on water management structures, practices, and conservation methods, recent work on other Caribbean islands have examined the environmental impacts of intensified sugar planting. They have identified chronological phases in the intensification of and technological advancements in sugar cultivation, pointed out the dependence of local environmental conditions on planter decisions and resulting plantation activities, anointed initial deforestation as one of the most significant of plantation impacts, and have made the analysis of plantations' landscape use, spatial layout, and access to natural resources common practice (Delle 1994, Meniketti 2015, Pulsipher and Goodwin 2001, Ryzewski and Cherry 2015).

Of particular inspiration are the efforts of Lydia Pulsipher, and later Conrad Goodwin at Galways Plantation, located on the southern mountain range of the Caribbean Island of Montserrat, which focused explicitly on the examination of hydrology as a dominant factor in the financial success of sugar plantations (Pulsipher 1977, Pulsipher and Goodwin 2001). Without water and lots of it, sugarcane simply will not grow at profitable rates and to profitable size, yet cane roots cannot be too long saturated with water, as it would cause the cane root to rot. Though drought or insufficient rains are frequently thought to be a problem for any agricultural pursuit, on Galways Plantation (a plantation located near the top of a mountain), the planters also had to find ways to manage large amounts of excess precipitation, in ways that did not harm the cane crop. As a result, Pulsipher and Goodwin examined the development of water management features on Galways Planation over the span of 250 years to demonstrate how agro-industrial adaptations to the local environment, such as the relocation of facilities, construction of water catchments, reservoirs, underground tunnels, and cisterns can produce successful harvests and or lead to long term deleterious impacts on the hydrological systems of a given location. Though the plantation did manage to stay profitable, they did so at the cost of constructing and maintaining numerous surface catchments, reservoirs, underground tunnels, and cisterns. Even then, the plantation still saw extensive erosion (Pulsipher and Goodwin 2001:190). By calling attention to both the natural precipitation regimes, and the planters successful (and unsuccessful) attempts to regulate rainfall Pulsipher and Goodwin rightfully elevated the importance of the study of the hydrological systems in areas occupied by sugarcane plantations.

Pulsipher and Goodwin's hydrological focus in their study of the site of a long-term sugar plantation also highlighted how the spatial layout of water management features could be interpreted as indicators of past interactions between precipitation patterns and the humans who depend upon them (Pulsipher and Goodwin 2001:172). Following in these traditions the survey work undertaken on St. Croix for this research took on the deliberate recording of built water

management features as pertains to the cultivation of sugarcane and their relationship to natural water features on the landscape. As a result, this work heavily considers the ways in which the inhabiting culture took advantage of natural features in the landscape, built upon them, or worked against them to satisfy their water management needs.

In a similar vein to the works of Pulsipher, Marco Meniketti (2006 and 2015) deployed data from his examination of sugar factory elements on sugar plantation ruins he found on colonial era ruins across the Caribbean Island of Nevis to understand the impacts of planting on the island. In his works Meniketti readily acknowledges that the "environmental changes on Nevis [throughout the colonial period] were increasingly tied to systemic expansion of [sugar] production" and cites primary and secondary source accounts of widespread deforestation, sheet erosion, the modification of local ecologies (through the introduction of hogs, cattle, sheep, horses, donkeys and dogs), and wind based as well as rain based topsoil erosion to support this argument (Meniketti 2015:195, 201, 202, and 206). Through a combined use of planters' papers, government officials' notes, and secondary historical sources, as well as data from an archaeological examination of several sugar factories and their components (i.e. boilers, grinders, cisterns, windmills, distilleries, and store houses) across the island Meniketti calls attention to the ways variables such as factory location, natural wind patterns, and soil nutrients could all impact the "dynamic interplay of cultural processes over time, and the effects of human-environment interactions" (Meniketti 2015:207).

Following in the efforts of Pulsipher and Meniketti, this research expressly seeks to reveal more about the demands placed on St. Croix's environment through sugarcane planting, though instead of investigating the industrial features of sugar plantations, such as, boilers, grinders, and distilleries, this investigation targets water management features on former plantations for examination, and accounts for their purpose and role in the perpetuation of sugar planting activities on the island of St. Croix. This research seeks to build upon the methodologies deployed by Meniketti to speak towards the environmental degradation caused by sugar planting, through the development of a water balance model which quantifies the impacts sugar planting can have on the environments that are subjected to it. By quantifying the water demands of sugarcane agriculture alongside historically documented rates of rainfall, this research pushes the subdiscipline of sugar plantation archaeology to develop strong, demonstratable, links between past planting practices and a former plantation's current environmental conditions.

Recent archaeological research on plantations in the Caribbean has recognized the role of landscape development in environmental change and has begun in earnest to acknowledge the tremendous extent of landscape modification brought on by the seventeenth, eighteenth, and nineteenth century sugar industry (Delle 1994, Ryzewski and Cherry 2015, Wells et al. 2017, Fox 2016, Pratt 2015, Tricarico 2019). To continue to push the subdiscipline of Caribbean plantation archaeology however, studies which make tangible connections between past activities and present environmental conditions must be pursued. This is because they contribute to our greater understanding of the ever increasingly more pronounced capacity of humans to modify their environment (Crutzen and Stoermer 2000, Ruddiman et al. 2015, Sandweiss and Kelley 2012, McGovern 2018, Nelson et al. 2016). Research more deliberately and explicitly examining and evaluating the role that activities of past societies had in causing deleterious impacts to an environment might also help in the accurate identification of particularly harmful activities, and through their examination, perhaps learn of ways to reverse, alleviate or adapt to

their induced environmental changes (Tsing 2001, 2011, McGovern 2018, Wilkie and Bartoy 2000).

Chapter 7. The Archaeological Survey of Colonial Era Water Management Features on Plantations in St. Croix

Methods

The archaeological survey of water management features located on former sugar plantations across St. Croix consisted of the examination of the archaeological remains of above ground features that were built and in use during the island's sugar planting era (circa 1733 to 1925). The ruined remains of six plantations were examined, including Estate Morning Star, Estate St. George, Estate Washington, Butler Bay, Estate Whim, and Estate Little Princess (Figure 20). Thirteen water management features were examined on these former plantations, consisting of cisterns, wells, water towers, a water mill, a "flume" (or aqueduct), two rainwater jugs, and a dripstone. These survey efforts took place over the course of two weeks in June and July 2019, one week in December 2021, and six weeks during June and July 2022. These surveys were conducted by the author. The features recorded were selected for a variety of reasons including site accessibility, publicly or archivally provided knowledge of the presence of and location of water features, and opportunistic survey, as some water management features were encountered either during more intensive and wholistic archaeological investigations of plantation sites or identified during the deliberate automobile-based survey of all paved roadways on the island for colonial era water management features. Through this latter method any water management feature observed from the road while driving on paved roads was eventually visited on foot and recorded.

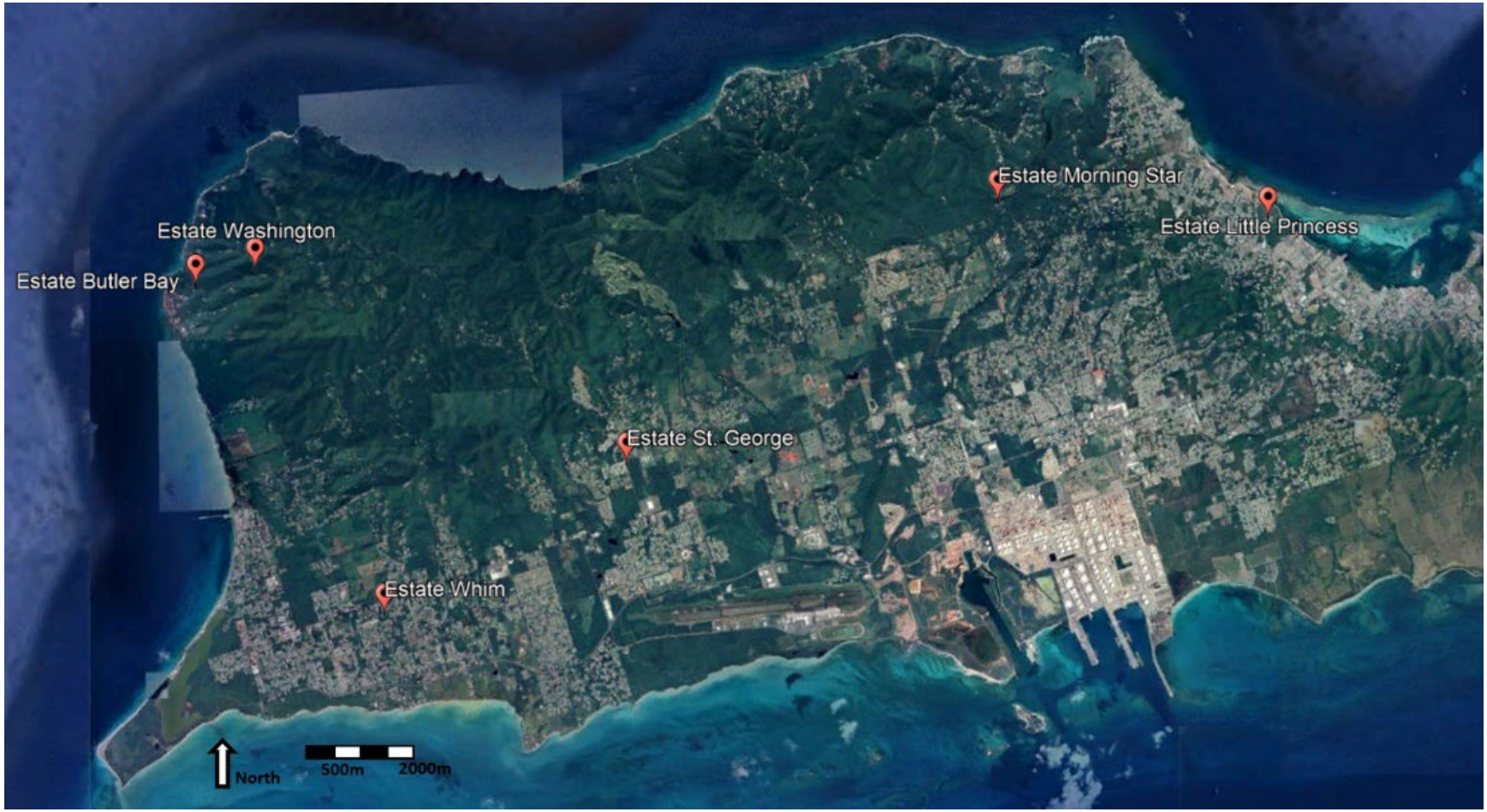

Figure 20. Map of western St. Croix depicting the locations of surveyed plantations. Map created by author, December 2023.

Each colonial era water feature encountered during these survey efforts was recorded via narrative notes, photographs, and GPS points. The narrative notes were transcribed into the main text in the results section of this dissertation, while GPS points of these resources were withheld from this document to protect the exact locations of these resources. The precise locations of these resources can be shared however, upon request. Whenever possible, measurements of each feature were also collected. Cameras used for this documentation include a Canon Powershot G10, a Samsung Galaxy 9 phone camera, and a Fujifilm X200 digital camera. In some cases, photographs were taken from angles and distances to provide for the contextualization of water management features against larger landscapes to better understand use of natural setting and the selection of the features location. In others, closer detailed photographs were taken to emphasize certain elements of the features encountered, and to assist with the consideration of features' condition, date of construction, purpose of use, volumetric capacity, and means of construction. Regardless of my intent, site accessibility, dense vegetation, and other realities of the spaces occupied by these features also played a large role in determining the nature of photographs taken. Other field equipment used in these recording efforts included a Trimble GeoXH 6000 GPS system, a TruPulse 360B laser range finder, photo-scales, and tape measures and reels. The results from these recording efforts are presented below, grouped together by the plantations on which they were found.

Results

Estate Morning Star Water Tower

The former grounds of Estate Morning Star are located on the west bank of the Salt River estuary (Figure 20). Today the ruins of this estate lie within the boundaries of the Salt River National Park. On July 14, 2019, I was granted permission to access and examine the partially rebuilt remains of an eighteenth century-built water tower which once served the active sugar estate. In recent decades the NPS has put in quite a bit of restoration work on the tower and its immediate environs. No more than 10 years prior to the currently described examination, a ghut was detoured down east scenic highway (a modern highway) through to Salt River Park and prompted the creation of an erosional channel to the adjacent north of the water tower (Dr. Meredith Hardy, personal communication, 2019). With heavy rains this channel began to undercut the water tower. NPS officials later (within 5 years of 2019) created a different path for the ghut and reinforced the foundations of the water tower, with levels of fine-grained gravel, in the form of a 1 m tall, raised fill level, encompassing the tower and a 50 x 50 m area around it. It was also around this time that the NPS refurbished some of the top rim of the structure, using period appropriate construction materials including cut stones and plaster. The original door frames (woodwork) of the tower were replaced by the NPS prior to these external refurbishments as they were in particularly poor shape (Dr. Meredith Hardy, personal communication, 2019). Despite the twenty-first century date of these modifications to the tower, the NPS's attention to period specific detail when conducting these refurbishments enabled the tower to still serve as an excellent example of colonial era water management architecture.

During the 2019 archaeological survey, the water tower was found sitting atop the NPS artificially raised gravel level (Figure 21). The tower itself measured 8 m tall and 5 m wide at its base, with an interior diameter of 2.7 m, suggesting a wall thickness of approximately 1.15 m. The tower was constructed out of cut and uncut limestone, yellow brick, and plaster (sometimes called quicklime). Within the tower, there was evidence of a stone-lined well lying beneath the

ground surface, in the form of the top of that well's wall lining poking up above the ground surface, which consisted of a stone and plaster circle with a diameter of 2 m (Figure 22). This stone-lined well, save for portions of its top surface, was found buried and covered over with dirt. The thickness of the south doorway (and effectively the thickness of the water towers walls) measured 1.15 m while the width of the doorway measured 1.1 m, by 2.67 m tall. In the north doorway the rock walls measured 1.17 m thick, with a wooden doorway 1.0 m wide, and 2.67 m tall (Figure 21).

Figure 21. View of north side of the Water Tower at Salt River. Photograph by author, 7/14/19.

Figure 22. View of subsurface well, with all but top buried, within the interior of the Water Tower at Salt River. Photograph by author, 7/14/19.

Figure 23. View of southern doorway, taken from within the interior of the Water Tower at Salt River, facing southeast. Photograph by author, 7/14/19.

The first tier of the water tower gives way to a second tier approximately 3 m above the arch of the north and south side doorways. The second tier is about 1 m narrower than the first at its base and possesses a cut archway approximately 1.6 m tall by 30 cm wide. This archway was built for use in the installation of the tower's main crankshaft (connected to a wind turbine at its top, which is no longer present) and, later, for the purposes of water tower maintenance after its initial construction (Figure 24). Though not present on either this water tower, nor at the water tower at Estate Little Princess (described later in this chapter), many water towers on St. Croix are reported to have had built limestone and plaster stairs wrapping up and around their exteriors to provide easy access for tower and turbine/crankshaft maintenance and repair (Dr. Meredith Hardy, personal communication, 2019). At the very top of the first tier (roughly 4 m up off the ground), there is a rim adorned with a few bricks, but still mostly cut limestone. The transition between the first tier to the second is characterized by an abrupt change in the tower's width by roughly 0.5 m around its exterior, with this extra space providing a walkway around the circumference of the tower (Figure 24). From here the second tier continues to narrow on its way up, before ultimately reaching a width of approximately 2.5 m narrower in diameter than at its base.

Figure 24. View of second tier of Water Tower at Salt River, showing archway used in tower's construction and maintenance, facing northeast. Photograph by author, 7/14/19.

Cut spaces in the exterior wall of the tower are visible from the interior, looking up. Some of these spaces still hold the remnants of the wooden support beams they were designed to hold. These support works once held up the turbine shaft for the wind driven turbine which once sat atop the tower (Figure 25). At the very top of the tower, all that remains is the tower's outer stone walls. The wind turbines, crank shaft, and gear box, which would have adorned the top of the tower in the past, have since been removed by NPS staff (Dr. Meredith Hardy, personal communication, 2019).

Figure 25. View of interior of the Water Tower at Salt River. Photograph by author, 7/14/19.

Built Water Management Features at the Estate St. George

On July 18, 2019, I was granted permission by the St. George's Botanical Garden Board of Directors to access and examine the plantation's landscape and ruins (Figure 20). This former sugar plantation is now listed on the National Register of Historic Places (NRHP). At the time of survey St. George's was found to still possess remnants of several above ground features related to water use and water management during the sugar planting era on the island. These features included a stone-lined well, a water driven mill, and a water flume (aqueduct). These built water management features are described separately below.

Stone-lined Well

The stone-lined well at Estate St. George is located 15.5 m west of the northwest corner of the plantation's sugar factory building. The well's interior, which is circular in shape, is 1.8 m in

diameter. This wall is made from red and yellow brick, as well as cut stone, river worn cobbles, and limestone-based plaster (Figure 26). At its largest, the exterior of this wall measured nearly 4 m in diameter, with the thickness of the wall measuring nearly 1m exactly at its widest, and 74 cm at its narrowest. The height of the well, measured from the (still extant remains of the) plastered top of the well, to the top of its now filled in well pit, measures 3.8 m. The well's walk-in entrance, situated along the south side of the well wall consists of a dugout descending path into which cut limestones were laid, from the ground surface level down into the subsurface well basin. The gap in the stone and brick well wall which make room for this walk-in area spans 1 m wide.

Figure 26. View of Stone-lined Well at St. George's Botanical Gardens, facing north. Photograph by author, 7/18/19.

The stone-lined well was first noted in plantation records on an 1807 inventory and is thought to have been built between 1800 and 1807 by enslaved Africans (Tyson 1993). For a time, it was adorned with a metal fan mill and pump. When first built, the flight of steps, consisting of cut stone and plaster, were installed down into the subsurface, and would have provided individuals

with access to water when it was at lower levels. The well and a fan driven turbine which once adorned it were cited in every plantation inventory for St. George through 1837. In 1836 it was reported in plantation inventories as no longer in use, and there is no further mention of the well in records after 1837 (Tyson 1993). The well is thought to have completely run dry by 1840, and it was thereafter used as a refuse pit for the plantation. Previously conducted archaeological excavation of the well conducted by Kim Hoaglan in 2003 revealed a variety of refuse materials including bricks, roof tiles, pink plaster (locally produced with crushed brick inclusions for decorative purposes), furnace waste from the nearby sugar factory (bagasse), layers of coal, and iron barrel hoops (Dewey Hollister, personal communication, 2019).

Water Mill

St. George's water driven mill is located 5 m to the north of Mint Ghut within the southeastern quadrant of the plantation. Mint Ghut is one of the largest natural water courses on the island. It traverses down from a mountain range with headwaters some 2,000 m to the northwest of the plantation, down, along the western edge of St. George's until it crosses over and eventually exits the property close to the planation's southeastern corner. During the water mill's active period of use, it was fed by an aqueduct system spanning 1,828 m long supported by 39 stone and plaster arches which carried water to the mill from much further upstream (Tyson 1993). The mill's southern, western, and eastern walls are set into an artificially built-up earthen wall. The sluice for the mill's water wheel, which at the time of survey was found to be in ruins, consists of now partially disarticulated walls of stacked and plaster laid stone (including limestone and granitic rock). During the 2019 survey the feature's walls were recorded as having a maximum height (off the modern ground surface) of 2.44 m and extended to a length of 9.87 m roughly north to south (Figure 27). The sluice is 1.07 m wide on its interior, and 3.14 m wide on its exterior. At its eastern end, the wall of stone measured 1.2 m thick, whereas at the western end the wall measured 95 cm thick. The position for the wooden axle that once harnessed the energy of water dropped over the mill wheel was visible and apparent when facing the sluice from its northern side (Figure 28). These designed gaps for the wheel axle measured 70 cm wide (from north to south) by 45 cm tall.

Figure 27. View of St. George Water Mill sluice, on the east side of the millhouse, facing south. Photograph by Author, 7/18/19.

Figure 28. View of St. George Water Mill sluice, showing space in walls left for water wheel axle, facing southeast. Photograph by author, 7/18/19.

The water wheel sluice structure is connected on the exterior of its western wall to rectangular foundations. These foundations once supported the millhouse. At the time of survey, the superstructure of the millhouse was entirely absent, with no additional traces of the millhouse observed during a pedestrian survey of a surrounding 50 m radius from the foundation walls. The extant walls were built of heavily plastered stacked stones, including unevenly shaped and sized limestone and granitic rocks. It is clear from the standing elements of the millhouse foundation walls that the foundation measures 4.17 m wide (roughly east to west), and 5.70 m long (north to south) along the length of the sluice. From the extant foundation walls of the millhouse, it is also apparent that the sluice had a maximum height of 2.06 m along the span of the house (Figure 29).

Figure 29. View of St. George Water Mill house, showing stretch of southern wall, facing south. Photograph by author, 7/18/19.

This water mill was used for crushing sugarcane. Moving water, supplied by an aqueduct would turn the wheel attached to the axle, which itself turned a gear, which then turned the drums of the mill which would press the sugarcane to extract its juices. The cane juice would then have been transported via conduit lines to the nearby sugar factory for boiling. No traces of the aqueduct, which once provided the mill with water from a higher point of elevation on Mint Ghut, could be found on the ground surface within the vicinity of mill structure or on any other part of the plantation. When it stood, this aqueduct was built out of cut and uncut limestone that had been stacked and held together with poured plaster (Tyson 1993).

Estate St. George records suggest this mill was constructed between 1829 and 1831. Very soon after its construction, the water mill's mill house was constructed, where sugarcane grinding elements were kept. A drought in the early 1840s, is recorded as having impeded the mill's operation, and in an 1846 plantation inventory the mill was described as "not being in good order" (Tyson 1993). By 1849 the mill was in such disarray, and of such little use, it was not considered valuable enough to be listed in an inventory of the plantation's structures and assets. Evidently the water mill remained useful for only a short time, running for perhaps a little more than 15 years. Later in 1867, the structure fell into ruin after being severely damaged during an earthquake which struck the island that year. Water mills like this one were an atypical site on the island, with few other such mills listed on the inventories on plantations across the island (Tyson 1993). Mills of this type would have required a significant and constant flow of water,

consisting of quantities and flow rates of water in local ghuts which the island's annual precipitation patterns could not have sustained.

Water Flume

The remains of a poured plaster and stone aqueduct, referred to within plantation papers as a "flume," lie not 30 m to the northwest of the water driven mill and not more than 8 m to the northeast of Mint Ghut. The flume flows in a northwest to southeast path, running just over 100 m from a stone dam placed inside Mint Ghut. The flume carries this diverted water into a small plaster cistern on the flume's southeastern end. The aqueduct widens and shallows as it proceeds from the northwest to the southeast on its approach to the cistern (Figure 32). The cistern is circular, with a 1.14 m interior diameter, and a 1.44 m exterior diameter. It is 1.50 m tall and has plaster walls that are between 17 and 23 cm thick (Figure 31). At its base the cistern has a plaster base. This base was broken in parts at the time of recording, but it still had portions that extended to a maximum length of 19 cm away from the bottom of the cylinder and a maximum height of 10 cm above the current ground floor. The cistern also features an iron pipe which extends to the south and is 7 cm in diameter. This metal piping stems out 43 cm from the top of the cistern. The cistern also features an iron tube which extends to the southeast. This pipe is 11 cm in diameter and extends 50 cm before fastening to another tube via two 22 cm diameter disc fittings, to a segment of pipe which goes underground after 1.59 m. The bolts holding the disc fasteners together are 2 cm in diameter and hexagonal (Figure 32).

Figure 30. View of St. George Flume cistern, facing east. Photograph by author, 7/18/19.

Figure 31. View of St. George Flume cistern, facing west. Photograph by author, 7/18/19.

Figure 32. Overview of St. George Flume, facing northwest. Photograph by author, 7/18/19.

The flume's waterway measures 22 cm wide by 12 cm tall in the vicinity of the cistern, but its measurements fluctuate quite a bit along the flume's length. Some points are far narrower, reaching as small as 7 cm wide by 20 cm deep. Right at the lip, where the aqueduct flows into the cistern, the aqueduct channel is 18 cm wide by 21 cm deep, which is the same depth at the splitter (further upstream) (Figure 30, Figure 32, and Figure 33). The splitter is 66 cm at its widest, with both an east and west channel, each measuring 12 cm wide. There is a nearly cylindrical hole in the center of the splitter's ovoid, measuring 48 cm in diameter and 50 cm deep (Figure 33). Just underneath this splitter, the base of the flume, which is ordinarily solid plaster laid stone with a plaster outer wall, gives way to a small archway. This archway measures 30 cm wide by 41 cm tall off of the current ground surface (Figure 34).

Figure 33. View of St. George Flume splitter, facing north. Photograph by author, 7/18/19.

Figure 34. View of archway at base of St. George Flume, facing northeast. Photograph by author, 7/18/19.

100 m to the northwest of the cistern, the flume takes on different observable characteristics. In this vicinity not much of the flume is above the current ground surface, with between 10 – 20 cm maximum exposed above the surface. Here the plaster also has a discernably different amount of speckled black inclusions as compared to the end of the flume with the cistern, and the water way becomes narrower (less than 5 cm), and taller (by more than 10 cm) (Figure 35). In 2019 the dam from which the flume originated and emanated was observed roughly 120 m northwest of the flume's cistern and was found to be comprised of stone and plaster. Largely in ruins at the time of survey, the remnants of walls of the dam, on either side of the ghut, measured roughly 1.10 m tall, by 0.90 m thick (Figure 36). By 2019, the area of the dam that spanned across the ghut (or tributary) had been completely destroyed. The now dry ghut bed was exposed, with a width of 2.95 m. The dam was also recorded at the time of survey as extending 10 m beyond the apparent banks of the ghut to both the east and west.

Figure 35. View of Flume at St. George, facing north. Photograph by author, 7/18/19.

Figure 36. View of dam on Mint Ghut within St. George Plantation, facing east. The Dam fed the plantation's Flume in the mid- to late-nineteenth century. Photograph by author, 7/18/19.

According to plantation records, the flume was built in 1846. At the time it was built to facilitate the transportation of water to a then newly built steam driven mill located on the north side of the plantation's boiling house, within the sugar factory complex (Dewey Hollister, personal communication, 2019, Tyson 1993:30). This mill was damaged in the 1867 earthquake but was rebuilt in 1869. The steam mill is thought to have remained in use through the early twentieth century, but it is thought that that the flume fell out of use in the later half the nineteenth century because of both drying conditions within the ghut, and damage to the system sustained during the 1867 earthquake.

Water Cistern at Estate Washington

On December 13, 2021, I had the chance to visit Estate Washington, a former sugar plantation located in the elevation of St. Croix's northwestern mountain range. During the visit, I was given a guided tour of the grounds by current owner Mark Gelband (Figure 20). While I noted numerous structures and ruins on the plantation dating to the sugarcane era (including an animal driven mill, sugar warehouse, and factory) the single built water management feature identified during our tour consisted of a rectangular water cistern, made of brick, cut limestone, and river cobbles held together by plaster. This cistern is thought to have been built during the late eighteenth or early nineteenth centuries (pers comms Mark Gelband December 2021, Figure 37). Bricks and cut limestone were more prevalent in the corners and in the top tenth of the walls of

the cistern, while larger river cobbles played a larger role toward the structure's base. The cistern was built roughly 5 m east of the estate's sugar factory, with its length spanning across the western exterior wall of the factory, and spanning approximately north to south for close to 20 m (Figure 38). The width of this cistern is roughly 7 m, and its walls measured roughly 2.4 m tall by .5 m thick (Figure 38). At the base of the cistern's northeastern exterior wall, there is a small trough, extending roughly 0.75 m wide beyond the length of the cistern and measuring 7 m long (along the width of the cistern itself) (Figure 37). This trough is fed through an iron spigot which is attached to an iron tube which pierces through the northeastern cistern wall into the cistern's water reserves. As of the date of the recording, the cistern was still in active use, and three fourths of the top of the cistern was found to be covered in corrugated (and clearly oxidized) iron sheets which spanned the entire width of the cistern (Figure 39). The installation of these metal covers predates the purchase of the property by the current owner (Mark Gelband, personal communication, 2021). Based on the recorded measurements, the Estate Washington cistern could have conceivably held 288,000 liters (76,082 gallons) if entirely full. The cistern appears to be strictly rainfed, only being replenished by any water that happens to fall directly over its open top. This was deduced as attempts to identify connected catchments, or catchments elsewhere on the property connected to the cistern via slue or aqueduct, proved unsuccessful.

Figure 37. View of Estate Washington Water Cistern, facing southwest. Photograph by author, 12/13/21.

Figure 38. View of Estate Washington Water Cistern, facing west. Photograph by author, 12/13/21.

Figure 39. View of Estate Washington Water Cistern, facing northwest. Photograph by author, 12/13/21.

Water Management Features at Butler Bay

Butler Bay is a former sugar plantation, in operation first as a cotton plantation in the 1750s, and later as a sugar plantation from the 1760s through the early twentieth century. My first glimpse of built water features at Butler Bay came during a drive to another location along West End Road, a paved road which hugs the western coast of the island. Not 2 m from the east side of this roadway I encountered a plantation era stone-lined well, and an old entrance way to Butler Bay Plantation, both now heavily covered in vegetation (Figure 20). I examined these features, which nearly lay within the eastern right-of-way of West End Road, in an impromptu fashion on June 17, 2022. The current owner of the Butler Bay great house and much of its former grounds, Ryan Flegal, invited me to tour additional built water features on the former sugar producing estate on July 19, 2022. In more recent years, Mr. Flegal has renovated the great house and several of the smaller structures on the property into a hotel/bed and breakfast, and a small farm called the Feather Leaf Inn. Informing Mr. Flegal that I was particularly interested in examining built water management features from the colonial period, he soon showed me the plantation's colonial era cistern (still in use), and another stone well that had been dug and developed in the eighteenth and nineteenth centuries. The plantation has been listed in the NRHP since 1977 for its representation as "one of the finest examples of a restored Danish great house in the Virgin Islands" (Lader and Wright 1977). Recorded details and observations collected from my examination of these three built water management features are described below.

The Great House's Cistern

The cistern was affixed to the southeastern extent of the plantation's Great House. Most of the exterior of the structure is made up of cut stone and brick held together by quicklime plaster, with an arched top comprised strictly of bricks and plaster. The cistern effectively forms a rectangular prism, save for its arched top, and measures 18.89 m long by 2.8 m tall, and 4.5 m wide with its length extending at a compass bearing of 208 degrees to the southwest along the backside of the Great House (Figure 40). The cistern was deliberately built into a westerly sloped hillside on its eastern side, making use the exposed hillside (exposed through the deliberate cutting of the hillslope) as a supporting exterior wall for that side of the cistern (Figure 40 and Figure 41). On its western side, the cistern is supported by two buttresses which are approximately 20 m apart and measure 1.5 m each along the southwest to northeast. These buttresses each start nearly flush with the western wall of the cistern, and then increase in width in an angled fashion, such that they form a flat westerly slope out towards the west of the cistern, for a maximum width of 1 m at their bases (Figure 42). The cistern's southernmost wall is supported by a single buttress of identical size and shape of those adorning its western wall, located approximately midway along the cistern's width (Figure 43).

Figure 40. View of Butler Bay Planation's Cistern, facing southeast from the Cistern's northwestern corner. Photograph by author, 7/19/22.

Figure 41. View of Butler Bay Planation's Cistern, facing northwest, from the Cistern's southeastern corner. Photograph by author, 7/19/22.

Figure 42. View of Butler Bay Planation's Cistern's western buttresses, facing west (and down), from the top of the Cistern. Photograph by author, 7/19/22.

Figure 43. View of Butler Bay Planation's Cistern's southern wall, taken from the top of the Cistern at its southernmost extent, facing south and down, showing the Cistern's southern buttress. Photograph by author, 7/19/22.

The top of the cistern is formed by an arch that starts roughly 50 cm above the height of the cistern's walls. The rock and brick structure tapers off to a point where it is 2.7 m wide at the base of the arch, which extends along the entirety of the cistern (Figure 44). The arched top of the cistern is comprised of one coarse of bricks, held together by locally produced lime plaster. At its approximate center, the top of the cistern has an opening which measures roughly 1 m x 1 m wide which once served as the primary means by which the cistern collected water (Figure 45). This opening provides a view of the cistern's interior which consists of a plaster lined interior wall that has been covered with antifouling white paint in more recent years.

Figure 44. View of Butler Bay Planation's Cistern's northern wall, showing its arched top, facing southeast. Photograph by author, 7/19/22.

Figure 45. View of Butler Bay Planation's Cistern's interior, showing the profile of its arched top as well as the plaster lining on the interior of the cistern, facing east. Photograph by author, 7/19/22.

This cistern is thought to have been in use on the plantation since the late eighteenth century and continues to be of great use for the current property owners (Ryan Flegal, personal communication, 2022). As of the date of survey, a more recently fashioned metallic cover (painted red) is used as a lid to this opening, as water is fed into the cistern via twenty first century fashioned gutters, piping, and conduits which carry rainwater into the cistern from the Great House's various roofs (Figure 41). The labels of marks on the interior of the cistern reveal that is has a maximum holding capacity of some 68,894 liters (18,199 gallons) of water, though at the time of survey (which was amidst a year long drought) the water level was noted to be several hundred gallons below a 5,200-gallon marker (less than 19,684 liters).

Stone-lined Well near West End Road

Approximately 400 m north of the present Feather Leaf Inn entrance along West End Road I encountered a stone-lined circular well and a trough feature (Figure 46). The circular well was found to be made of pieces of coral, yellow brick, cut and uncut granitic stones, and plaster (Figure 47). The well's wall measured approximately 3.8 m thick, and its top was capped in plaster. The well's interior wall was strictly comprised of cut stone and plaster (Figure 48). The well's internal diameter measured roughly 4.57 m and from the top of the well's walls down to it's current bottom (which consisted of wet clayey soils) it measured 7.6 m (Figure 48). Though the well did not bear water at its surface during the time of survey, the soils at the well's bottom

were observed to be moist and inhabited by amphibious crabs, who were not only present in a high number within the well, but who had also excavated habitation pits into the soils which now formed the well's bottom.

Figure 46. View of Stone-lined Well found in the vicinity of Butler Bay Plantation, showing exterior, facing southeast. Photograph by author, 6/17/22.

Figure 47. View of exterior wall of Stone-lined Well found in the vicinity of Butler Bay Plantation, facing southeast. Wall is comprised of Flensborg yellow brick, coral, granitic stone, and plaster. Photograph by author, 6/17/22.

Figure 48. View of interior and bottom of Stone-lined Well found in the vicinity of Butler Bay Plantation, facing southeast. Photograph by author, 6/17/22.

The well also possessed a walk-in staircase. This staircase consists of a 2 m deep by 2 m wide, 3-sided wall made of cut-stone and plaster, which had been built into an equally deep cut into the surrounding earth (Figure 49). These walls measured roughly .5 m thick and were topped with a finished layer of plaster. This wall structure connects on its east side to the wall of the well, allowing the stairs to descend into the well. The stairway has a flourish in the well wall, consisting of an archway of cut coral (Figure 50).

Figure 49. View of exterior of the staircase of the Stone-lined Well found in the vicinity of Butler Bay Plantation, facing south. Photograph by author, 6/17/22.

Figure 50. View of archway above the stairway within the Walk-in-Well found in the vicinity of Butler Bay Plantation, facing east. Photograph by author, 6/17/22.

Attempts were made to identify additional features in the densely vegetated vicinity of the stone well. These efforts revealed a small ghut roughly 4.5 m northwest of the well, measuring approximately 1 m wide by 0.5 m deep. Though dry at the time of survey, a twentieth century installed metal culvert is present to allow water from this ghut to pass freely underneath the paved surface of West End Road and onto the nearby beach, just to the west of the road. To the southwest of the well, there was another built feature which has been described by the current property owner, Tanya G. Burnett, "as an old entry way to the plantation" (Tanya G. Burnett, personal communication, 2022). This feature is semi-circular in shape and made of cut coral, cut limestone, brick, and plaster (Figure 51). The raised lips on either side of the width of this semi-circular feature, appears to form a drinking trough for cattle or horses, with high, raised, plaster covered lips on its eastern and western sides, with the lip on the eastern side standing roughly 15 cm taller. The semi-circle trough formed by these features is approximately 1 m wide, with the east lip standing approximately 1 m tall, and the west lip standing approximately 15 cm above the current ground surface. The edges of either end of the semi-circle structure had square shaped brick pillars affixed to their tops, though a portion of the pillar at the southern end of the structure has broken off and fallen to the ground just to the northeast (Figure 52 and Figure 53). This entire feature lies just 1.5 m east of West End Road.

Figure 51. View of entry way/trough in the vicinity of Butler Bay Plantation, facing northeast. Photograph by author, 6/17/22.

Figure 52. View of northern pillar of the entry way/trough in the vicinity of Butler Bay Plantation, facing west. Photograph by author, 6/17/22.

Figure 53. View of southern pillar of the entry way/trough in the vicinity of Butler Bay Plantation, facing northeast. Photograph by author, 6/17/22.

Stone-lined Well Near the Sugar Factory

Property owner Ryan Flegal also invited me to record details from another plantation era-built water feature on Butler Bay Plantation. This feature was a large stone-lined well located approximately 20 m north of the plantation's sugar factory structure ruins, just 300 m east of West End Road on the southern side of the modern entrance way to the Butler Bay Great House. Observed from its exterior, the above ground portion of this well is a four-sided square wall which stands approximately 65 cm tall from the current ground surface, and which spans roughly 3x 3 m in length and width (Figure 54). This wall is comprised of stone (some of which may be cut), brick, and plaster, and has a finished plaster top. Looking inside the well, the interior of the well wall is round with a diameter of roughly 4 m, and it is constructed of cut granitic stone and plaster (Figure 55). On the date of survey, the depth from the top of the well, down to the water level was recorded to be 10.36 m (roughly 34 ft). Upon hearing this, Ryan Flegal was not surprised. "Last year," he said, "it measured 29 feet [(8.34 m)] down, but it's been a year of drought since then" (Ryan Flegal, personal communication, 2022).

Figure 54. View of Stone-lined Well near the Sugar Factory at Butler Bay Plantation, facing south. Photograph by author, 7/19/22.

Figure 55. View of the interior of the Stone-lined Well near the Sugar Factory at Butler Bay Plantation, facing southeast. Photograph by author, 7/19/22.

Estate Whim Plantation Water Jugs

Estate Whim, located in the west central portion of this island, has also been listed in the NRHP since 1976 (Wright et al. 1976). The plantation was originally laid out in the 1730's by the Danish West Indian Company and was initially worked as a cotton plantation. By 1754, however, most of the acreage of the estate was repurposed for the cultivation of sugar. Tax records for Whim, dating from 1751 onward, reveal that Whim was one of the most prosperous sugar plantations on the island during the eighteenth century (Wright et al. 1976). Beyond merely processing its own cultivated sugar, the Whim factory also received and processed cane from nearby plantations as well. Later, in the early twentieth century, most plantation lands were cleared of cane and instead used to raise cattle. In 1932 the United States federal government purchased the entire plantation for the purposes of breaking the plantation up for use in a homesteading program. Finally in 1954 the 12 acres which contain most of the plantation's structures, were leased to the St. Croix Landmarks Society, for management and eventual operation as a museum. The still extant built features on plantation consist of the Great House, cookhouse, kitchen structure, privy/bath house, an animal mill, windmill, and steam mill, a watchhouse, and a carriage house (Wright et al. 1976).

Two large ceramic jugs were observed close to the plantation's kitchen structure during a visit to the plantation on June 25, 2022 (Figure 56). The first jug (Jug 1) was recorded as measuring approximately 1.06 m tall, and 60 cm at its widest, forming a bulb shape from its mouth, down to the floor. On its bottom it possesses a ring foot to help it rest on the ground (Figure 57). The second jug (Jug 2) was more barrel like in shape, almost measuring 1.10 m tall, with a maximum width of about 50 cm (Figure 58). Both jugs were topped with cut pieces of particle board. Judging from their wear, these jugs were likely produced sometime before the turn of the twentieth century. A look inside Jug 2 revealed that the jug's interior was slip lined, likely to help ensure the vessel would stay watertight (Figure 59). Though it seems unlikely that these water jugs were in active use as water vessels in their observed location in 2022, jugs of this nature are known to have been used on sugar plantation settings for a wide variety of purposes. These include the collection of rainwater from either designed catchments, or through exposure to the open air (uncovered) during a storm, the storage and transport of rainwater and or water collected from cisterns or wells for later use and or at a different location for personal consumption, cooking, bathing, and even perhaps religious rituals (Hauser 2017, Farnsworth and Wilkie 2005).

Figure 56. View of coarse ceramic Water Jugs at Estate Whim Plantation Museum, facing south. Photograph by author, 6/25/22.

Figure 57. Closeup of Jug 1 at Estate Whim Plantation Museum, facing south. Photograph by author, 6/25/22.

Figure 58. Closeup of Jug 2 at Estate Whim Plantation Museum, facing south. Photograph by author, 6/25/22.

Figure 59. Closeup of interior of Jug 2 at Estate Whim Plantation Museum. Photograph by author, 6/25/22.

Built Water Management Features at Estate Little Princess

The Estate Little Princess (ELP) is located on the north central coast of St. Croix, nestled in a small coastal plain which gently slopes down towards the ocean to the northeast (Figure 20 and Figure 60). Records indicate that ELP was first occupied by Fredrick Moth (a later governor of the Danish West Indies) in 1739 (Wright et al. 1980). By 1743, he is understood to have officially claimed the property and is thought to have had upwards of 200 acres cultivated in sugarcane (GDWII 1905). From then until the mid-twentieth century ELP cultivated sugarcane, and employed its own cane mill and factory in the production of muscovado sugar (GDWII 1892,1905). During that period of time, several structures were erected on site, including an

animal driven mill (as of 1749), two great houses (the first built in 1759, and the second built in 1840), a wind driven mill (as of 1766), a first and second sugar factory (first factory construction date unknown, second factory constructed circa 1850), a water tower (thought to have been built in 1745), an overseer's house (with an unknown construction date, though its proximity to the second factory suggests circa 1850), and an enslaved, and later indentured African village, with at times as many as 53 waddle and daub or masonry cabins, present on the plantation (Wright et al. 1980).

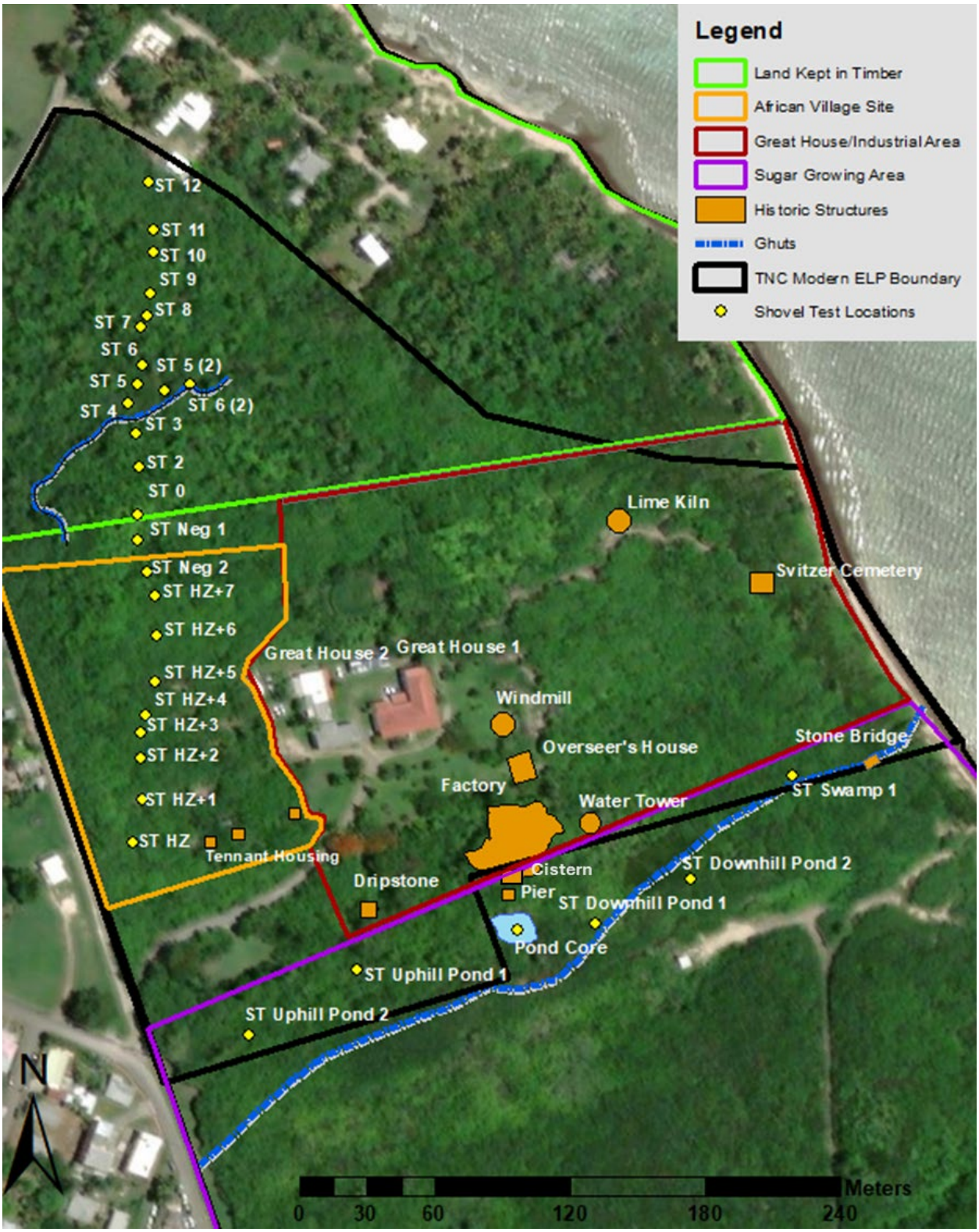

Figure 60. Map of the Estate Little Princess depicting locations of its still extant historic era structures. Note that structural remnants are demarcated by orange polygons. Map by author, Spring 2023.

An archaeological survey of the water management features on the estate took place during Summer 2019, Winter 2021, and Summer 2022. In addition to gleaning details from the plantation's previously identified water tower, windmill (eventually converted to a cistern), sugar factory, water tower, and sugar factory cistern, these efforts also included the recordation of the ruins of a dripstone which were identified in the summer of 2022, when receding vegetation in the wake of an extended drought, revealed the ruins to surveying archaeologists. The precise date of construction of this dripstone is unclear, as the feature never shows up in any plantation inventory lists or tax records. Details collected from the examination of these water at ELP features are provided below.

Water Tower

The water tower at ELP is located to the southeast of the estate's sugar factory and lies at the bottom of the hill upon which the plantation's wind-driven sugar mill (later turned water cistern) sits (Figure 60). Approximately 40 meters to the south of the water tower, is a naturally occurring and unnamed ghut. This ghut was also surveyed and was noted to extend across the entire west to east extent of ELP, taking a slightly northeastern route from the western boundary of the plantation to the island's coast which faces the Atlantic Ocean to the east (Figure 60). The water tower is 4 m wide in diameter, narrowing as the structure gains height (Figure 61, Figure 62, and Figure 63). The tower also possesses a trough spanning the exterior circumference of its base (Figure 64, Figure 65 and Figure 66). The trough pool as well as the exterior wall of the first tier of construction are segmented by an archway facing west along the circumference of the tower. The floor of the archway begins 44 cm above the surface of the ground, and spans 112 cm wide, with the center of the archway 220 cm from the step top (Figure 64). Heavy weathering, along with the presence of a maintenance doorway, creates the appearance of two distinct tiers of construction, a lower portion measuring 7 m tall, and a second tier measuring an additional 5 m tall (Figure 61, Figure 62, and Figure 67). The tower is made of limestone and coral and includes brick detail work. These elements are held together by a form of quicklime (calcium oxide) locally produced (and colloquially referred to as "plaster"). Brick arching starts 1.61 m off the ground level on each side of the doorway. While many of the stones and corals used in the archway were of irregular shapes, the bricks used were found to be of one type only: a yellow brick measuring 11 x 5 x 21.5 cm. Walking through the archway, an 80 cm thick well wall was revealed on the north side (where the structure was still complete) and a 58 cm thick well wall on the south side (where the structure is partially ruined).

Figure 61. Views of the Water Tower at Estate Little Princess, facing east. Photograph by author, 7/9/19.

Figure 62. View of upper portion of Water Tower at Estate Little Princess, facing east. Note doorway for maintenance work. Photograph by author, 7/9/19.

Figure 63. View of lower portion of Water Tower at Estate Little Princess, facing east. Photograph by author, 7/9/19.

Figure 64. Detail view of the entrance to Water Tower at Estate Little Princess, facing east. Photograph by author, 7/9/19.

Figure 65. View of backside of Estate Little Princess Water Tower showing Well, facing north. Photograph by author, 7/9/19.

Figure 66. Closeup of "1745 RM" written in plaster on the northeast exterior of the Estate Little Princess Water Tower. Note the metal pin also on the wall exterior to the south. Photograph by author, 7/9/19.

Figure 67. View of upper and lower portions of Water Tower at Estate Little Princess, facing east. Photograph by author, 12/14/19.

Figure 68. View of interior of the second phase of the Estate Little Princess Water Tower. Note the wooden support beams which once facilitated a wind turbine crankshaft. Photograph by author, 7/19/19.

Within the archway, there is a wood timber held in place (visible in the top left corner of Figure 64). It is located 25 cm above the step, at a measure of 53 cm inward from the north side of the archway, and 30 cm from the south side of the archway. The timber measured 8 cm tall by 11 cm wide. It is not flush with the interior wall of the well, but instead extends 5 cm into the wall and is secured on either end by plaster. At the same height as the wood timber in the archway, are two cut areas along the interior circumference of the well structure, presumably placed at opposite ends of the structure to hold additional support timbers for the drive shaft. These are in the opposite end of the interior from the archway, and off center. These cuts are approximately 1m apart, and measure 10 cm tall by 10 cm wide. Below and perpendicular to the archway is a large wood timber, held in place by two large cuts in the interior. These cuts are larger than the others and support a much larger timber. These cuts are 27 x 27 cm and hold a rectangular timber which possesses nearly those widths and heights, and spans 185 cm long across the interior of the well. Generally orientated towards the north and south, and two meters above of, and off center of the previously described larger rectangular timber, lies another smaller timber, which is also placed in cut insets in the wall of the well. This piece of wood is 14 cm tall by 14 cm wide and stretches 185 cm along the interior of the well. Tied around this timber is a rope. The timber also possesses three cut marks spaced equal distance along its length, each with its own threaded metal bolt, which run through the wood and are held in place with square metal nuts.

There is an abrupt change to the construction style in the structure, visible on the exterior of the well tower, at a height of 7 m. Here the second tier of the tower is approximately 25 cm narrower in diameter than the lower tier (Figure 61, Figure 62, and Figure 67). This second tier also appears more weathered. It also seems to have been built with a more consistent and regular application of quicklime to hold limestone stones in place, and features occasionally included bricks and pieces of coral that are also held together with plaster. The second tier also has its own doorway/archway large enough for a person to pass through (approximately 1.75 m tall and .5 m wide), presumably so that individuals could install and later repair or replace upper portions of the wind turbine crank shaft and or perform maintenance tasks on the upper portions of the tower.

Views from the interior of the structure make several features within the second tier of the tower apparent. Just at the start of the second tier there is a second set of cut slots designed to support timbers that would form a square (Figure 68). These wood slot features also extend to the exterior of the structures, making any extant timbers that are still *in situ* visible from the well's exterior. When this well was in use, these cut slots would have allowed the timbers to be set and replaced from the exterior of the structure with relative ease. Another 180 cm above this second set of timbers lie a third set of timber cuts in the stone. This set of cuts are eight in number, and are also visible from the tower's exterior. Another 2 m above these timber cuts were an additional six vertical cuts into the stone spanning the remaining height of the tower, spaced equal distance apart along the interior of the circular structure, just off center from due north. It is clear that the cuts or spaces in the stone structure all once held timbers as several timbers were still seen *in situ* (Figure 68). Two-thirds the way up this last set of cuts, a fourth set of, still extant, crossed woodworks, were found, consisting of two timbers each.

At its very top the structure narrows to just 2 m wide. From wooden remnants at its top, it is clear that it was at one time covered with wood which served to support and house a wind turbine platform and gear box during the well tower's active use. While these elements are no longer present on the structure, photographs taken during the late nineteenth century of ELP's sugar factory depict the water tower in the background and give us an idea of what these superstructure components looked like when the structure was in use (Figure 69). This photograph shows that the water tower once possessed a four bladed drive shaft with wooden sails. It is also clear from this photograph that the drive shaft was seated on a platform which was designed to be rotated, which would have allowed the sails to face, and better catch, prevailing winds at a given time. It is less clear if this platform at the top of the mill possessed a dome in which the turning mechanism for the shaft would have be housed, or if the shaft was turned via a "tailpole" often made of several joined pieces of timber which would reach down from the mill shaft to the ground surface so that it could been turned using manpower or animal power. Based on the technologies implemented on other wind driven mills on the island, it is more likely that the ground-based turning technology was used, as this type has been noted to be in use on windmills at St. George's Plantation, Butler Bay Plantation, and Whim Plantation during the nineteenth centuries.

Figure 69. Photograph of Estate Little Princess Factory (center) and Water Mill (top left corner), from northwest of the Factory, facing southeast, from the ELP on site collection, entitled "Estate Little Princess STX #1958". Photograph by unknown, taken sometime between 1860s and 1949, based on the factory's size and use, and the fields behind the factory being planted in cane.

The trough running along the base of the exterior of the well forms a semicircle 14 m in circumference, and a rim that comprises 40 cm of that circumference (Figure 64, Figure 65, and Figure 66). The width of the pool ranges from 60 – 70 cm and varies due to undulations in both tower wall and rim wall. The height of the rim varies between 22 – 27 cm (measured from the interior plaster floor of the pool). At the time of examination, only the south half of the pool held standing water. The north half was filled with hydrated mud. The trough's circumference of the tower is cut short on the north side of the entrance by a 2 m wall emanating from the exterior well wall, and on the south side by a wall equal to the width of the exterior of the wall. This north wall (visible within the right half of Figure 64) is 40 cm wide, and 44 cm tall from the pool base, but is in poor condition, and worsening, with stone, brick, and plaster pieces actively eroding from exposure to the elements.

There are a few cracks in the exterior of the well wall that seem to feed the trough, though it is suspected these are more signs of wear than original design. There is however one intentional hole at the north point on the perimeter of the well tower, intended to feed the trough with water. On the northeast exterior of the well, there is an almost pink sandy plaster smattering lying 1.16 m above the pool floor with the numbers "1-7-4-5" (presumably representing the year 1745) and the letters "AT RM" scrawled into it (Figure 66). While admittedly a piece of speculation, considering a possible construction date of 1745 would mean that it was built within just 2 years of the plantation's original Danish purchase by Governor Frederick Moth. If true, this would suggest that the well was perceived as a necessity that would need to be prioritized to make the plantation inhabitable and or profitable. While we might speculate as to the meaning of the numbers "1-7-4-5," the letters "AT RM" on the plaster remain a mystery, as the letters do not

correspond with any of the known owners of ELP. The pink color of the plaster comes from clay and or smashed bricks, which was added to the quick lime during mixing, strictly for its aesthetic qualities (David Hayes, personal communication, 2019).

The water tower sits at the lowest point of elevation of any of the major structures associated with the plantation. The plantation's sugar works area is seemingly strategically placed to be both close to the sugar factory where it would be needed most (whereby it would afford workers easy access to the areas kept in sugar on plantation to the south) and set in a location close to the ghut which runs through the plantation (where drilling down into the earth would effectively tap into the freshwater table). It is also interesting to note that the water tower lies only 154 m to the southwest of the Atlantic Ocean, suggesting that during its period of use, fresh water was sufficiently available in the area to enable the well to draw down its share without inadvertently drawing oceanic salt water into the local water table via the well's cone of depression.

The Windmill Turned Cistern

The ELP also contains the ruins of a windmill which lived a second useful life as a retrofitted cistern once steam technology came to the plantation (Figure 60 and Figure 70). This windmill/cistern structure stands atop a hill approximately 3 m higher in elevation than the base level of the water tower and 125 m to the northwest of it. The mill was originally built in 1766 as a wind driven mill, which was used to press sugarcane to harvest cane juice. As a sugar mill, this structure has been described as "typical of windmills in the West Indies" in that it is conical in shape and was clearly once topped by a flat platform designed to receive the windshaft housing (Wright et al. 1980:4). Some remnant wooden planks still covered the rim of the top of the cistern at the time of recording. The introduction of a 10-horsepower steam mill to the plantation in the latter half of the 1840s prompted the wind mill to be remodeled into a water cistern. The mill structure is built of coral blocks and bits, cut and uncut pieces of limestone, structural and decorative plaster (both gray and pink), and yellow and red brick. The base and crest of the cistern are comprised of equally sized cut stones (at the base) and bricks (at the mill's crest), which were laid an equal distance apart around the circumference of the structure.

Figure 70. View of the Windmill Turned Cistern on Estate Little Princess, facing northeast. Photograph by author, 7/31/22.

The mill/cistern is 8 m in diameter at its base and reduces in size as it rises to a height of 6.5 m pinching off to 3 m in circumference at its top. The structure's circular base is comprised of comparatively well organized and intentionally laid limestones and plaster (Figure 71). The extent to which base stones protrude above the ground varied from stone to stone. Stones that were found above ground proved to have a "lip" which extended beyond the cylinder of the mill, with widths ranging from 14 cm to 20 cm. Base stones on the mill's eastern side (on which it is built into the natural hill) are entirely subterranean. The maximum height of the lip was recorded at 65 cm on the western side, though its height varied considerably, with some stones either partially or completely buried beneath the ground surface. At the top of the windmill a scant collection of wooden planks are all that remains of a super structure which was once used to house and support a wind turbine, crank shaft, and large set of mill gears. These elements of the mill were still extant as recently as 1980 when the property was surveyed for a National Register of Historic Places nomination. At that time additional traces of the housing at the top of the mill were noted (Wright et al. 1980). In all, the sugar mill was of typical design for the eighteenth century on St. Croix and lived up to its utilitarian purpose.

Figure 71. View of the lip at the base of the Windmill Turned Cistern at Estate Little Princess, facing southwest. Photograph by author, 7/12/19.

As a retrofitted cistern, however, the structure proved to be a bit more unique. This transformation – from a sugar processing mill into a water management feature – was completed through the covering of the sugar mill's openings, entrances, ventilations, and non-watertight crevasses with a mixture of construction materials (including cut coral, cut rock, and brick) slathered (on both the exterior and interior) with a heavy coating of plaster (Figure 70, Figure 72, and Figure 73). The main archway/entrance to the mill (which faces west) measured 4 m wide by 4.5 m tall and was sealed by a combination of brick, coral, limestone, plaster, and perhaps even some fired bagasse (though it is difficult to be certain without having broken off pieces of the structure for further analysis) (Figure 70). A secondary archway smaller than the first and located just 2 m to the southwest of the first, was also sealed. The top of this archway was entirely comprised of yellow bricks, with their narrow sides vertically oriented. Beneath this arch, the gap was filled with a mixture of coral, brick, and plaster. In its second life, this archway was made to hold a 15 cm tall by 15 cm wide timber, which protrudes into the structure (Figure 72).

Figure 72. View of the south side of the Windmill Turned Cistern at Estate Little Princess, facing north. Photograph by author, 7/12/19.

Figure 73. View of the north side of the Windmill Turned Cistern at Estate Little Princess, facing south. Photograph by author, 7/12/19.

The cistern possesses a 1 m wide building scar on its northern side which reaches 5 m up the wall of the structure. This feature was likely designed to allow for the installation of the main shaft of the windmill, a timber far too long to be installed through the mill's main archway (Figure 73). While it is evident that the scar was eventually made watertight through the generous application of plaster, it is far less clear whether the scar was filled in during the mill's useful life, or only during the conversion of the structure into a cistern. Indeed, plaster seems to be the defining characteristic of this conversion work, as the patchwork nature of, and in places, generous applications of, and apparent reapplications of, plaster on the exterior of this structure, suggest that there was not only an initial conversion/construction process but subsequent repair episodes that likely followed water and wind-based erosion of stones/corals, and plaster.

Sugar Factory Cistern

The ELP sugar factory cistern is rectangular in shape, with one of its two longer sides facing the north and abutting the ELP's sugar factory. The other side runs quite close to due east to west (Figure 60 and Figure 74). ELP plantation records do not specify when this cistern was built, but it seems likely that it would have coincided with a series of plantation infrastructure improvement projects which included the installation of the plantation's first steam engine, the

plantation windmill's conversion into a cistern, and the expansion of the plantation's sugar factory, all of which transpired during the latter half of the 1840s (Tyson N.D., Wright et al. 1980). The cistern is made of cut stone, red and yellow brick, and cut and broken coral held together by plaster, and measured 91 cm thick on all sides. (Figure 74 and Figure 75). On its exterior the structure measures 9 m long, and 5.4 m wide. The southern wall's maximum exposed wall height was 1.88 m above the ground surface. The cistern's southeast corner was noted to be the lowest of the four, demonstrating an overall gradual slope down towards the southeast for the structure. The cistern's southern wall has two columns comprised of brick, stone, and plaster. These columns are roughly equidistant from both each other and the southwestern and southeastern corners of the southern wall. These columns are 60 by 60 cm in width and depth, with the highest still extant portion of the easternmost column standing 1.32 m tall (Figure 74). The westernmost column is shorter, which is a result of the building's decay over time through exposure to the elements.

Figure 74. View of southern exterior wall of the ELP Sugar Factory Cistern, facing northeast. Photograph by author, 7/31/22.

Figure 75. View of western exterior wall of the ELP Sugar Factory Cistern, facing east. Photograph by author, 7/31/22.

The southern wall of the cistern is also punctured by what appears to be a silver-colored metal pipe which is seated within the wall 30 cm below the wall's maximum height (Figure 54). The wall around the pipe has deteriorated to the point that portions of the pipe are exposed, but the pipe is still held firmly in place. The pipe has a diameter of approximately 2.5 cm, and it extends approximately 8 cm into the interior. The pipe also extends 14 cm beyond the southern extent of the wall.

What appears to be a pier lies approximately 8 m south of the wall, at an approximately 135-degree angle. The pier is composed of yellow brick, red brick, plaster, coral, and cut stone, standing 1 m tall (though several coral, cut stone, and brick pieces are missing from the top). It is 1.32 m wide and 1.27 m deep, sitting atop a 3 m wide berm that measures roughly 30 cm above the ground surface (Figure 76). This pier may have served to help allow run off from the cistern to be directed into a nearby pond located approximately 5 m to the south of pier via the metal pipe in the southern wall of the cistern (Figure 77). This pond is also thought to have been used as dumping grounds for the wasted materials generated through sugar production activities including sugarcane bagasse, dry leaves, sugarcane tops, pressed sugarcane, and water used in the rinsing and cleaning of factory equipment (Richard Gideon, personal communication, 2022).

Figure 76. View of eastern side of the Pier to the south of the ELP Sugar Factory Cistern, facing west. Photograph by author, 7/31/22.

Figure 77. View of the Pond to the south of the ELP Sugar Factory Cistern, facing southeast. Photograph by author, 7/31/22.

Dripstone

The remains of a dripstone structure were found lying approximately 60 m southwest of the southwestern corner of the plantation's sugar factory ruins (Figure 60). Overall, the structure appears to have either been demolished or reduced to ruins through weathering and a lack of maintenance, with the remains arranged in a fashion to suggest that the structure at one point collapsed downslope towards the east. The dripstone housing structure is comprised of Danish (yellow) brick, red brick, cut stone, and plaster (coral is notably absent) (Figure 78). The dripstone itself consisted of a carved piece of limestone which not only included the "bulb" that formed the dripstone's bottom, but also a small rectangular prism of limestone used to mount the apparatus via plaster to a hanging brick and plaster column which was once connected to the structure when it stood (Figure 79). This hanging brick column measured 2.15 m long by 25 cm deep and wide (Figure 79). The cut cube portion of the limestone measures 58 cm on all sides. The diameter of the dripstone bulb is only slightly smaller than the 58 cm which comprises the side of the limestone cube. A large piece of rubble of irregular shape consisting of brick, plaster, and cut stone, measures approximately 3 m long by 1.07 m wide, and lays to the northwest of the dripstone. This piece likely once formed a portion of the structure's northwestern wall. Another smaller piece of rubble lies to the southeast of the dripstone. This piece is roughly cube shaped, consisting of bricks, plaster, and cut stone, that was broken off from the standing structure in an uneven way.

Figure 78. View of the ruins of the ELP Dripstone Housing Structure, facing west. Photograph by author, 7/31/22.

Figure 79. Detail view of the ELP Dripstone, facing west. Photograph by author, 7/31/22.

The dripstone is located within 60 m of a ghut, which runs from southwest to northeast across the southern half of the plantation, and the plantation's sugar factory cistern. This proximity makes it conceivable that water was run over the dripstone via a conveyance drawing water from either the ghut or the cistern (Figure 60). At the time of survey however (July 2022) no material evidence could be found in the vicinity of the dripstone ruins (or in the vicinity of the ghut or sugar factory cistern for that matter) to suggest the presence of a water conveyance connecting these features. Alternatively, it is possible that the water was poured over the dripstone via hand carried water buckets, filled with water from either the ghut, the cistern, or the plantation's water tower.

Chapter 8. The Characterization of Water Uses on Sugar Plantations in St. Croix

The findings from this archaeological survey of colonial era water management features on plantations in St. Croix (Chapter 7), combined with data collected through other archaeological, historical, and ethnographic studies conducted across the Caribbean can help us characterize types of water uses and water management strategies deployed on St. Croix during the seventeenth, eighteenth, nineteenth and early-twentieth centuries. The water management features examined during the survey on the island included: three stone-lined wells, two wind driven water towers, three plaster lined cisterns and a windmill converted into a cistern, a water driven mill, a water "flume" (or aqueduct), two coarse earthenware water carrying jugs, and a dripstone. These were recorded on the grounds of six former sugar plantations including Estate Morning Star, Estate St. George, Estate Washington, Butler Bay Plantation, Estate Whim, and ELP. These plantations were located across the western half of the island, where sugar planting and manufacturing once dominated the landscape.

The recorded water management features allude to three categories of water use on the sugar plantations of St. Croix. The first category is water that was managed for use by humans who occupied and worked on plantations, both free persons and enslaved Africans, for drinking, preparing foods, washing clothes, washing themselves, and use during religious or spiritual ceremonies. The second category consists of the water required by draft animals, cattle, or other livestock kept on plantation which might have served various purposes, including but not limited to: ploughing sugarcane or other agricultural fields, pulling heavy loads or carts or wagons, or turning cane-crushing mills. Some animals kept on plantations were also eventually butchered for consumption including cattle, hogs, goats, and chickens, to sustain the human populations working on the plantation. These livestock had daily drinking water requirements and would have needed ready access to ghuts or wells with large quantities of water. The third category of water use on these plantations is that which was used during the processing and manufacturing of sugarcane into muscovado (brown sugar), rum, or molasses. While the amount of water required for these processes and to clean the equipment between runs of production are not particularly large, a discussion of this category of water use is warranted because it is through these processes that the entirety of the water present in the harvested sugarcane is lost to the surrounding environment.

There is also an important fourth category of water use on sugar plantations that must be considered even though it is not directly referenced by the water management features recorded on St. Croix. This category consists of the water used to grow the sugarcane plant, which includes the ground water within reach of the roots of the plants, the rainfall that directly falls onto the plants (as well as any water that falls uphill of the plans and rolls and percolates down slope), and any water that planters stored or extracted from elsewhere for use to water their crop. This category of water use represents the sugarcane industry's largest opportunity to impact local hydrological systems, as it constitutes the single largest use of water on a sugar plantation.

A more thorough description of each of these four categories of water uses on sugar plantations on St. Croix and the various activities that are associated with each, is provided below. Reference to recorded details from remnants of recorded water management features on the island are

drawn to demonstrate the role these recorded features might have played in plantation water management strategies. It is a goal of this work to ultimately present the findings of a water balance model intended to simulate the amount of water available vs the amount of water used on a sugar plantation in St. Croix. Consequently, I also present scientifically informed estimates for the quantities of water that would have been consumed in association with each of the four categories of water use described.

Category 1 Water Consumed by, or Otherwise Used by, Humans

From the start of Danish rule on the island (1733) through 1848, planters on St. Croix forced enslaved Africans to work on sugar plantations either as sugarcane field hands, sugar factory workers, drivers, or house servants. Even after emancipation, technically free, but largely indentured black laborers were subjected to harsh living conditions, exhausting working regimens, and spartan diets, and expected to work the cane fields. In this way the 200-year long sugar planting industry's success on St. Croix was largely predicated on the labor forcibly extracted from first enslaved, and later free Africans and Afro-Crucians.

The drinking water imbibed and otherwise used by laborers on sugar plantations was stored in a wide variety of vessels in settings across the Caribbean including buckets, glass and clay jars, metal pots, and leather containers. The water jugs recorded on Estate Whim Planation, would have perfectly filled this role (Figure 56, Figure 57, Figure 58, and Figure 59). The jugs from Whim are made of coarse earthenware, and possess a clay slip which would have required lower firing temperatures than other forms of ceramics. Requiring only readily available materials and low overall effort to produce, utilitarian jugs like these would have still possessed a good level of water impermeability. These jars would have had the additional benefit of being inexpensive to produce, bearing no adornments, and would have been effectively maintenance free (save for the removal of debris, and or the occasional cleaning). The jars from Whim were also designed to be able to stand freely without support. These water jugs could have been left out in the open during rain events, or deliberately placed at the lowest corner of a roof to collect water. They might have also been used to collect and store water from wells or ghuts. Simple wooden tops would have also assisted in the prevention of evaporation from these jugs and or, protected the jugs' contents from the inclusion of unwanted contaminants or critters.

Elsewhere in the Caribbean, both similar and dissimilar variations of water vessels were used. In Dominica "biot jars," which bear a striking resemblance to the examples from Estate Whim, were used, but goglets, and re-used glass wine bottles and jugs are known to have also been used for water storage (Hauser 2017, Figure 80). In Barbados and the Bahamas wider mouthed and coarser ceramic jars are known to have been used in a similar fashion (Wilkie 2005). Across the Caribbean water collected and or stored in these types of containers was used for cooking, washing clothes, cleaning houses, structures, or objects, or for personal hygiene on plantation settings. Some of this water might have also been used in conjunction with Christian or Afro-centric religious rituals (Finneran 2017, Hauser 2017). It is reasonable to consider that jugs like those recorded at Estate Whim might have held water for the same variety of purposes in St. Croix.

Figure 80. Examples of Caribbean water vessels, on left, Goglet, and on right, Biot Jar, both from plantations in Dominica. Images from Hauser 2017:237.

Dripstones are another water management system that were deployed in a variety of Caribbean settings as water purifying systems for water that will be consumed by humans. These systems consisted of two pieces of porous rock (usually limestone) with one placed above the other, and a jar placed underneath them to collect water that had "dripped" down the two stones (Finneran 2017, Figure 61). The dripstone ruins recorded for the current study were found 50 m to the southwest of the ELP's sugar factory. Possessing two cut limestone elements stacked on top of one another, this structure allowed water poured on top of one the cut stones to permeate down through both, before finally dripping into a receptacle for storage and later use. This water purification method was quite popular across the region, and Barbados is known to have exported large amounts of cut limestone to customers on other islands who sought to build dripstone setups. Some dripstone examples have even been found with traces of charcoal added into the pours of the stones to aid in filtration (Mathison 2002). Despite the system's crudeness, recent studies have suggested that while dripstones did not remove all bacterial contaminates from the water, they were able to extract significant amounts of harmful coliform bacteria (Mathison and Barker 2002).

Figure 81. Limestone "Dripstones" for water purification. Barbados Museum. Image from Finneran 2017:8.

House cisterns were another recorded means of water collection and retention for eventual use by humans living and working on sugar plantations on St. Croix. The cistern attached to the Great House at Butler Bay plantation for instance, likely stored water primarily for use by plantation owners or managers, their guests, and house staff living and or working in the adjacent structure (Figure 40 - Figure 45). It is also certainly possible (though undocumented in this case) that water rations from cisterns, might have been doled out to enslaved or free laborers living on the planation in times of drought. This archway topped cistern is thought to have been in use since at least the 1800s and can hold some 68,894 liters (18,199 gallons) at maximum capacity. In the past it may have been rain fed (through the opening in its center), however it has been more recently modified to receive water through roof top catchments and conveyances (Ryan Flegal, personal communication, 2022).

It is not uncommon to see cisterns holding water for human consumption in other colonial-era Caribbean contexts. On the particularly rainy island of Saba, for instance, a vast network of shared cisterns was constructed, 250 of which have been archaeologically recorded (Espersen 2013). These structures would have represented a great deal of communal investment to construct and maintain. Connected to flat rectangular catchments, each measuring between 8 and 9 m in length, and an average width of 5 m, the cisterns on colonial Saba were about half the size of their respective catchments and held a volume of water ranging between 10,000 to 36,000 liters (or 2,641 to 9,510 gallons) (Espersen 2013). While the cistern attached to the Butler Bay Greathouse is far larger (with a maximum capacity of some 32,894 liters more than the largest found on Saba), the purpose of these reservoirs remained the same: to store and manage captured rainwater. The greater size of the Butler Bay cistern can be attributed to the less frequent precipitation on the island (especially when compared to Saba), which would have encouraged its owners and managers to prioritize storage capacity for quantities of water that would be sufficient for extended periods of drought or infrequent rains.

Recorded ruins on St. Croix also included three stone-lined wells. Wells like those found on St. George (Figure 26) and Butler Bay (Figure 46 - Figure 50 and Figure 54 - Figure 55) plantations would have served to separate ground water from the surrounding water table, providing an accessible, and to the extent that local precipitation and ground water limitations would allow, re-chargeable, water supply. Deep stone-lined wells, like the one found in the proximity of Butler Bay's sugar factory, would have been appropriate in areas where the water table was particularly low, or slow to recharge. On other islands like Barbados and St. Eustatius, deep stone-lined wells provided access to groundwater that would later be used by the enslaved, or later free laborers, and to maintain livestock (Finneran 2017). The staircases found in the stone-lined well near West End Road on the Butler Bay property, and the stone well on St. George's plantation, appear to have been a local adaptation or stylistic flourish, perhaps indicative of a local custom to draw water by hand into jars or other water containers, or perhaps to provide easier access when water levels inside the well were particularly low.

Much like the wells recorded on St. George and Butler Bay, the wind-driven water towers at Estate Morning Star (Figure 21 – Figure 25) and Estate Little Princess (Figure 61 – Figure 68) served to access water stored in the ground and make it available for use. These towers' wind-driven fans would spin around on a shaft, which would in turn drive a mechanism that converts the fans' sideways facing rotary motion into downwards facing rotary motion, to drive a screw (or vertical plane wrapped around a wheel) which would draw groundwater up from depth to the

ground surface. Windmill derived ground water was commonly used to provide water for livestock and to water gardens. These waters were rarely used for the purpose of human consumption due to their high mineral content, but in times and places of need, ground water extracted in this way may have also been used by enslaved and later free plantation laborers.

A conservative estimate on the amount of water consumed per day, per enslaved or free laborer on a Crucian sugarcane plantation can be understood to be approximately 0.396 gallons (1.5 liters). This estimate is interpolated from peer reviewed scientific papers and biology journal articles published throughout the twentieth century (Vivanti 2012). This estimate is set intentionally below the recommended water intake of 0.740 gallons (2.0 liters) for an average male (weighing approximately 154 pounds or 70kg), and even more so beneath the recommended amount for an average male who is exerting himself and perspiring (0.740 gallons or 2.8 liters), which laborers did regularly in the tropical heat (Craton and Walvin 1970, Hauser 2017 and Vivanti 2012). This deliberately low estimate is in consideration of how poorly enslaved and later freed Africans were often treated. This estimate does not account for the water that is regularly obtained from food, especially fruits and vegetables, as these amounts have not yet been fully studied (Vivanti 2012). Lastly, it should be mentioned that this estimate does not accurately reflect water requirements that enslaved or free laborers had for cleaning or bathing, and certainly does not consider water as an instrument in religious practices or ceremonial practices (White 2012). These omissions notwithstanding, the 0.396 gallon (1.5 liters) daily per person estimate still provides us with a baseline quantity of water necessary to sustain life for the laborer populations on a given plantation.

European/white plantation owners, managers, and staff likely had access to higher quality (more safe/naturally filtered) water, and likely, on a per person basis, used larger amounts of water than their black captives and laborers. An estimate of 0.740 gallons (2.8 liters), or the recommended water intake for someone regularly exerting themselves, could be put forward as a daily amount consumed for each European/white that lived on a plantation (Vivanti 2012). This larger number is because the plantation owners and white workers, would have had better access to, and control over, the water resources available within a given watershed. Furthermore, this increased estimate can help account for the fact that plantation owners and managers were afforded the opportunity to bath more frequently than the enslaved that lived on plantations (White 2012). This larger daily estimate does not amount to much additional tax on the water systems however, as the ratio of white owners, managers and staff, to enslaved or freed African laborers on sugar plantations was heavily lopsided. Depending on the specific island and size of a given plantation, the ratio could range anywhere between 1 to 6 and 1 to 150 (Dunn 1973).

Category 2 Draft Animals and Cattle

The second category of water use on sugarcane plantations consisted of the water required by livestock, including cattle, horses and donkeys, sheep, goats, and pigs. These creatures might have served various purposes within the plantation. Plantation animals also provided a happy byproduct in the form animal manure, which was readily used as a fertilizer on agricultural crops including sugarcane. High in nitrates and other nutrients that nourish plant and encourage plant growth, cattle, horses, and sheep were common sites on colonial period plantations throughout the Caribbean to assist in the production of this valuable planting material (Meide 2003, Dunn 1973). As sugar cultivation was the leading source of income throughout the Caribbean, animal manure was in high demand. This led some planters, incapable of amassing the property or

capital necessary to grow sugar or other cash crops, to pursue the ancillary industry of raising animals strictly for dung production and draft work.

Water management structures were developed on St. Croix with the intention of providing access to, and storage of, fresh water for animal use. Though also for human use, stone-lined wells were used to provide water for draft animals, cattle, and other livestock. Wind driven water towers were also used for this purpose. This reality was made quite clear in both the case of the ELP water tower, and through the presence of a watering trough located very close to the stone-lined well identified on the grounds of Butler Bay Plantation. Located around the back side of the circumference of the ELP's water tower, was a watering trough that was designed to seamlessly draw water from the near surface water reservoir that the wind driven pump once filled, making the water easily accessible for consumption by livestock (Figure 63 –Figure 66). The trough at Butler Bay (Figure 51 – Figure 53) located just 15 m to the southeast of a stone-lined well, seems to have been built in close proximity to the well so that it could be readily recharged for use through the carrying or pumping of water from the well to the plaster lined trough basin.

Estimates for the daily water requirements of various animals commonly found on a plantation vary based on sources. However, by taking the approach of averaging three provided sets of estimates, we can develop a useful understanding of these animals' water requirements. Using averages taken from two university based agricultural extensions, and a USGS based study of livestock water use in the US Virgin Islands and Puerto Rico we have the following estimates: 12.25 gallons (46.37 liters) per day per cow/cattle, 15.4 gallons (58.29 liters) per day per horse, 1.67 gallons (6.32 liters) per day per sheep, 1.75 gallons (6.62 liters) per day per goat, and 3.33 gallons (12.61 liters) per day per pig (Molina-Rivera 1998, Meehan 2015, Ingram N.D.).

Category 3 Sugar Processing

The third category of water use suggested by the built water management features recorded on plantations on St. Croix is water used in the processes of sugarcane juice extraction, sugarcane manufacture, and the maintenance of sugar producing equipment. Cleaned sugarcane culms (or the jointed stem of the sugarcane plant, where sugar is primary stored) were taken via horse drawn cart, or by hand, to the nearest mill to be pressed. Earlier in St. Croix's Danish history these mills were located on site on the plantation where the cane was harvested, but in some instances several plantations would share a mill. Mills on the island relied on dense rolling pins made of wood or iron that would be placed close to each other with a gap smaller than the diameter of sugarcane stocks. These rolling pins were turned by gears that were driven by draught animals in the seventeenth and eighteenth centuries, wind from the eighteenth century onward, and on plantations that could afford it, steam engines from the middle of the nineteenth century onward. The culms of the plant would be placed between the two rolling pins. Beneath the pins a pan was placed to capture the cane's sugary juices as they were pressed out of the culms (Meide 2003:12). The juices of these cane culms were derived from two parts of the plant; the pith cells (or growth cells), largely present between each node on the cane stock, and the plant tissues (or fibrovascular bundles), located in both the node and internode of the cane. The fibrovascular bundles are more structural, contain less water, and are much harder to break but still do contain enough sucrose to be worthy of planters' concern. Thus, cane was pressed through the rolling pins twice, with the first run through the mill extracting the bulk of the juice from the pith cells, and the second, applying more pressure but ultimately releasing less juice from the fibrovascular bundles in the cane stock (Deerr 1905:5).

Pressed cane juice was then transported to the aptly named boiling house which on some plantations was its own standing structure, and on other plantations was located within a larger sugar factory where it would have been more of a boiling room. There it would be continuously boiled to remove water from the juice, ultimately producing crystalized muscovado sugar. The cane juice could sometimes be transferred from the mill to the boiling house by emptying the rolling pin's pan into jars or other vessels and carrying those vessels via hand or cart to the boiling house. In many instances where both proxemics, and the relative elevations of, a plantation's mill and boiling house would allow, cane juice conveyances (or slues) were often built. These were constructed out of either poured plaster, or, in the twentieth century, metal, and carried cane juice directly to holding tanks within the boiling house. Once inside the boiling house, the juice was transferred, again by a vessel or conveyance, to the first (and largest) of a series of four to five heated copper kettles or pans (called coppers) placed from largest to smallest atop a furnace (Meide 2003) (Figure 82). Over time technological developments in the coppers' furnace structure, which were later designed to better concentrate and guide air and heat over each copper allowed the use of bagasse (already pressed cane stocks) as fuel for the fires. As factory laborers moved the juice down the line of successively smaller pans with copper or iron ladles, they would skim impurities off the surface. Using evaporation, they would cook the juice down into a dark brown taffy-rope like mass. At the point of crystallization (known as the strike) a skilled worker would dampen the fire and move the taffy-like substance into a cooling cistern. One gallon of freshly pressed juice was expected to produce around one pound of muscovado sugar (Dunn 1973, Meide 2003:13). Once cooled, the sugar was packed into containers, shaped into cone-shaped loaves, and drained.

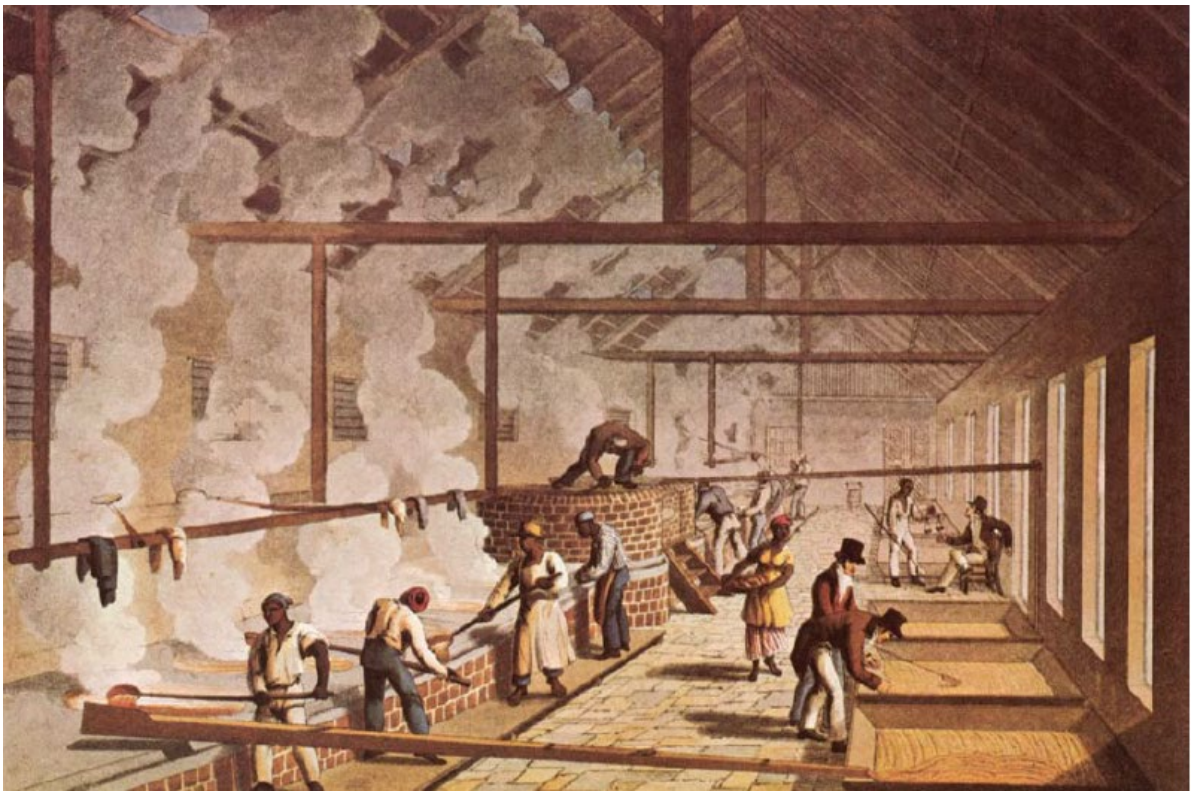

Figure 82. Interior view of a working boiling house, the Delap sugar factory on Antigua, ca. 1820. Image from Meide 2003:14.

At first glance, the uses of water in the processing of sugar just described, are not entirely obvious. The processes of harvesting a cane plant, pressing it, and boiling its juice down to brown sugar, are not steps that explicitly spell out the use of water. It should be acknowledged however, that through the sugar making processes, the whole of the liquid present within the sugarcane plant is lost through evaporation brought on by the boiling of the cane juice and the use of husks and bagasse as fuel for the fire under the boilers. These water losses are considerable when compared to the fate of the water trapped in other agricultural produce. Soybean for instance, is another water intensive crop. However, even after harvesting, soybeans retain water in their fruit. This water is ultimately passed on to the human or animal eating it and thereby reduces the daily water intake needed by the consumer. Even rice, which is another water intensive crop, does not see all of its water wasted after harvesting. Instead, the grain's parent plant is mulched after harvesting, enabling the return of its moister to the soil. By contrast, nearly 100% of the water initially soaked up into a sugarcane culm during the plant's development is lost through the processes of pressing sugarcane juice, boiling it, and fueling the fires required for boiling (Anda et al. 2018, Bouman et al. 2007).

Besides the water from the plants themselves, water is also needed to clean the cane processing equipment between batches or harvesting seasons. Rolling pins, pans, cane juice conveyances, cane juice boiling coppers, and holding and cooling tanks and cisterns, would need to be rinsed or washed periodically. Often this was done simply by pouring or pumping fresh supplies of water onto the apparatus requiring cleaning, and perhaps the application of hands or scrubbing brushes or mops to pry loose any debris like cane fiber or cane stock husk (in the case of rolling pins, pans, and conveyances), or granules of sugar or additives added to the cane juice during the boiling process which adhered to the interior of the boiling coppers. On occasion, a readily available disinfectant was sometimes fashioned by combining rinsing water with vinegar to aid in the cleaning of the equipment. The precise amounts of water used in these cleaning and maintenance processes on colonial era plantations is unknown and would have varied from plantation to plantation depending on the sugar processing equipment on site and the preferences of planters and managers. While a common, and potentially even frequent occurrence on active sugar plantations, it is unlikely that these practices constituted a major drawdown on local water reserves.

The proximity of the water cisterns at Estate Washington and ELP to other structures on the plantation strongly suggested that the water within these cisterns was at least partially used in the maintenance of sugarcane processing equipment. The cistern at Estate Washington, for instance, was built within 6 m to the northeast of the estate's sugar factory (Figure 37 – Figure 39). Similarly, one of the recorded cisterns on ELP was found attached to the southwestern exterior of the plantation's sugar factory itself (Figure 74 and Figure 75). While it is reasonable to acknowledge that water from these cisterns could have also been used by humans, or consumed by livestock on the plantation (indeed, the cistern at Estate Washington also seems to possess a trough on its northeastern exterior, and lies within 25 m of the plantation's animal driven mill which once pressed sugarcane), it also stands to reason that it also may have been used in sugar refining and processing. Representing a considerable amount of effort to plan for, construct, and maintain, it is likely no accident that the cisterns at Estate Washington lay no more than 6 m from the sugar factory on that estate, and that one of the cisterns on ELP was built directly adjacent southeast of the plantation's factory.

The windmill turned cistern on ELP, represents another cistern whose water may have been used in association with sugar manufacturing (Figure 70 – Figure 73). However, this cistern's location on plantation is such that it is difficult to evaluate whether the water it contained was intended to serve the needs of those living and working in the great houses, those living in the laborers village, or the needs of the sugar factory as it is located between the great houses and sugar factory, and just 100 m east of the laborers' village (Figure 60). Nonetheless, it is certainly possible that the water kept in this cistern was occasionally drawn from for the purposes of cleaning sugarcane processing equipment. This cistern is also worthy of discussion again within this third set of water uses, because it also once served as a wind driven mill in the sugar producing process. The mill is thought to have been converted into a cistern at a time that was coincidental with either the expansion of the plantation's sugar factory, the introduction of a 10-horsepower steam mill to the plantation's sugar factory, or both (circa 1850). Tied to the production of sugar on plantation, the decision to convert the mill, rather than to destroy or abandon it, even after it was outmoded, strongly points to the need for rainwater collection and storage on the island and may even point towards the additional water requirements for the proper maintenance of steam driven mills introduced on the island in the mid-nineteenth century. Further historical and archaeological research, outside the scope of this present study, may assist in ascertaining the precise dates of both conversion of the wind driven mill into a cistern, and of the explicit purpose for this additional water storage capacity on the plantation.

Category 4 Sugar Agriculture

The fourth category of water uses on sugar plantations on St. Croix differ from the first three categories mentioned above because they did not require the construction of plaster, cut-limestone, coral, and brick built-water management features. Consisting of the water that would have been required for the successful cultivation of the sugarcane crop, these water uses were not directly suggested by the results of the hydrologically focused survey of built features on the island, but instead implied by the island's broader history of sugar production. Sugarcane has been identified by contemporary scientists and agriculturalists as a particularly thirsty crop, requiring more water than coffee, cocoa, and most root crops to produce an economically viable yield. Demonstrating this point are the prevailing estimates of the composition of ripe sugarcane which include between 69 – 75% water, 10 – 18% sugar, 0 – 2% glucose, 8 – 16% fiber, 0.3 – 0.8% ash, and 0.5 – 1% organic non-sugar (Deerr 1905:6). The known thirst of sugarcane led many planters across the Caribbean to seek out properties with access to running creeks or reliable sources of ground water so that they could develop irrigation systems ahead of planting sugarcane. This was not the case, however, on St. Croix. Here sugarcane fields were strictly rainfed, with planters relying on local precipitation patterns, and the natural flow and availability of local groundwater (largely dependent on precipitation) to keep their plants hydrated and growing (Hans Lawaetz, personal communication, 2022).

The fourth category of water use left behind no material culture to record in the sugarcane fields, but it is also by far the largest of the four categories of water uses observed in a sugar plantation setting. Estimates made regarding sugarcane's water needs vary, but all suggest very high levels of water consumption for the plant. One estimate worthy of consideration stems from a twenty first century study documenting water usage in the Niger and Chad basins (Davis 2003). Looking at the water consumed by various types of crops that were not being irrigated, this multi-year study determined that 71,937 cubic yards (or 55,000m^3) of water was required to grow 107,639 square feet (1 hectare) of sugarcane, compared with 40,546.5 cubic yards (31,000m^3) of water

needed for rice, 27,467 cubic yards (21,000m^3) of water for needed for wheat, and 23,543 cubic yards (18,000m^3) of water needed for mixed vegetables (Davis 2003). Converted to a per acre basis, this study provides us with an estimate of 29,112 cubic yards (or 22,258 m^3) as the amount of water sugarcane requires to mature over the span of its 14-month life cycle. Extrapolated to a monthly average need, one acre of sugarcane would require 2,079 cubic yards (or 419,904 gallons or 1,589,509 liters) per month.

Another estimate for sugarcane's water needs comes from Noël Deerr, author of a widely read early-twentieth century treatise on sugarcane cultivation and sugar manufacturing. Here Deerr posited that a combined 2.5 million gallons (or 9,591,666 liters) per acre would be required to grow sugarcane over a 17-month growth period to ensure a successful crop (Deer 1905:36). Extrapolated to a per month, per acre average, Deer's sugarcane water needs amount to 147,058 gallons (or 556,675 liters) required per acre per month.

We can also consider the water lost to acres of land kept in sugarcane and the amount of water lost by the plant itself through transpiration, taking a different tact in the assessment of water loss through sugarcane production. Known as evapotranspiration, the total amount of water lost from the soils due to evaporation (considering a crop's provided shade) plus the water lost in a crop's transpiration (that is, the release of water vapor from plant leaves, which varies based on the number of stomata, and rates of respiration of a given plant). Using a widely accepted method of calculation, the Penman-Monteith method of Potential Evapotranspiration estimation (or PET), hydrologists conducted a ten-year study on the evapotranspiration of sugarcane fields in Paraiba, Brazil and produced a usable estimate (Vicente et al. 2013). According to the study typical sugarcane PET amounted to 0.106 inches (2.7 mm) per day in rain-fed sugarcane fields. Multiplied by thirty (as a place holder for the average days in a month) and then fifteen months (as a place holder for what Vicente et al. considered the average time to maturation for sugarcane) we arrive at a total growth cycle potential evapotranspiration of approximately 47.83 inches (1,215 cm) per rain-fed crop. It should be noted however, that this potential evapotranspiration estimate explicitly does not account for the water retained by the plants in the growth process, which in the case of sugarcane is quite a substantial proportion of the water consumed (~72% of the mass of the adult harvested plant). Nonetheless, Vicente and his colleagues provide us with a 667 gallon (2,523 liters) per acre of sugarcane per day estimate of water lost to evapotranspiration on a rainfed sugarcane plantation.

Chapter 9. The Estate Little Princess Sugar Plantation Water Balance Model

Having examined the archaeological evidence of colonial era water management practices on sugar plantations on St. Croix (Chapter 7) and having contextualized those practices against the water requirements of various aspects of sugarcane cultivation and manufacture (Chapter 8), we are now well situated to develop a water balance model for the case study plantation of ELP. Water balance models calculate water inputs (usually precipitation) and subsequent water movement through the water cycle, be it through living organisms, or non-organic forces of evaporation (Abdollahi et al. 2019). The ELP is an ideal location for such a study, because much is known about the estate's land use history, residential population, and precipitation history. Provided below is a brief history of the ELP with an emphasis on major developments in the plantation's ownership and the expansion of sugarcane cultivated lands, sugar manufacturing works, and other capital improvements. With this data on hand, we will be well situated to prepare an historically, archaeologically, and hydrologically informed water balance model for the ELP, enabling us to consider the scale of water required to manage the sugarcane plantation for nearly 200 years.

A Brief History of the Estate Little Princess

The National Register of Historic Places Nomination form for ELP, written by Russell Wright, Phillip Lader, and William Chapman in 1980, is a good starting point for learning about ELP's land use history. Additional records regarding the history of the plantation, however, were found spread across archives in Denmark and St. Croix. A description of the resources examined, their origin, and the key information extracted from each resource can be found in **Error! Reference source not found.** below. With aggregated data from rainfall collection points located across the island, these precipitation records offered valuable insight into the rainwater that would have been available for use on the ELP during the nineteenth and early twentieth centuries. What follows is a brief synthesis of available records on the history of sugar planting on ELP from 1739 onward.

Table 1. Archival resources which inform the history of the Estate Little Princess

Name of Resource	Produced By	Key Data Contained in Resource	Where Resource Can be Accessed
Statistics Concerning Sugar Production in St. Croix from 1862 – 1889	Government of the Danish West India Islands (1892)	Annual tally of acres owned by ELP and acres kept in sugarcane as well as precipitation records for described years	Rigsarkivet Digital Online Collections
Statistics Concerning Sugar Production in St. Croix from 1890 – 1902	Government of the Danish West India Islands (1905)	Annual tally of acres owned by ELP and acres kept in sugarcane as well as precipitation records for described years	Rigsarkivet Digital Online Collections
First Danish Map over St. Croix	Johan Cronenberg and Johan Jaegersberg (1750)	Historic map depicting land use in 1750 for ELP and other plantations	Rigsarkivet Digital Online Collections
Map of St. Croix	Peter Oxholm (1799)	Historic map depicting land use in 1790 for ELP and other plantations	Rigsarkivet Digital Online Collections
Testimony and Memories of Granddaughter of Emil Erik Svitzer and Marime Johanne Svitzer (owners of ELP from 1879 – 1933)	Camila Staples (1998)	Land use practices and labor customs on ELP from 1879 – 1933	Estate Whim Archive, operated by the St. Croix Landmarks Society
Vertical File summarizing all available Probate, Deed, and Tax Records for ELP	Dr. George Tyson, of St. Croix Landmarks Society (N.D.)	Periodic tallies of: acres owned, acres kept in sugarcane, laborers on and livestock on ELP, taken from tax assessments, ELP annexations, death of ELP owners, and instances where ELP was sold	Estate Whim Archive, operated by the St. Croix Landmarks Society
Monthly and Annual Rainfall Records for Saint Croix, Virgin Islands by 10-Year Periods (Average between Frederiksted, Kingshill, Christiansted)	Cedric Nelthropp, of Federal Experiment Station at Kingshill, St. Croix US Virgin Islands, (1966)	Precipitation records for described years	Estate Whim Archive, operated by the St. Croix Landmarks Society

Deed records suggest that ELP was first developed for sugarcane planting by Frederick Moth and Peter Heyliger in 1749, just 16 years after the Danish crown had purchased the island. The original complex consisted of a great house, a windmill (built as early as 1749) and likely a small village for enslaved African laborers. Moth was born in Copenhagen in 1694 and moved to St. Thomas in 1722 to serve as the merchant of the Danish West India Company (Hopkins 1987). He was named governor of St. Croix in 1735 and acquired ELP in 1739 shortly after having been given the task of completing the island's cadastral map for the crown of Denmark in the 1730s and 1740s (Hopkins 1987, 1992). Moth made several improvements to the property over his tenure including the construction of the first mill on the property (an animal driven mill) noted on the property by 1749. Moth's ownership of the plantation was also marked by a property boundary dispute with the nearby Grande La Princess plantation to the northeast, which was owned by the crown (Hopkins 1987). Evidently this prompted the crown to take title of the property for a brief period in 1754 (Wright et al. 1980:6). Despite this complication, and partially through a suspected use of royal company funds, Moth is thought to have occupied the residence with his wife, (the daughter of Lucas van Beverhout, a prominent planter in nearby St. Thomas) and their children. His youngest daughter, Alette Moth, would grow up to marry Peter Heyliger Jr., enabling them to both inherit the property in 1756. From that time through 1803, Peter Heyliger Jr., and his direct descendants and heirs held and maintained the property, keeping it in sugarcane cultivation and production. In 1759 Peter Heyliger Jr. constructed the plantation's first great house, and by 1766 he had constructed a wind driven mill to aid in the crushing of juice from sugarcane stocks (Wright et al. 1980).

In 1804 ELP was purchased by Cornelius D. Battelle, a private investor. Under Battelle's ownership ELP annexed 125 acres of the nearby Estate Golden Rock, located to the ELP's southeast (Figure 41), a move that increased the ELP's total acreage, and acreage kept in cane by roughly 50%. The property next transferred to Cornelius's widow, Sarah Battelle after Cornelius's passing in 1818. Then in 1834 Sarah Battelle sold the property at auction. 19 Acres were sold to Peter V. Scholten, a Danish Investor, while the remainder was sold to Robert Innis Grant (Staples 1998, Tyson N.D.).

Under Grant's ownership, ELP saw the development of the second Great House (completed in 1840). Soon after completing this improvement Grant sold the plantation to joint purchasers Alexander Lang (an attorney and investor) and George Philips. By 1847, Philips, a more experienced plantation manager, was able to secure enough funding to buy Mr. Lang out of his share of the property and became the sole owner of ELP. Under his ownership Philips oversaw the installation of a 10-horsepower steam mill (circa 1847) and the expansion of the plantation's sugar factory (circa 1850) (Hatchett 1859). It was also Grant who ordered the conversion of the plantation's windmill into a water cistern (completed circa 1850) (Hatchett 1859). Following George Philips' death in 1857, the plantation passed into the ownership of Jenny Phillips, George's widow. She held onto the property for a short eight years, during which time she made no major improvements to the property. In 1865 Jenny Phillips sold ELP to Hugh Percy who also seemed content to turn a profit off the sugarcane fields already in cultivation and sugar producing capacity of the plantation's already expanded factory. (Vaughn 1977, GDWII 1892, Staples 1998, Tyson N.D.).

In 1879 Emil Svitzer purchased ELP from Hugh Percy at a public auction. Emil was understood to be an industrious and "hard man" who sought to extract great profit from the plantation, and

who expected a great deal from his laborers (Staples 1998). Svitzer was also known to host a variety of high profile guests on the estate including scientists, and members of the Danish royal family. The estate is also thought to have become one of the centers of scientific study of the island's flora and fauna during that time (Staples 1998). Between 1886 and 1889 Emil purchased the 153-acre Bellevue plantation, located roughly 1.5 miles to the southwest of ELP, and expanded the ELP's holdings to include 106 acres of the southeast adjacent Golden Rock Plantation (GDWII 1892, 1905). These increased holdings gave Svitzer the capacity to deploy a larger labor force to work and develop either of his two expanded plantations as the opportunities to do so presented themselves. This resulted in ELP reaching the highest levels of acres kept in sugarcane production during the plantation's active use, with an increase from 97 to 130 acres noted between 1879 and 1889, and a steady rise upwards before hitting its zenith in 1893 with a total of 229 acres kept in sugarcane that year (GDWII 1892, 1905). Furthermore, sugarcane cultivation acreage stayed at or above 190 acres at least through 1902. By 1920, falling sugar prices, and Emil's declining health resulted in the reduction of the plantation's acres kept in sugar to drop to just 50. After Emil Svitzer's death in 1922 the plantation would never again see cane production like that of the late 1800s. Marie Svitzer (Emil's wife) took over the plantation after Emil's passing and maintained some 50 acres of sugarcane throughout the end of 1920s (Staples 1998, Tyson N.D.). By the time she passed the plantation on to her children in the 1940s none of the estate's lands were kept in sugar.

In the second quarter of the twentieth century, most of the plantation's acreage was briefly used to raise cattle instead of sugarcane. This change in pursuit was likely brought on by the declining global price of sugar in the 1930s and 40s, and the presence of an already extant, and at this time expanding, cattle ranching economy on the island (D'Adamo 2018). The cattle industry, which had taken root elsewhere on the island during the late 1800s, came into its prime in the 1940s, 50s, and 60s, affording ELP's owners a method of extracting income from the property in the face of ever declining sugar prices (Hans Lawaetz, personal communication, 2022).

In the winter of 1945 and 1946 George Dudley, a property investor, purchased the ELP from the Svitzer's heirs, and within three years sold it to Clayton Shoemaker, a US businessman, who sought to buy the property for use as a vacation home for his family. By the 1950s, the buildings of ELP, including its great houses, water tower, windmill, and sugar factory lay in ruins, with the roof of the first great house destroyed in a 1928 hurricane. Clayton and his wife Opal made several improvements to the property, almost all of which pertained to the great houses' viability as livable residences. Sometime in the later 1950s or early 1960s the Shoemakers installed a chlorinated pool with a pump into the southeastern portion of the sugar factory ruins (Wright et al. 1980).

The Shoemaker family enjoyed the property in this way until 1977 when the family made the decision to part ways with the estate. While the northern and southern portions of the estate were sold to private investors and later developed into private residences or condominiums, the central 25 acres of the former planation, which contained all the plantation's structures, were donated to The Nature Conservancy (TNC), a US based nonprofit, for use as the organization's Virgin Islands headquarters (D' Adamo 2018, Harty 2003). This central portion of ELP has remained in the Nature Conservancy's hands since that time, with the agency restoring the plantation's two great houses for use as office space and conference rooms. In 1980 the plantation ruins on the TNC property were listed on the US National Register of Historic Places (NRHP) for their noted

level of preservation of what was described by the author of the NRHP nomination forms, as typical representations of Danish style great houses and plantation features (Wright et al. 1980). In more recent years TNC has built a coral nursery and rehabilitation center on site and has hosted archaeological investigations including the Estate Little Princess Field School run by the Society of Black Archaeologists from 2016 – 2023 and the current study.

Inputs for the Estate Little Princess Water Balance Model

Estimates for Precipitation on Estate Little Princess

Water balance models weigh water inputs (usually precipitation) against subsequent water losses from a hydrological system be it through living organisms or non-organic forces of evaporation. We can first populate ELP's water balance model with values for the water which the plantation received over the years (Abdollahi et al. 2019). In the case of ELP, we can weigh the area's water inputs, against water losses within a Microsoft Excel spreadsheet, and run basic addition, subtraction, multiplication, and division formulas to understand the amount of water that was added to and removed on an annual basis from the plantation. Effectively the means by which water was introduced to the plantation during the historic period consisted of climate-based rainfall. Available rainfall inputs for the ELP's water balance model consisted of historically collected rainfall records for the island which used averaged monthly data from rain gauges located in Fredricksted, Kingshill, and Christiansted, to provide average rates of rainfall across the island for a total of 113 years. One of the publications that provides these records was produced under the auspices of the Government of the Danish West India Islands. Entitled *Statistics concerning Sugar Production St. Croix from 1862 – 1889*, this document provides the precipitation records for the island over those 27 years. In all but 4 of the years covered in this document, (1861, 1878, 1879, and 1881), St. Croix received less than 440 Danish lines (55 inches) of rain, an amount generally understood to be necessary to efficiently raise sugarcane of sufficient size to ensure profitability (Davis 2003, Deerr 1905, Shaw 1933). Indeed, the average annual rainfall during this period consisted of only 369.8 Danish lines (46.22 inches) of rain per year. Of the 27 years recorded, the highest annual rainfall consisted of 540.7 Danish lines (67.59 inches) in 1879, which was ushered in by an uncharacteristically wet May where 110 Danish lines (13.75 inches) of rain fell (a sum amounting to roughly 29.7% of the average annual rainfall on island during the 27 year period). It bears mentioning, that in such a deluge, sugarcane would likely have drowned, rather than thrived, with the plant's roots being susceptible to flooding. Far more common though were dryer years, with 11 years during which annual precipitation was within 16 lines (2 inches) of, but less than, the 27-year average of 369.8 lines (46.22 inches), and eight years during which the island saw less than 300 lines (37.5 inches) of precipitation. 1873 was the driest year of this study, where the island only received 236.8 lines (29.6 inches) of rain (GDWII 1892).

Rainfall data for the island was also collected between 1890 and 1902 in a similar fashion, with this data once again consisting of the averaged collection of observations made at the Christiansted Fort, Frederiksted Fort, and King's Hill. Made available within *Statistics Concerning Sugar Production in St. Croix from 1890 – 1902*, another 12 years of Crucian rainfall have been documented (GDWII 1905). In total the average annual rainfall during this period was found to be 394.4 lines (49.3 inches) of rain per year over the recorded 12-year period, with May, September, and October being the rainiest months (with 50.2 lines or 6.275 inches, 49.2 lines or 6.15 inches, and 46.5 lines or 5.81 inches of rain on average per month

respectively). Three anomalous months with rainfall in excess of 100 lines within these 12 years are worth mentioning, including October of 1891, May of 1897, and September of 1901, in which monthly rainfall averages were 115.7 lines (14.46 inches), 118 lines (14.75 inches), and 131.1 lines (16.39 inches) respectively. The highest annual rainfall came in 1901 with 535.4 lines of rainfall (66.93 inches). In only 3 years of this study period, did the island receive less than 300 lines (37.5 inches) of rain, including 1890, 1892, and 1899, where it rained 242.7 lines (30.34 inches), 281.5 lines (35.19 inches), and 273 lines (or 34.13 inches) respectively.

Another set of St. Croix precipitation records examined for, and included into, the ELP water balance model were from the Cedric Nelthropp Collection, held within the St. Croix Landmarks Society's Archive at Estate Whim Plantation. Entitled *Monthly and Annual Rainfall Records for Saint Croix, Virgin Islands By 10-Year periods* these records, collected at the Experiment Station in Kingshill, expand our understanding of historic rainfall records from 1902 through 1965 (FES 1966). Like the other rain records examined, these recorded rainfall rates contain precipitation data that has been averaged from observation points in Frederiksted, Kingshill, and Christiansted.

The combination of these three records (GDWII 1892, 1905, and FES 1966) provide us with usable average annual precipitation rates for each year between 1852 and 1965 which in turn allows us to include annual variations into the ELP's water balance model. For years in which there were redundant values amongst the collected rain records (e.g. 1862 – 1889 and which were encompassed by the start and stop dates of the Cedric Northropp collection) available annual rates of precipitation were averaged for incorporation into the model. As these rainfall records consist of over 100 years of data, the provided annual precipitation estimates included in the reports are not reproduced here but are included in the water balance model which is presented within Appendix A. Average annual precipitation values from 1739 to 1925 are presented (in inches per year) in the column second from the left within the model (Appendix A).

Estimates for Water Uses on Estate Little Princess

The four different categories of water use on colonial era sugar plantations on St. Croix have been characterized in some detail in previous sections. What is presented below then, are strictly the volumetric estimates associated with the four different categories of water use regularly seen on sugarcane plantations that can be incorporated into the ELP water balance Model. All estimates provided below are ultimately included into the water balance model on an annual scale. They are provided in the Tables below, however, in amounts of water used per day to help the reader better understand these water quantities in amounts that might be more familiar.

Table 2. Daily water requirements of humans on Estate Little Princess, estimates derived from Vivanti 2012.

Water Consumed per Human per day	Water in Gallons	Water in Liters
Enslaved or Free Africans	0.396	1.5
Planters or Free Laborers	0.74	2.8

Table 3. Daily water requirements of animals on Estate Little Princess, estimates derived from Molina-Rivera 1998, Meehan et al. 2015, Ingram N.D.

Water Consumed by Livestock per Individual per day	Water in Gallons	Water in Liters
Cows/Cattle	12.25	46.37
Horses	15.4	58.29
Sheep	1.75	6.62
Goats	1.67	6.63
Pigs	3.33	12.61

While we possess an estimate for water that might have been consumed per person per day, and per livestock animal per day, we possess only an incomplete record of the number of humans present, and animals present on the ELP for specific years. This data comes from compiled probate records, tax records, and inventories identified by historian and local scholar Dr. George Tyson, which are on file at the St. Croix Landmarks Society Archive on Estate Whim Plantation (Hatchett 1859, Staples 1998, Tyson N.D.). To fill in these gaps, estimates for years in which the number of laborers on plantation are not known are determined using the last known number of laborers on the plantation in a previous year. As they are not nearly as well documented, the numbers of white laborers and permanent plantation residents, and livestock animals on ELP for any given year, are estimated for the model by assuming a conservative ratio of 4 laborers to every 1 white planter, manager, or laborer. In cases where no data on the quantity of livestock were available, estimates on the number of livestock on ELP for a given year were derived using ratios of livestock to field laborers described within a widely circulated instruction manual on sugar planting during the colonial period (Thomspon 2009). These ratios are provided in the Table 4 below.

Table 4. Estimates for the ratio of the number of enslaved or free Black laborers, White planters, managers or laborers, and livestock, for years when no data is available for the Estate Little Princess, derived from Thompson 2009.

Category of Water Consumer on Plantation	Estimated Ratio
Enslaved or Free Black Laborers	12
White Planters/Mangers/Laborers	3
Horse	5
Sheep/Goat/Pig	10
Cattle/Oxen	16

Sugarcane is a crop with a 15 – 17 month maturation cycle. In addition, following a cane crop's harvesting, a cane field in the eighteenth, nineteenth and early twentieth centuries would have been allowed to lie fallow for somewhere between three to four months. While these realities of cane planting may seemingly detract from the model's input accuracy, it should be kept in mind that the volumetric estimates of sugarcane's water use provided in Table 5 (above) were presented in an average gallons or liters per day format deliberately to enable the reader to make direct comparisons between the tremendous quantity of water needed to keep sugarcane crops alive and healthy and the previously provided daily water needs of humans (Table 2) and livestock (

Table 3) that lived on ELP. While in reality a plantation field left fallow, or populated with young, mid-growth stage, or mature sugarcane plants would have experienced different rates of water loss in each of those scenarios, the daily water use values presented in Table 5 are an artificial "daily average" of the water required for an acre which was deliberately kept in sugarcane or maintained for future sugarcane planting year after year (Davis 2003, Deer 1905, and Vicente et al. 2013).

Table 5. Water needed for sugar cultivation and lost to sugarcane, water absorption, and evapotranspiration on Estate Little Princess, estimates derived from Davis 2003, Deerr 1905, and Vicente et al. 2013.

Water Needed for Sugar Cultivation Per Day/Per Acre	**Water in Gallons**	**Water in Liters**
Davis 2003 Estimate	13,997	52,984
Deerr 1905 Estimate	4,901	18,556
Water Lost by Sugarcane due to Evapotranspiration Per Day/Per Acre	Water in Gallons	Water in Liters
Vicente et al. 2013 Penman-Monteith method based Potential Evapotranspiration (PET) Estimate	67	252

Table 6. Water lost to evaporation in sugar manufacture on Estate Little Princess, understanding derived from Meide 2003, Deerr 1905, Craton and Walvin 1970.

Water Lost to Evaporation in Sugar Manufacture	Entirety of Moisture in Plant is Lost to Soils and Groundwaters
Boiling Juice (Evaporation)	
Running Boilers (Bagasse Evaporation)	
Distilling Rum	
Cleaning Equipment (amount to fill all containers on site at once)	

In accounts of colonial era sugar manufacturing processes, nearly all of the water collected by and held within the sugarcane plant during its development and maturation are lost. Once the plant is cut and cleaned of its leaves, tops (seeds), and stems, sugarcane was pressed (usually twice) to have the majority of its sugar juices (water content) extracted. These extracted juices would then be boiled, quite literally until all but the sugar crystals themselves and all but the smallest amount of water, remained to produce muscovado sugar. This still slightly wet brown sugar would then be pressed or molded into a cone or loaf and set out to dry (meaning the remaining moisture would be lost to the air via evaporation) (Armstrong 1990, Craton and Walvin 1970, Mintz 1986, Ragatz 1928, Meide 2003). On many plantations, any moisture retained in the sugarcane stalk husks after the sugarcane had been pressed, would also be lost through evaporation, as the husks were regularly burned to aid in the boiling of the sugarcane juices (Meide 2003, Deerr 1905). As we have already estimated the amount of water absorbed within, and lost to the air (via PET), through sugarcane's development, the water lost to the environment through sugar processing, is encapsulated in the model through those figures. As a result, the water lost during sugarcane processing is only re-listed in this section of the chapter

for the purposes of calling attention to this additional means by which moisture introduced into the plantation are lost.

Running the Water Balance Model

Using the historic precipitation records to account for the annual water introduced into the ELP, and estimates for each of the potential paths by which water might have been lost to the plantation, the ELP water balance model produced annual estimates for the water balance of the ELP each year between 1739, the first known year of the plantation's occupation, through 1925, the last year for which available records described ELP's number of acres kept in sugarcane. Each year's estimated water balance was derived by taking the rainfall value ascribed to a given year, and subtracting the water estimated to be used by humans and livestock living on the plantation, as well as the water estimated to be lost in the soil and to evapotranspiration by the acres kept in sugarcane on ELP that given year.

Some assumptions still needed to be made to enable the model to run, even with the research invested in developing the data inputs. For instance, while archival records for the island revealed the plantation's annually received rains for the years between 1852 through 1965, a lack of precipitation data spanning between 1739 and 1852, obliged the use of the annual average rainfall over the span of 1852 and 1965 of 45.67 inches, as the annual rainfall for the planation on years for which there was no rain data. The model also operates with the assumption that sugarcane was not planted on ELP to any significant extent between 1739 and 1743, as 1743 is the first year for which there is record of some 200 acres having been in cultivation. Further, as the counts of the number of acres in sugar cultivation on plantation were not updated within available records on an annual basis, the number of acres under cultivation for each year were kept at the previous year's values for each successive year in the model, unless those estimates could be specifically updated by available records. For example, while available records revealed that there were 130 acres dedicated to sugarcane planting on the estate in 1766, available records do not provide additional information on the amount of acreage kept in cane for the years between 1767 and 1771, prompting the use of the estimate of 130 acres in the model, until 1772, where records indicated that 133 acres were dedicated to sugarcane (Hatchet 1859, GDWII 1892, 1905, Tyson N.D.). An identical methodology was deployed to provide data inputs for the number of enslaved and or freed laborers thought to be on plantation each year when insufficient data was available. Furthermore, while some records were found detailing the number and types of livestock kept on plantation for some years in the plantation's history, for most years, a model input was deduced for this form of water use, according to the ratios of the numbers of types of livestock commonly kept on Caribbean plantations during the model's study period (Thompson 2009, Table 4).

Three different values for the water lost to the environment during sugarcane's development were accounted for within the model when estimating the amount of water absorbed by sugarcane kept on ELP. First, two estimates for the amount of water required by sugarcane to successfully mature were included, consisting of estimates developed by Davis (2003) and Deerr (1905). Both estimates are for water used by sugarcane that has not been-irrigated, which was the case on the ELP. Second, a PET estimate, that is, an estimate of the amount of water lost through evaporation (of the soils underneath sugarcane plants) and transpiration (of the sugarcane plant itself), was used for the acres of sugarcane planted on ELP which was derived from the work of Vicente et al. (2013) through their study of sugarcane planted in Brazil over a 10-year period. As

the Davis and Deerr estimates for sugarcane's water use vary quite widely (Table 5) the water balance model ultimately produces two versions of outputs, one for each of the two estimates of sugarcane's water needs provided. In either case, the Vicente et al. 2013 estimate for water lost via evapotranspiration is included (Table 5, Allen et al. 1994).

Ultimately the water balance model presented here compares the inches of annual rainfall at ELP (which is converted into gallons of water per acre kept in sugarcane per year), against historically justified estimates for the number of gallons of water used by humans, livestock, and the sugarcane plant itself on ELP in sugarcane cultivation activities and in sugar manufacturing processes between the years of 1739 and 1925. The model in its entirety is presented in Appendix A. The outputs of this model are discussed in the next section of this chapter.

Results from the Estate Little Princess Water Balance Model

The outputs produced by the water balance model reveal a great deal about historic water use on the ELP. Importantly, they reveal just how insignificant the amounts of water required by humans and livestock on plantation are when compared with the burdens placed on local water systems by the practice of growing sugarcane itself. Even in the years where the estate was estimated to have the highest number of humans and livestock on plantation (1772 to 1779) of any years for which the model was run, the model shows that the amount of water required to sustain these 177 humans, 188 cattle, 59 horses or donkeys, and 118 sheep, goats, or pigs, per year equaled 30,104 gallons for humans and 1,315,657 gallons for livestock adding up to a combined 1,345,761 gallons of water needed per year (Appendix A). Though not a particularly small sum unto itself, it pales in comparison to the amount of water estimated to be required to sustain the 133 acres of sugarcane thought to be in cultivation during those same years. Estimates of 679,484,365 gallons or 237,919,045 gallons of water per year would have been required to successfully cultivate 133 acres of sugarcane according to the Davis 2003 and Deerr 1905 estimates respectively. Along with the additional 3,252,515 gallons assumed to be lost in either case from evapotranspiration in accordance with the Vicente et al. 2013 estimate, we see that even the combined annual water needs of all humans and livestock living on plantation during each year between 1772 and 1779 amounted to less than 0.2% (using the Davis 2003 estimated sugarcane water requirements) or less than 0.56% (using the Deerr 1905 estimated sugarcane water requirements) of the water needed per annum to sustain the 133 acres of sugarcane kept on plantation during those same years.

The relatively small quantity of water needed to sustain the plantation's human and livestock populations (compared with the plantations' water needs for sugar) would have likely made accommodating these needs far less of a stressor (at least in years where drought was not a concern) than concerns a plantation manager might have had over the amount of rainfall the sugarcane crop would receive over the span of a given year. Water on the scale required by humans and livestock living on the plantation could have also been more readily furnished through cisterns kept on site, and the well and water tower-based water pump, located just northeast of the plantation's factory. In times of severe drought, such as in 1873, when only 30 inches of rain fell over the span of the year (16 inches less than the annual average), humans and livestock would have been able to travel to, be transported to, or to have water imported from, other locations where water was more available, including neighboring plantations, or in later years, municipal wells located in the nearby town of Christiansted. The options to either move humans and livestock to sources of water, or to move smaller amounts of water to the plantation

for the purposes of sustaining its human and livestock populations would have enabled plantation managers to, at least to some extent, reduce the water requirements that human and livestock on the plantation would usually apply to the plantation's overall available water. Ultimately, considerations of the water requirements of humans and livestock on the plantation call attention to the far greater, and less compromising, water needs of the sugarcane crop being cultivated on plantation.

The model's projected discrepancies between the amounts of water introduced into the plantation's water system annually through rainfall and the amounts of water estimated to be required for the successful cultivation of tens, and in many years hundreds, of acres kept in sugarcane on the estate are quite striking. Using the Davis 2003 estimate of 5,108,905 gallons being required per acre of sugarcane per year (calculated by multiplying Davis's suggested requirement of 13,997 gallons per acre per day for sugarcane, the quantity presented in Table 5, by 365, the number of days in a year), as well as the Vicente et al. 2013 estimate of 24,455 gallons lost to evapotranspiration per acre of sugarcane per year (calculated by multiplying Vicente et al. daily estimate of 67 gallons lost per acre per day of sugarcane by 365) the water balance model estimates that sugar was grown on the estate at an annual deficit of between 3,299,549 gallons per acre per year and 4,331,367 gallons per acre per year of sugarcane between the years 1744 and 1925. When considering annual fluctuations in precipitation, as well as the varying number of acres kept in sugarcane cultivation each year, the water required for maintaining all the sugarcane fields on the ELP each year ran an annual deficit ranging between -46,718,557 and -854,974,714 gallons per year between 1744 and 1925.

The projected annual water deficit on a per acre basis is less severe but still large and noteworthy when the model utilized the more conservative Deerr 1905 estimate of sugarcane's annual water needs. Combined with the Vicente et al. 2013 estimate for anticipated evapotranspiration, the Deerr iteration of the model projected that the ELP grew sugarcane at an annual negative balance ranging between -1,011,327 gallons and -122,712 gallons per acre per year in every year for which the model was run, except for 1879 and 1901. For these two years the model actually estimated small annual water balance surpluses of 20,491 gallons and 1,585 gallons per acre of sugarcane per year, respectively. During these two outlying years 67.53 and 66.84 inches of rain are recorded as having fallen onto the plantation (the two highest years of annual precipitation on record for the island, each by a margin of over 20 inches greater than the annual average between 1752 and 1925). When taking into account all acres kept in sugarcane each year on ELP, and fluctuations in annual rainfall, the Deerr 1905 estimate for sugarcane's water requirements plus the Vicente et al. 2013 estimate for evapotranspiration suggests that the plantation's annual water balance deficit for sugarcane growing alone reached levels ranging between -6,878,077 and -176,978,116 gallons per year between 1744 and 1925 (with the outlying particularly rainy years of 1879 and 1901 excepted).

The high annual water balance deficits suggested by the ELP water balance model unveil a critical disparity between the sugarcane crop's significant water needs and the water made available to the crop at ELP via annual rainfall. This large discrepancy begs the question, in the face of such tremendous water needs, how did ELP manage to cultivate sugarcane on plantation for 181 years? At least a portion of this water deficit might be explained by sugarcane roots reaching down to, and drawing supplemental water from, the Kingshill Aquifer, which lies underneath the soils of the plantation. This is an intriguing idea to consider, as this understudied

water reservoir is believed to be the only significant aquifer in all of the US Virgin Islands, and today supplies the overwhelming majority of water needed by the public and industrial sectors of St. Croix (USGS 2016, Davis 2019).

The Kingshill Aquifer extends to a maximum depth of 61 m and is comprised of marl (crushed and compressed coral) and limestone rock. It is thought to possess water at depths shallower than 15.24 m in the northern half of the island (where ELP lies) (USGS 2016a, 2016b). Meanwhile, sugarcane root systems have been noted to have the potential to achieve root depths in excess of 6 m suggesting that sugarcane plants may have had the ability to tap into this freshwater resource (Smith et al. 2005). Taking into account the potentially quite significant drawdowns of sugarcane plants, it is important to appreciate that the exact recharge rate of the Kingshill Aquifer is not fully understood, especially within the vicinity of the 1,102-acre "Princess" watershed (within which ELP lies), where the water table of the Kingshill Aquifer is known to locally slope towards the northeast (USGS 2016b, CADMUS 2011). This topographic attribute isolates the extractable water within this portion of the aquifer from the far larger cache of water stored in the rest of the aquifer which lies to the west of ELP and extends to the southwest, underlying some 25 square miles of the island's landmass (Robinson 1972, Davis 2019). Despite these estimation challenges, it has been suggested that while the majority of rainfall on the island is returned to the atmosphere via evapotranspiration, a maximum level of 3% of rainfall on the island may be able to percolate through the soil column and recharge the Kingshill Aquifer (USGS 2016a). This rechargeable water resource may well have served as a reservoir that sugarcane plants growing on ELP, with their longer tap roots, may have been able to draw upon. A 1985 estimate of ground-water withdrawals from the Kingshill Aquifer by individuals and corporations on St. Croix amounted to roughly .96 million gallons per day (or 350,400,000 gallons per year) (USGS 2016a). While these estimates of potential withdrawals are island wide, we can create a rough estimate of the water that might have been extractable from the aquifer within the Princess watershed as 8.6% of that sum (or 30,134,400 million gallons per year) as the watershed occupies 8.6% of the land above the aquifer. Though this estimate would be based on more modern water extraction techniques (including mechanically excavated and electrically pumped wells, that would tap water resources far deeper than those reachable by the roots of sugarcane plants), it does give us some idea of another water resource sugarcane plants might have made use of beyond the limited water supplies offered by rainfall on ELP.

The annual water balance deficits suggested by the ELP water balance model would have vastly outpaced the Kingshill Aquifer's annual recharge, ensuring that over time the aquifer's freshwater table would be greatly lowered (USGS 2016a). With the plantation modeled to run at an annual water balance deficit measuring in the millions to hundreds of millions of gallons of water per year, (using either the Davis 2003 or Deerr 1905 estimates for sugarcane's water needs), it is clear that the annual levels of precipitation received on plantation were insufficient for the amount of sugar grown regularly on plantation, a discrepancy which likely resulted in the degradation of local freshwater reserves. Such aggressive drawdowns on local ground water reservoirs, potentially including the Kingshill Aquifer, are particularly troubling when considering that a freshwater-saltwater interface occurs just beneath the ELP on the northeastern coastline of the plantation and island. Here, at this interface, intense drawdowns on subterranean freshwater reserves could precipitate their infiltration by salt water from the sea. As sugarcane was cultivated on ELP for nearly 200 years, it is not hard to imagine that this long-continued and water intensive industry played a role in the irreparable contamination of the area's precious

fresh-groundwater resources, which have recently been reported to be in poor condition (VIWRRI 2012).

The vulnerabilities inherent in sugarcane cultivation across St. Croix are highlighted by the glaring juxtaposition between its tremendous water needs and the available water at ELP. Such circumstances likely meant that the crop frequently endured, or was at least under threat of, severe water stress at various times during its growth cycle, potentially leading to diminished yields, stunted growth, and compromised quality of harvest. This stark imbalance between the water demanded by sugarcane and the annually received precipitation also underscores the precariousness of relying exclusively on rainfall to sustain sugarcane cultivation, especially in environments prone to erratic or insufficient rainfall patterns. Facing a scenario where the water needs of sugarcane cultivation exceeded the water supplied by rainfall (and or that could be supplied by the plantation's underlying aquifer), adverse consequences including drought-induced crop failures and subsequent financial ruin, would appear to have been a constant threat on ELP according to the results of the water balance model. Perpetually operating at a projected per acre water balance deficit ranging from hundreds of thousands to millions of gallons per year, fear of crop failure, or at least reduced sugarcane yields per acre, must have weighed heavily on the minds of plantation proprietors.

Discussion: The Hydrological Legacy of Sugar Planting in St. Croix

Chapters 6 through 9 have taken an intensive look at the ways in which water was used on sugarcane plantations across St. Croix during the sugar planting period, in order to better understand the relationship between sugar planting and its impacts on the island's hydrological systems. Recording and cataloging the features' spatial locations, proxemics to other features on plantation, conditions, measurements, and in some cases, water holding capacity (Chapter 7), this analysis continued by contextualizing these water management features against three categories of water uses commonly seen on Caribbean plantations (Chapter 8). Fitting into one or several of three categories of water use, these features provided or stored: water consumed or used by humans, water consumed by draft animals and cattle, and water used in the extraction of sugarcane juice from the plant, and the manufacture of muscovado sugar.

An important fourth category of water use on sugar plantations—the water used in the cultivation of the sugarcane plant—was tacitly implied by the recorded features and their sugar cultivation and production-related purposes, even though it was not directly referenced by the water management features recorded on St. Croix. Understood to be strictly a rain-fed crop in St. Croix, thousands of acres planted in sugarcane on the island would have readily soaked up most rainwater that fell on the island, and readily attacked ground water resources within the reach of the plants' roots. Eager to further investigate the sugar industry's capacity to impact the hydrological systems of the island, Chapter 9 developed a water balance model to estimate the quantities of water that sugar plantations would have required to sustain the ELP sugar plantation in the eighteenth, nineteenth, and early twentieth centuries. This model incorporated historically recorded precipitation records for the island, and details from the plantation's land use history, including the number of acres kept in sugarcane per year, and estimates for both the number of humans and livestock on the plantation for a given year, as well as the amount of water that that would have been consumed by humans and animals on the plantation as well as the water that would have been consumed by the sugarcane plants themselves on an annual basis. Several key

components of the relationship between sugar planting in St. Croix and the water resources available on the island were derived from this analysis.

The legacy of the sugar plantation era water management features examined in this research reveals how Crucian plantations came to terms with the realities of the islands' climate and available water resources. These realities likely stood in stark opposition to their goals of cultivating sugarcane and manufacturing muscovado sugar (Lawrence and Davies 2012). Navigating the scarcity of water on the island, planters insisted on, sponsored, and oversaw the construction and maintenance of cisterns, wells, water towers, troughs, and water conveyances to capture, store, and control the flow of water on their plantations. Cisterns, like those seen on Estate Washington, Butler's Bay Plantation, and ELP, were built in response to the finite amount of rain which would fall on an annual basis, which was often insufficient to suit their needs. Working as protective stores for water, cisterns structures would have enabled planters to keep water well past the period in which it fell. Similarly, stone-lined wells (and in some cases their wind-driven water pumps), like those recorded on Estate Morning Star, Butler's Bay, St. George's, and ELP are features which exposed and made available sources of ground water for consumption and use which would otherwise have been inaccessible. Such features reveal that planters knew that they could not rely strictly on naturally occurring sources of water like rainfall and running surface water in local ghuts. Instead, they took on extensive, and likely costly construction projects to secure water for future use.

The water management features recorded on St. Croix were all constructed using utilitarian materials that were either locally produced or readily available. These materials included cut and uncut pieces of limestone and coral, plaster made in local limekilns, red and Danish yellow brick, often brought as ballast aboard visiting ships, and clay used to produce coarse earthenware water jugs. Even using these relatively cheap and available materials the construction and maintenance of these features represent a substantial investment of time, money, labor, and planning on a small island on the fringes of the Danish colonial trade network. Such capital improvements required skilled architects, masons and, in many cases surveyors, as well as hundreds if not thousands of labor hours to construct. Such works were years in the making, and once finished, often found their way onto plantation inventories, increasing an estate's value, and in some cases subsequently raising the taxes owed on a given property (Hatchett 1859, Staples 1998, Tyson 1993, N.D.). As they were clearly expensive to build and keep, the water features found on sugar plantations on St. Croix reveal local planters' tacit acknowledgement that the management of the island's limited supply of freshwater was of the utmost importance.

Some recorded resources in St. Croix reveal where planters misjudged their environmental adaptations. While cisterns and stone-lined wells acknowledge the island's climatic realities, the short-lived water-driven mill and water flume at St. George's plantation represent missteps in technological adaptation to local conditions. Likely based on observations made of Mint Ghut in the early 1800s which might have revealed a strong and steady flow of water for several years, plantation owners at St. George's built a dam across the ghut and sought to channel its waters via aqueduct to a water mill which would be used to press sugarcane. Built between 1829 and 1831, a drought in the 1840s abruptly, and permanently took the mill out of commission. A similar fate befell the water flume on St. George's plantation as well. The flume was built in 1846 to carry water from Mint Ghut to a then newly built steam driven mill on the property. However, use of the flume for this purpose is thought to have been aborted sometime in the latter half of the

nineteenth century, in part due to decreasing flows within the ghut. Though far less successful than their water conserving counterparts, these ruins today represent the legacy of sugar planting era water management on St. Croix, testifying to both the interests of the planters, who sought to take advantage of the water resources they thought would be consistently available, and the hydrological realties of the relatively dry island.

The results of the ELP based water balance model proved to be equally revealing. While it is no surprise that the sugarcane industry required copious amounts of water per annum to remain profitable, the ELP water balance model underscores the vast discrepancies between the water required on a colonial era plantation in St. Croix and the water resources that would have been locally available on an annual basis. Producing an estimate of the annual water inputs and ouputs that would have transpired during the years between 1739 and 1925, the model suggests that ELP regularly ran at an annual water balance deficit ranging from millions to hundreds of millions of gallons per year (Appendix A). With such tremendous annual losses suggested by the model, the hydrological impacts of centuries of sugar planting start to come into view. Clearly capable of consuming more water than local weather systems would provide, sugarcane kept on ELP may well have tapped into water reserves kept within the Kingshill Aquifer, an, understudied and vulnerable limestone aquifer which lies below the ELP and many of the other former sugar plantations on the island (USGS 2016a). Even if this were so, however, drawdowns on this water reserve even close to the annual water deficit suggested by the model would have vastly exceeded the annual recharge rate of this aquifer and would paint a gloomy picture for the aquifer's long-term health. With a freshwater-saltwater interface occurring within the aquifer along northeastern coastline of ELP, such a reduction in the aquifer's freshwater reserves may well have enabled salt water from the sea to infiltrate this critical underground water reserve. Considering that sugarcane was grown on the ELP for nearly 200 years, this practice may have resulted in the irreparable contamination of the Kingshill Aquifer and made it susceptible to saltwater infiltration.

The physical remains of colonial era water management features on the island and the results of the ELP water balance model serve to show us that despite the deliberate efforts of sugar planters to fight against local climatic and environmental conditions, sugarcane cultivation was still an unsustainable practice on the island, and that the long-term adoption of this industry on the island may well have led to some of the island's currently experienced water stress. Effectively, planters forced the sugarcane industry upon an island not particularly well suited to it (Shaw 1933). Serving as a built hydro-scape, these built water management features provide us with an understanding of the physical and cognitive realities of the planters who managed the island during the colonial period. Physical markers of planters' coming-to-terms with the island's conditions, they represent the adaptation of technologies and expectations to local circumstances and limitations in local water supplies (Lawrence and Davies, 2012).

Though sugarcane cultivation has long since subsided on the island, it seems clear that the island's long-term adoption of sugarcane monoculture between 1733 and the early-twentieth century has left its mark on the island. Growing sugarcane at a gigantic water deficit each year, the effects of sugarcane planting on St. Croix is one with a delayed reaction. While local aquifers may have been able to supplement the adoption of these unsustainable planting practices for a time, they did so at the expense of their long-term health. Receiving limited annual rainfall, and possessing slow infiltration rates, ground water reserves on the island like the Kingshill Aquifer,

would have been overexerted in the watering of hundreds of acres of sugarcane per year. It is no wonder then, that more recent hydrological studies on the island have revealed that natural aquifers have become contaminated with salt water, and that potable freshwater on the island is incredibly scarce (VIWRRI 2012).

In the twenty-first century, the island's population, most of whom had nothing to do with the adoption of, and or centuries long perpetuation of, the sugarcane industry, are left to endure its hydrological legacy. Incurred through the implementation of unsustainable agricultural practices, pursued in spite of the island's relatively dry climate, the present-day inhabitants of St. Croix face a future filled with water scarcity and water stress. Making matters worse still, the Hess Oil Virgin Islands Corporation built a massive oil refinery on the southern coast of the island in 1966. This refinery presently occupies over 1,500 acres of land on the island (nearly 3% of the island's total land mass) and spills or overflows of various chemicals into the ground soil have wreaked havoc on subsurface freshwater in the vicinity. In fact, this refinery has been run so poorly that it was closed by the United States Environmental Protection Agency (EPA) in 2021 after a series of harmful chemical releases from the refinery sickened neighboring residents (Sanicola 2022). With St. Croix facing an ever-increasing scarcity of freshwater, it has never been more important to explore the relationship between past land uses and current water conditions on the island.

By examining the water management features from the sugar planting era and the water requirements for sugarcane cultivation, we have revealed insightful connections between the long-adopted sugarcane monoculture, and the current condition of water resources on St. Croix. It is hoped that this work, which has drawn upon archaeological, historical, hydrological, and scientific data sets will encourage future interdisciplinary scholars to continue to explore the cause-and-effect relationships between contemporary environmental circumstances across the globe and their historical antecedents (Ezcurra and Rivera-Collazo 2018, Thomas et al. 2019, Tsing 2001).

Chapter 10. The Soilscape Legacies of Sugar Planting and other Land Uses at the Estate Little Princess

Introduction: The Reputation of Sugar Planting

European expansion in the Western Hemisphere between 1500 and the early 1900s took place at such an unprecedented rate that it fundamentally altered local environmental systems (Lightfoot et al. 2013). Plantation colonies established across the western half of the globe necessitated the clearing of wide tracks of land, the reduction of biodiversity (particularly that of local flora) and placed high nutrient and soil retention demands on local soil systems as plantation managers primarily placed value on the hyper-focused production and processing of singular agricultural commodities including coffee, tobacco, cotton, cocoa, and sugar, and often marshalled capital and enslaved (Black) labor to do so (Richards 2003:414, Crosby 1986, Hare 1970, Carney 2001). Of the various forms of plantations that were spawned during this era of European expansion, sugar plantations have a reputation for being among the most environmentally impactful type to have appeared in the Americas during the sixteenth through twentieth centuries (Mintz 1986, Meide 2003, Ragatz 1928, Dunn 1973, Watts 1990).

The Caribbean region is currently experiencing what are believed to be human induced environmental changes that continue to negatively impact the two main pillars of the region's fragile economy: agriculture and tourism. Recent studies across the Caribbean have revealed unstable soils with areas showing signs of significant erosion resulting in decreased agricultural productivity and the siltation and disturbance of tourist friendly coral reefs, as well as soils depleted of nutrients critical for plant growth such as phosphate (Rawlins et al. 1998). These conditions are decreasing local agricultural productivity while simultaneously disrupting marine ecosystem services (VIWRRI 2012). When asked during interviews local agriculturalists, environmentalists, and government officials stated that the more recent mismanagement of public water resources by the USDA and other government agencies, is responsible for the water scarcity currently experienced on the island (Laundry list some personal comms or reference previous section which talks about oral interviews). For nearly 100 years, however, historians, archaeologists, and natural scientists have speculated that centuries of sugar planting are to blame for the poor environmental conditions now documented throughout the Caribbean (Ragatz 1928, Crosby 1986, Mintz 1986, Grove 1996, Watts 1990). Despite the ubiquity of these allegations, little empirical work has been done to support this hypothesis, with only a small group of scholars having started to methodologically examine the links between current conditions and their historical antecedents (Meniketti 2015, Fox 2016).

Chapters 10 and 11 explore the connections between various forms of land use on the Estate Little Princess (ELP) sugar plantation during the eighteenth, nineteenth, and twentieth centuries and the conditions of the soils found on the plantation today (Figure 83). Deploying Christian Wells' concept of "soilscape legacies," or the idea that the soils of today represent an anthropogenically modified and examinable membrane which can reflect the long-term consequences of human behaviors, this research makes use of historical, topographical, and geoarchaeological data collected on ELP to link known periods and locations of sugar cultivation and other activities with observable and datable changes in local soils (Wells et al. 2013:28). The data presented in these chapters come from a geoarchaeological investigation of the long-term

impacts of sugar planting and other ancillary activities on the ELP, a plantation located on the Caribbean Island of St. Croix which was in active use for nearly 200 years.

Figure 83. Location map of the Estate Little Princess, a sugar plantation in active use from the eighteenth through the twentieth centuries. Map created by author, Spring 2024.

Much has been written about the cultural, economic, political, and social legacies of the sugar plantation industry in the Caribbean and the Americas (Mintz 1986, Dunn 1973, Craton and Walvin 1970, Wilkie 2005, Singleton 1985, Armstrong 1990, Farnsworth 2001, Wilkie and Farnsworth 1997). Within the last half century scholars have identified distinct phases of agro-industrialization and intensification of sugar planting, each increasingly more capital intensive, mechanically efficient, and dramatically capable of influencing local environmental conditions than the last (Pulsipher 1977, Pulsipher and Goodwin 2001, MacLennan 2004, Meide 2003, Ryzewski and Cherry 2015, Meniketti 2006, 2015, Fox 2016). In so doing, these researchers highlighted elements of local landscapes which were pivotal to sugar planting operations and have demonstrated how these planter societies pursued the intensified cultivation of sugar and sugar manufacturing, often at odds with the environmental conditions they faced. Through these works, scholars have used archival, cartographic, and archaeological evidence to demonstrate that European plantation development led to the introduction of foreign animals and plants, and widespread deforestation.

Overall, these works *indirectly* link the activities on sugar plantations, the "known" cause of these environmental degradations, to present day environmental conditions seen across the Caribbean. Past changes made to island landscapes in the name of plantation development or sugar cultivation are chronicled in existing archaeological and historical literature, where environmentally minded studies in the Caribbean have detailed the steps involved in the clearing of wide tracts of land, the consumption of large amounts of water, and the intensification of cash crop planting throughout the eighteenth, nineteenth, and twentieth centuries (Delle 1994, Pulsipher 1977, Grove 1996). Accurately citing the widespread changes that occurred across the broader landscape throughout the colonial period, these studies frequently point towards the grim environmental future which these former plantations now face (Bosma 2023, Gonzalez-Scollard 2008, Meniketti 2015).

Only a few of these studies directly link specific past activities on Caribbean plantations to the long-term impacts these land uses have had on local soil systems enduring into the present, well beyond the active use of a given plantation. This gap in the development of direct ties between past sugar plantation activities and the environmental conditions seen on that same plantation today, has been pursued by a group of scholars who conducted geoarchaeological investigations at Betty's Hope plantation on the Caribbean Island of Antigua. This research cluster includes Christian Wells (Wells et al. 2017), Georgia Fox (2016), Suzanna Pratt (2015), Anthony Tricarico (2019) and Peter Siegel (2018). Together and individually, these scholars have collected soil and sediment samples from soil probes and sediment cores gathered across the sugar plantation at Betty's Hope and the plantation's watershed; subjected these soils and sediments to geophysical and geochemical analyses, and compared the results with the plantation's known land use history to draw direct ties between observed conditions in local soil systems today and plantation era activities.

Christian Wells (University of South Florida) and his colleagues have developed the concepts of "cultural soilscapes" and "soilscape legacies" which guide us to "address the effects of past human-environmental interactions that are detectable in the analyses of archaeological soils" (Wells 2006:126). To achieve these ends, Wells and colleagues (2017) identified the locations on plantations where specific activities are known to have taken place and, in those areas, examined the results of their soils and sediments analyses for signs of past stability, instability, current

stability (or instability) and present-day fertility. The geophysical and geochemical properties examined within the soils and sediments of Betty's Hope plantation by this research group include color, texture, nature of transition between encountered strata, organic and inorganic carbon content, pH levels, and phosphate, magnesium, and zinc concentrations. They also tested for several other elements that are vital to plant growth, or substances known to be particularly harmful to humans.

Through these efforts Wells and his colleagues identified a variety of locations on the landscape of Betty's Hope's that contained clear signs of a volatile past (such as the absence of B horizons, or the presence of clearly deposited and poorly sorted sediments). These works also identified numerous locations on the plantation that possessed evidence of a history of relative stability (for example, profiles with gradual transitions between each stratum and well sorted strata) and still showed signs of present-day fertility (such as strata with phosphorus levels sufficient to sustain agricultural use in the future) (Pratt 2015). Through cartographic and archival research, Suzanna Pratt (2015) and others identified specific sugarcane fields on Betty's Hope where annually recorded sugar production levels never dramatically fell. Despite having hosted centuries of continuous intensified agricultural activity, geophysical and geochemical testing of these areas proved to reveal signs of stable development *in situ*, "suggesting that continuous human activity ha[d] contributed to the intentional or unintentional stability of these locations" (Pratt 2015:149). These findings led the research group to consider that perhaps sugar cultivation alone was not the only cause of environmental degradation on the grounds of the plantation. Instead, the group hypothesized, the means by which the plantation's sugarcane fields on the plantation were abandoned, as well as episodes of, and the persistence of, intense storms and precipitation, and other forms of plantation era and subsequent land uses may have played equally, if not more, important roles in the development of current environmental conditions (Fox 2016). While most scholars hold, "little doubt that the effect of sugarcane on the environment… has been overwhelming negative," work at Betty's Hope suggests that further empirical work is required to support or refute this presumption (Watts 1990:533).

Following in the footsteps of Wells and his colleagues, this investigation seeks to draw direct connections between past land uses on a former sugar plantation, the ELP, and present soil conditions, to better understand the long-term impacts of sugarcane planting and other forms of plantation land use. Including the results of several interwoven lines of study into the impacts of sugar plantation era activities on the landscape of the ELP, Chapter 10 details the systematic excavation and sampling of 27 shovel tests located across two transects on the estate's grounds, and the lab-based analyses of the geophysical and geochemical properties of collected samples. Collected bulk samples were tested for Munsell color, soil texture, pH, organic and inorganic carbon content, and phosphorous concentrations. Several radiocarbon datable materials including charcoal and snail shells were also found at depth during excavations (see radiocarbon dating subsection within the methods sections later in this chapter regarding the interpretative value of snail shells). These materials were collected and tested, potentially providing further insight into the chronology of the developmental history of the soils examined. Using the results from these interwoven analyses, Chapter 11 concludes with the examination of current soil condition against the background of the plantation's known land use history as derived from historical, archaeological, cartographic, and photographic evidence. Ultimately, this study finds signatures of instability in the area occupied by enslaved, and later free, African laborers, both stability and instability in a portion of the plantation that was kept in timber and undeveloped, and relative

stability (as well as relative fertility) in a portion of the plantation which is thought to have been kept in sugarcane agriculture for nearly 200 years. By identifying key signatures of past volatility and stability within the soils present on the plantation today, the results of this study enable us to draw explicit links between present day soil conditions and their historic antecedents (Courty et al. 1989). Moreover, by finding evidence of relative stability within areas previously used for sugar planting, this research contributes to a growing body of archaeological, geoarchaeological, and environmental work which emphasizes not only the examination of past human impacts on the environment, but also consider how the cessation of specific forms of land use may have led to present day conditions (Pratt 2015, Tricarico 2019, Wells et al. 2017).

The goal of this geoarchaeological investigation of the soils of the Estate Little Princess (ELP) was to examine the long-term environmental impacts of a historic era sugar plantation which was in operation for nearly 200 years (circa 1734 – 1925). More specifically, this work sought to isolate geological evidence of the long-term outcomes of plantation era land uses in three distinct locations on ELP: the African Village Site, the Lands Kept in Timber, and the Sugarcane Fields. Examining geophysical and geochemical evidence found within the ELP's landscape, this study also followed Christian Wells' with the goal of understanding of the "soilscape legacy" left by activities during the estate's plantation era, whereby geological evidence was interpreted against the plantation's land use history as understood through topographic, cartographic, archival, and archaeological data to consider the historical processes that have contributed to present day environmental conditions (Wells 2006, Wells et al. 2018). As a result, the present discussion considers evidence from LiDAR based topographic mapping of the estate, pedestrian survey of the plantation's grounds, diachronic examination of georeferenced eighteenth, nineteenth, and twentieth century maps of St. Croix and nineteenth and twentieth century photographs (all depicting the ELP), the review of compiled deed, estate, probate, and sugar production records for the ELP, as well as a review of testimonials of plantation owner descendants, and island based histories pertaining to the estate's sugar growing period held within the St. Croix Landmarks Society's Archive at Estate Whim Plantation to develop a robust land use history for different portions of the plantation (Staples 1998, Vaughn 1977, Wright et al. 1980, Tyson N.D., GDWII 1892, 1905).

Background: The Exploration of Soilscape Legacies in the Caribbean

Understood to be a palimpsest of past human activities, soil is a thin, vulnerable, and sensitive resource that humans rely heavily upon, and on which they have left their mark (Redman 1999, Lewis et al. 2006, Pratt 2015). Wells explicitly defines "cultural soilscapes" as areas of the Earth's surface that are, "the result of spatially and temporally variable geomorphic, pedogenic and cultural processes" (Wells 2006:125). Striking at what Wells calls "soil memory," or, the, "reflection in the soil of physical, biological and chemical efforts of different human activities, including modifications to soil structure, soil pH, aeration and water drainage, nutrient cycling, soil temperature changes, and the addition of anthropogenic materials," geoarchaeological investigations into "cultural soilscapes" focus on the examination of the geophysical and geochemical properties of present-day soils to consider the enduring impacts of past human and soil interactions (Well 2006:126).

Wells et al. (2013:40 – 41) also bring to the forefront "the long-term socioecological consequences of human interactions with soilscapes," pointing out that, "despite widespread agreement among scientists about the long-term effects of soil resource management… the

outcome of thousands of years of human-environmental interaction… is largely underappreciated by today's farmers, urban designers, policy developers, and other key personnel who make practical decisions about land management issues on a daily basis" (Well 2006:126). Studying in conjunction the characteristics of present-day soils and the human antecedents that caused present-day conditions, Wells and colleagues encourage the examination of a human modified parcel of land over the long term (or *longue durée).* While many land managers and scientific or governmental agencies rely on the analysis of the recent past to account for current environmental conditions, Wells and colleagues push their research into the longer term history of an area's soils to help explain, and perhaps unlock, knowledge that might enhance the environmental circumstances of the present (Sandor and Eash 1991, Van der Leeuw and Redman 2002, Crumley 1994, Hardesty 2007, Fischer 2020).

Wells et al. most clearly articulated their idea of "soilscape legacies" as the "long-term socioecological consequences of human interactions… [evident within] soil bodies that have been physically and chemically altered as a directed result of human behavior" (2013:23-24). However, this perspective on the interpretative value of soils was first taken on by Wells and his research partners during their geomorphic mapping, excavation, shallow and deep auger probing, and analysis of the stratigraphy of prehistoric settlement sites in the Palmarejo region of Naco Valley, Honduras. There, the team used the lens of soilscapes to reveal both the changes in, and long-term trajectories of, the area's soils over time. In particular the team focused on how many observable changes in the soils over time had human-based antecedents, both physical (i.e. direct alterations of the soils, and cultural (i.e. social and historical frameworks that shaped those alterations over time) (Wells et al. 2013, Wells 2006). Among the signatures of human activities that the research team looked for when examining soils within or near known archaeological sites in the Naco Valley were heightened levels of phosphates and organic carbon, heavy metals and chemical elements, the development of distinct micro-fabrics and pedofeatures, and fluctuations in soils' magnetic susceptibility (Wells et al. 2013).

Wells argues that soilscapes of "virtually any size (and involving a single pedon or multiple cross-cutting pedons)" could be "spatially delimited for analytical purposes" (Wells et al. 2013:40). "At the micro-scale, these might include soil surfaces associated with activity areas for producing or consuming food or making craft goods" while at the meso-scale "one might consider the soils cultivated for household gardens or underlying gathering places for large groups of people" (Wells et al. 2013:40). Finally, "at the macro-scale, whole landscapes can be studied, such as managed forests, agricultural field systems, or entire resource catchment areas" (Well et al. 2013:40). For Wells, the lone critical element in the study of soils at any scale, is an appreciation that "the soil environment is not divorced from the specific human behaviors that shaped it" enabling us to understand soil development and erosion as manifestations of human beliefs and values about the nonhuman environment, while also perhaps revealing the "causes and consequences of such changes in socioecological systems" (Wells et al. 2013:40). In essence, Wells encourages the identification of specific geochemical or geophysical signatures of human activities (such as increased levels of phosphates, organic matter content, pH levels, rare earth elements, and compaction) within the context of an areas soils and sediments systems to reveal aspects of human interactions with that environment (Wells 2006).

Wells et al. have also recently applied the framework of "soilscape legacies" to the geoarchaeological investigation of Betty's Hope sugar plantation in Antigua, a site where

sugarcane was continuously grown for some 300 years. Using geochemical, geophysical, historical, and ethnographic data sets one of Wells' research partners, Suzanna Pratt, sought to demonstrate the extent to which intensified sugar planting and other anthropogenic factors on the site caused soil degradation and erosion (Pratt 2015). Working in conjunction with Wells, Pratt's geoarchaeological collection strategy on Betty's Hope consisted of the extraction of 20 soil profiles (through auger testing) from across the plantation, targeting columns of soil beneath the surface at and near topographical contours, hydrological features, and built cultural resources. Pratt then subjected these soil samples to an array of tests, both in the field and in the laboratory. By determining the extent of the present soil horizons, examining each encountered soil's texture, and assessing each soil's pH levels, phosphate concentrations, and carbonate and organic carbon content within each of the auger samples, Pratt was then able to compare the measured parameters of each stratum encountered within each auger test, and then to compare the overall results with the plantation's known land use history to draw inferences about the plantation's soilscape legacy, gaining insight into the human/environmental dynamics that caused the soil conditions we see on the plantation grounds today (Pratt 2015).

Pratt's geoarchaeological analysis allowed for the identification of the historical trajectories of both the land and the people acting upon it. Analyzing the soils and sediments themselves as the artifact or assemblage of interest, Pratt used the soils and sediments textures, Munsell soil colors, depth of stratigraphic horizons, biological contents, and chemical compositions along with a strong understanding of the plantation's land use history to identify locations where deliberate anthropogenic soil modification had taken place, and where it had not. Pratt also used geophysical and geochemical signatures to identify areas with relatively stable and unstable developmental histories across Betty's Hope plantation (for example, locations that have been subjected to the forces of erosion in the past versus those that had not). "Two types of stable locations are present [on the plantation]" concluded Pratt, "those located higher on the hillslopes of each catena and those located near areas of continuous [human] activity" (Pratt 2015:149). Locations of stability found at the tops of the plantation's hillslopes, where soils possess high amounts of potential energy, and are quite susceptible to the forces of erosion (i.e. rainsplash damage and gravity), certainly reflects a level of past human effort that was deployed to prevent or at least curtail erosive processes. These efforts might have included the deliberate planting of flora on top of hills to help retain soils, and or the development of structures along topographic contours, to reduce the impacts of construction projects or earthen works in the area.

Even more notably, Pratt also found that the stratigraphy observed within several locations on the plantation, which were known to have been in continuous agricultural use over the last several hundred years, contained geophysical and geochemical signatures that suggested the area had experienced a relatively stable history of development. These signatures included: the presence of large and well-developed strata which possessed gradual transitions between them, and which demonstrated heighted levels of organic carbon content and phosphate levels within their 'B' horizons, suggesting that these strata had been in place long enough to allow for the translocation of plant nutrients, a lengthy process which is readily disrupted by processes of erosion or sediment deposition. Keenly aware of the continuous sugarcane planting which had taken place in these areas, Pratt argued that these findings suggested, "that continuous human activity ha[d] contributed to the intentional or unintentional stability of these locations" rather than detracted from these areas' capacity to retain soils (Pratt 2015:149).

Recognizing these locations were subjected to centuries of intensified sugarcane agriculture Pratt, Wells, and their colleagues began to consider that perhaps the particular means of the plantation's abandonment, high erosivity from subsequent rainstorms, or other, later, forms of land use may have played equally, if not more, important roles than constant cultivation in the past, in the development of present conditions which show signs of depletion (Fox 2016). While historians, archaeologists, and environmental scientists studying the cultural and natural histories of the Caribbean have attributed the region's troubling soil conditions to degradation brought on by sugarcane cultivation itself, Pratt and colleagues' work at Betty's Hope suggests that further empirical examinations of the sediments and soils of previously used sugarcane plantations should be pursued to further test this understanding.

The "Abandoning the Garden" Hypothesis

Pratt closely considered the "abandoning the garden" hypothesis, first posited by Chelsea Fisher in 2005, after finding potential evidence that centuries of sugar planting might have caused stability rather than degradation at Betty's Hope. The "abandoning the garden" hypothesis posits that, "the abandonment of an intensive, anthropomorphized landscape dependent on labor for stability contributes directly to environmental degradation" (Fisher 2005:89). A central component of this concept is that significantly anthropogenically modified landscapes continue to require anthropogenic maintenance in order to retain their soils and productivity (Fisher 2005, Pratt 2015). Thus in an effort to link present day conditions to human and natural interactions in the past, Pratt examined whether the abrupt manner in which once heavily modified and maintained sugarcane fields were abandoned was the main cause of present day conditions in Antigua rather than the far more frequently blamed activities of repeated and intensified planting, maintenance, and harvesting of sugarcane (Pratt 2015, Abbot 1964, Ragatz 1928, Sheridan 1960, Watts 1990).

Whereas conventional wisdom suggests that rates of crop productivity on a landscape either remain constant or decline over time as local rates of erosion increase from repeated agricultural activities landscapes within which improvements of earthen works, soil amendments, and water flows have been anthropogenically introduced and maintained can instead show signs of relative stability and perhaps even consistent or increasing levels of productivity over a given time (Pratt 2015). On such a landscape, it would then be the manner in which such an improved landscape was abandoned that might be to blame for soil degradation, not the long-term intensified use of that landscape which came in years prior. To test this "abandoning the garden hypothesis," Pratt constructed a 298-year-long simulation (1674 – 1972) based on crop yields at Betty's Hope using the USDA's Erosion Productivity Impact Calculator (EPIC). The results were then compared the edaphic and geomorphological properties of the soil and sediments she sampled within her collected auger samples with annual records of sugar production on the plantation.

Pratt's work yielded results that challenged the traditional "common sense tenet" of agricultural studies, that overuse of soils is the primary cause of land degradation. Pratt achieved this effort through the synthesis of geoarchaeological soil analysis and historical research. Demonstrating that sugarcane production never significantly fell on a plantation where intensified sugarcane agricultural was pursued for nearly 300 years, Pratt was forced to consider exactly when and how soil degradation actually took place on Betty's Hope. While Pratt ultimately did acknowledge that, "some parts of Betty's Hope experienced degradation due to long-term sugarcane monoculture," her data also revealed significant degradation in other portions of the plantation

and within the plantation's watershed that may be the "result of the cessation of commercial agriculture in 1972, when human investment in the highly engineered landscape ended" (Pratt 2015:10). She argued, "current erosion and degradation experienced [on Antigua] today cannot be attributed to intensive plantation agriculture alone, but rather are part of a complex mosaic of human-environmental interactions that includes [the] abandonment of engineered landscapes" (Pratt 2015:10).

Pratt's examination of the "abandoning the garden" hypothesis highlights the possibility that poor or unsustainable agricultural activities, even when conducted for extended periods of time, may not necessarily play a dominant role in the sculpting of a landscape's future trajectories and agricultural capacities. This emphasis on the ability of sudden punctations of human/environmental trajectories, which through abrupt, (relatively) short-term, yet particularly intense instances of change echoes the argumentation of numerous historical ecologists, hydrologists, and other natural scientists, who insist that some of the most dramatic and defining episodes in environmental systems and their trajectories are those which occur suddenly, violently, and rapidly, rather than gradually, subtly, and over extended periods of time (Crumley 1987, 1994, Walsh 2004, Balée 1998, Dunne and Leopold 1978).

In the Caribbean, where long term and so-called unsustainable sugar planting practices have historically been blamed for causing soil degradation, such findings might countermand regionally prevailing wisdom, historical, archaeological, and environmental scholarship, and even contemporary environmental studies and policies (Ragatz 1928, Sheridan 1960, Watts 1990, Fox 2016, Wells et al. 2017, Pratt 2015). If the "abandoning the garden" hypothesis is correct, it would mean that investments made into, and modifications of local soils to maximize agricultural yields effectively created stable or even sustainable landscapes, though ones that were dependent on human maintenance and continued input for their success. If borne out through further site-specific geoarchaeological studies of past agricultural activities, these findings would certainly contrast with the growing number of scholars who emphasize the value of the *longue durée* perspective when weighing matters of contemporary public policy and planning for the future (Hill 2004, Crumley 1987, Balée 1998). Further, it might impact how geologists, (geo)archaeologists, natural scientists, and land managers attempt to define the "sustainability" of specific agricultural practices over the long-term (Altieri 2004, Fisher 2019, Redman 2005, Redman and Kinzig 2003).

Examining the Soilscape Legacy of the Estate Little Princess

The collection of methods presented here were developed to examine environmental outcomes from past long-term agricultural practices. They take advantage of a rich historical record to help isolate geological signatures of the interactions between humans and the environment on a colonial era sugarcane plantation, the Estate Little Princess (ELP). The methods chosen for this geoarchaeological investigation were also deliberately selected to replicate and build upon the works of Wells, Pratt, and their colleagues who conducted geoarchaeological investigations on Betty's Hope. Just as Wells, Pratt, and others sought to discern the "soilscape legacy;" of Betty's Hope, this work set out to identify the soilscape legacy of sugar planting on ELP, defined as the long-term social ecological consequences of human chemical and physical alterations of soils within the plantation's landscape (Wells et al. 2013:23). Through archival research of land use history, topographic mapping, and the geoarchaeological excavation and testing of soils across the plantation, Wells and Pratt revealed locations of relative soil stability and volatility within a

plantation setting where sugar was grown for nearly 300 years (Pratt 2015, Wells et al. 2017). Following the works of Wells et al. the present study seeks to explore the extent to which intensified sugarcane planting, and other ancillary land uses on ELP may have contributed to present environmental conditions. Employing the framework of Well's soilscape legacies, this work combines historical, geospatial, geophysical, and geochemical data sets to better understand the ways in which portions of the landscape were used, and the connections between those land uses and present-day conditions on the grounds of a colonial era plantation where sugar was cultivated for nearly two centuries.

At ELP I also sought to test the "abandoning the garden" hypothesis, first posited by Fisher, and more recently examined by Pratt in her 2015 study at Betty's Hope. Aware of the ELP's historical levels of sugar production, which never significantly declined on a pounds of sugar per acre yield basis through at least 1902 a secondary question arises as we investigate the developmental history of the soils at ELP. If through the examination of these soils, we find evidence of volatility (i.e. erosion) and or nutrient depletion, can that evidence also be used to determine whether these conditions were caused by sugar planting activities in the more distant past, or if they were the result of the fashion in which the sugarcane fields were abandoned? While it is a commonly held belief that intensified sugarcane agriculture is a primary cause of land degradation throughout the Caribbean, the sampling and testing methods deployed at the ELP, like those used at Betty's Hope plantation, were selected to better understand the role that plantation abandonment may have played in the development of the ELP's soils.

The influence of Wells and his colleague's work at Betty's Hope plantation in Antigua extended also into the specific geoarchaeological methods chosen for the current study, in terms of background research, fieldwork and testing. ELP is located on the northeastern coastal plain of the island of St. Croix. Similar to Wells and colleagues' study area of Betty's Hope plantation in Antigua, the work at ELP takes place on a plantation with comparable geological proveniences and one which shares a similar climatic, developmental, and agricultural history. Both sites sit in soils developed from oceanic limestone bedrock parent material, and both plantations were subjected to extensive clearing and intensified sugar monocropping for centuries. In the case of ELP sugarcane planting is thought to have taken place between 1733 and the early 1900s. By using a similar soil collection strategy, and by running a similar set of tests on the soils collected from locations across ELP the results of this research serve as a comparable and complimentary case study of the observable environmental impacts of sugar planting in a Caribbean environment. Looking to Pratt's work during her 2014 field season at Betty's Hope, the area's selected for testing were deliberately targeted to examine the full range of elevations on plantation, and to sample soils that were under a wide variety of present and past land uses. Further, as the parent material present at both Betty's Hope and ELP consisted of oceanic limestone, a similar suite of soil analyses could be applied to collected samples to produce comparable sets of data. Tests, including Munsell color, pH, particle size analysis (PSA), loss on ignition (LOI) testing, and phosphate analysis, were selected, as these had proven capable of identifying areas of soil stability and volatility by Pratt (2015), Tricarico (2019), Wells (et al. 2018), and Peter Siegel (2018), at Betty's Hope. There were however, some changes made to the methods used by Pratt and others. At ELP I elected to excavate 50 x 50 cm shovel tests units (STs), rather than soil probes, augers samples, or core samples, to enable for the more controlled recordation of, and sampling of, encountered strata. Furthermore, I also sought to refine our understanding of the chronology of the development of the ELP's soils using radiocarbon dating

of materials found at a variety of depths from across the plantation. Thus, through the replication and refinement of these sampling and testing strategies, this effort further refines the suite of geoarchaeological methods that might be used in the future to study the environmental impacts of past instances of intensified agriculture in less well documented locations across the world.

Methods

Desktop and Archival Research on the ELP's Land Use History

Desktop and archival research into the ELP's plantation era land use began in Fall 2018 and did not conclude until Spring 2024. This examination incorporated data from a wide variety of documents including; compilations of eighteenth, nineteenth, and twentieth century estate papers at the St. Croix Historical Landmarks Society's Archive at Estate Whim (Tyson N.D., Staples 1998, Vaughn 1977), eighteenth century cartographic records held within the Danish National Archives (Rigsarkivet) in Copenhagen, Denmark, nineteenth, and twentieth century photographs of the plantation held at the ELP and the Estate Whim Archives, National Register of Historic Places Nomination forms for the ELP (Wright et al. 1980), and published nineteenth and twentieth century accounts of the estate's number of acres kept in sugarcane cultivation and the number of hogshead (1 hogshead equals 300 liters) of muscovado sugar produced by the plantation each year (GDWII 1892, 1905).

I articulate the broader findings of this historical research more thoroughly articulated in Chapter 9. Importantly, these efforts revealed a great deal of information regarding the ELP's land use history. During its active use as a sugar plantation between the 1740s and the mid-twentieth century the ELP had four different activity areas. These included the Sugar Growing Area, the African Village Site, the Land Kept in Timber, and the Great House Industrial Area (as depicted in Figure 86). The approximate boundaries of these activity areas were initially determined through historical research and were confirmed and refined through pedestrian survey of the plantation grounds in 2019, 2021, and 2022, through collaborations with the SBA and their ELPFS during their archaeological investigation of the African Village Site, and a review of publications produced by the SBA pertaining to their 2017, 2018, 2019, 2022, and 2023 field seasons (Dunnavant et al. 2018a, 2018b, Flewellen et al. 2022).

Topographical and Hydrological Due Diligence:

The topography of ELP was revealed using National Oceanic and Atmospheric Agency (NOAA) collected LiDAR data from 2016 and its conversion into a digital elevation model using ArcGIS computer software (Figure 84). These efforts revealed that the ELP lies on a small coastal plain, abutting the Atlantic Ocean on its northeastern border. The tallest point of elevation on the plantation lies at the top of an 18.46 m tall hill which lies along the west central portion of the estate. This hill creates the steepest terrain on the property, with slopes leading downward to the north, east, south, and west. Upon the creation of this digital elevation model, I noticed almost immediately that the African Village Site lies directly at the top of this primary hill. To the south and east of the hill, beyond the soil creep of the main hill, the localized slope descends more directly down towards the northeast (towards the coast).

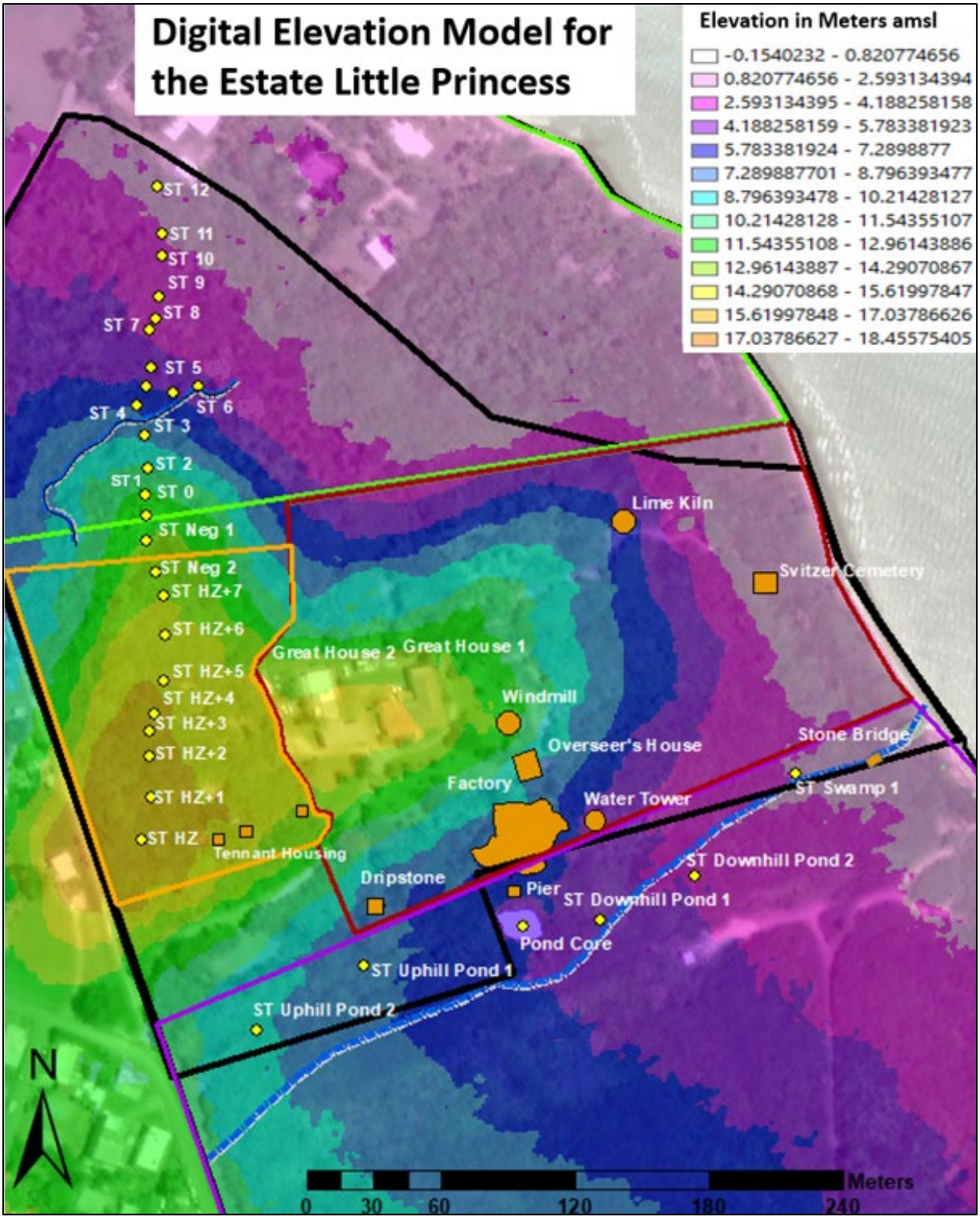

Figure 84. Digital Elevation Model (DEM) for the Estate Little Princess, based on 2016 NOAA collected LiDAR data. Map created by author, 4/27/24.

Hydrologically speaking the estate was found to lie near the coastal terminus of the 102-acre "Princess" Watershed where the water table of the Kingshill aquifer (on which the estate lies) is known, in the vicinity of the ELP, to locally slope towards the northeast (USGS 2016a, CADMUS 2011). Digital elevation mapping of the estate also revealed the location of a primary and secondary ghut with the former located to the south of the estate's factory (running from southwest to northeast), and the latter located to the north of the African Village Site (running from southwest to northeast and around the contours of the hill) (Figure 84). The locations of these ghuts, and the various built features depicted on Figure 83 and Figure 84 were confirmed during the pedestrian survey and excavations conducted on the estate in the summers of 2019 and 2022.

Geomorphological and Geochemical Background Research:

A geomorphological and geochemical understanding of the soils and sediments on ELP was developed through a review of existing literature discussing St. Croix's, and the estate's geological histories. The island of St. Croix is comprised of sedimentary rocks formed of the debris from eroding volcanic rocks and from volcanic ash spewed from sea floor volcanic eruptions which took place in the late Cretaceous period, some 80 million years ago (Wheeten 1966:7). These sedimentary rocks were formed after volcanic debris were deposited from eruptions to the south or southeast of St. Croix, on to the present day location of the island, where they interfingered with sandy layers and mudstones lying on the sea bed which had resulted from the settling out of fine particles from turbidity currents moving about the region of the Caribbean Sea in the earlier Cretaceous period (Whetten 1966a:7).

The limestone (often referred to as marl) which can today be found at or near the surface of St. Croix and on the ELP (often forming local parent material), is considerably younger than these volcanic born sedimentary stones, having formed during the Miocene period (23.03 – 5.33 million years ago). These limestones are thought to consist of the broken and transported remnants of a large coral reef that had developed around the volcanic island(s) formed to St. Croix's south and southeast during the late Cretaceous period. These limestone materials, which formed the early above sea-level surface of the island, were at first partially brought above sea level prior to the late Oligocene period (circa 33.9 to 23 million years ago), when mountain-building forces compressed, and caused numerous large folds, forming the Northside and East End Ranges of the island. In so doing, the two ranges formed two islands which would later be joined by a large coral reef located in the vicinity of the town of Kingshill. Overtime, this Kingshill Reef formed into limestone, and further uplift joined the two islands into the single island of St. Croix we see today (Whetten 1966a).

The Jealousy Limestone Formation (JLF) is a geological unit produced during the Miocene epoch (23.03 – 5.33 million years ago) which underlies the ELP and the entirety of the small northern coastal plain within which ELP lies. It consists of grey-blue, planktonic foraminiferal muds, and is still unlithified. The JLF is understood to be approximately 183 m thick and is comprised of the remnants of a fossil coral reef consisting of a fine powder or limestone, suggesting that pedogenic processes in the area (i.e. those which create soils from the physical and chemical weathering of parent material) took place atop alkaline materials. If broken loosen and transported from their place of origin, JLF sediments have been described as dominantly calcite, with significant components of quartz, feldspars and clay minerals (USGS 2016b, Gill et al. 1989).

Throughout the Quaternary period (from approximately 2.58 million years ago through the present), alluvium was deposited on top of JLF deposits, and across lower elevations and coastal portions of the island, like at the ELP. The alluvium consist of rainfall transported sediments (created through the erosion of the island's west and east mountain ranges), and of beach sands transported to the island's coast due to wave action and violent storms. At the ELP specifically, alluvium have been deposited as a result of erosion in the small string of hills/small mountains to the southwest of the plantation, and as a consequence of the creation and movement of sands from storm and wave action acting upon the seabed and coral reefs in Atlantic Ocean just to the northeast of the plantation (Whetten 1996b).

Shovel Test Excavations and Lab Tests:

Armed with an understanding of the plantation's known human, geological, and pedogeological developmental histories, the pursuit of this project's true research goal, to discern what aspects of the presently observable stratigraphic profiles at ELP can be attributed to specific land uses in the plantation's past, could begin in earnest. To do so this project collected close interval soil samples and conducted a suite of geophysical and geochemical tests on the collected samples to examine the depths, color, pH, texture, organic and inorganic carbon content, and phosphate levels of encountered strata, and to analyze the nature of the transitions found between each encountered stratum**.** In so doing, this study enables the interpretation of observable attributes found in soils and sediments across the plantation against the context of the plantation's historic era land use history, allowing for the identification of links between present soil conditions and specific types of human activities which are known to have taken place in various locations across the plantation in the past.

Soils and sediments differ fundamentally in their formation and context. Soils develop *in situ* through pedogenic processes, including biological activity and chemical weathering, which produce distinct horizons and evidence of long-term environmental interaction (Jenny, 1941, Joffe 1949). In contrast, sediments are unconsolidated materials transported and deposited by agents like water, wind, or ice, lacking the internal organization and biological influence seen in soils (Waters, 1992). During the present geoarchaeological investigation of the ELP, only soils were encountered. The procedures for the field excavations and subsequent soils analyses are presented below.

Shovel Test Excavations

The field team excavated two shovel test transects across the grounds of ELP in the summer of 2022 (Figure 60). The first transect was designed to examine the soils of both the estate's African Village and an area to the north of the village, thought to have been kept in timberlands throughout the colonial period. The second transect was laid out to the south of the plantation's factory works, in order to examine areas thought to have been kept in sugarcane from the 1740s through the early twentieth century (Figure 60). The above ground conditions of each shovel test were examined and recorded via narrative notes. This included the collection of information regarding flora growing on or over the shovel test and in the immediate vicinity, ground cover including leaf litter, rock, or other inclusions, detritus, local slope conditions, and other natural features, and GPS coordinates (including elevation data).

The team excavated a total of 27 shovel tests, each measuring approximately 50 x 50 cm in width and length, and each extending to a depth within local parent material. The reason these shovel

tests were excavated to such a width was to completely expose the stratigraphy present at each shovel test's location. This was done not only to ease the visual examination and photographing of each identified stratum, but also to gain increased control over which portions of the soil profile could be sampled. Depths of shovel tests ranged from 30 cm to well over one meter. All exposed strata were measured in terms of starting depth and ending depth relative to ground surface of the shovel test, and notes were taken to record details pertaining to the textures of, inclusions within, and the nature of the transitions between, each observed stratum. At a minimum, each soil horizon encountered during excavations was sampled. Whenever feasible, samples were collected every 3 to 10 cm within each stratum, while special care was taken to avoid collecting samples which included portions of two adjacent strata simultaneously (as such a sample would have yielded uninformative homogenized testing results that blended the characteristics of the two strata together). Samples were also collected with this heightened level of stratigraphic control to be able to identify (via subsequent testing) even subtle changes in the geophysical and geochemical signatures of local soils separated by even small increases in depth. The exception to this collection methodology was within the observed C horizons of the excavated shovel tests where often times one or two samples was considered sufficient for the purposes of the characterization of the stratum through later lab analysis. In addition to this systematic incremental sampling strategy, soil samples were also taken from what were thought to potentially be particularly informative parts of a given soil profile. These key sampling locations included depths just below the ground surface, just below and just above transitions between strata, transition layers (when present and large enough to be sampled individually), and soil discolorations/features (if present). A more complete list of the attributes recorded in the field or selected for sampling for each shovel test excavated can be found in Table 7. An example diagram showing how the exposed profile wall was typically sampled for each shovel test can be found in Figure 85.

Table 7. Attributes recorded in the field or selected for sampling within each shovel test and exposed soil profile

Shovel Test Environs	Encountered Stratum	Sampling Strategy
Flora above or close to ST	Depth of start and end of each strata (from ground surface)	At Least one Sample from each Encountered Stratum
Nature of and amount of Leaf Litter	Munsell Color of Strata	If Possible, Samples Collected in 5 cm Increments within each stratum
Contents of Ground Cover	Texture of Strata	Avoided Collecting Samples with Portions of Two Adjacent Strata Simultaneously
Nature and Size of Ground Cover Inclusions	Nature and Size of Transitions Between Strata	Samples from Just Below the Ground Surface
Slope	Type of and Quantity of Organic Inclusions within Strata	Samples from Just Below and just Above Transitions between Strata
Elevation	Type of, Size of, Angularity of, and Quantity of Lithic Inclusions	Samples from Transition layers (if present)
Other Nearby Natural Features or Conditions (i.e. water sources, or large piles of plant debris)		Samples from soil discolorations/features (if present)
Anthropogenic Disturbances or Modifications to the Environment		Samples From the Lowest Depth in Each Shovel Test

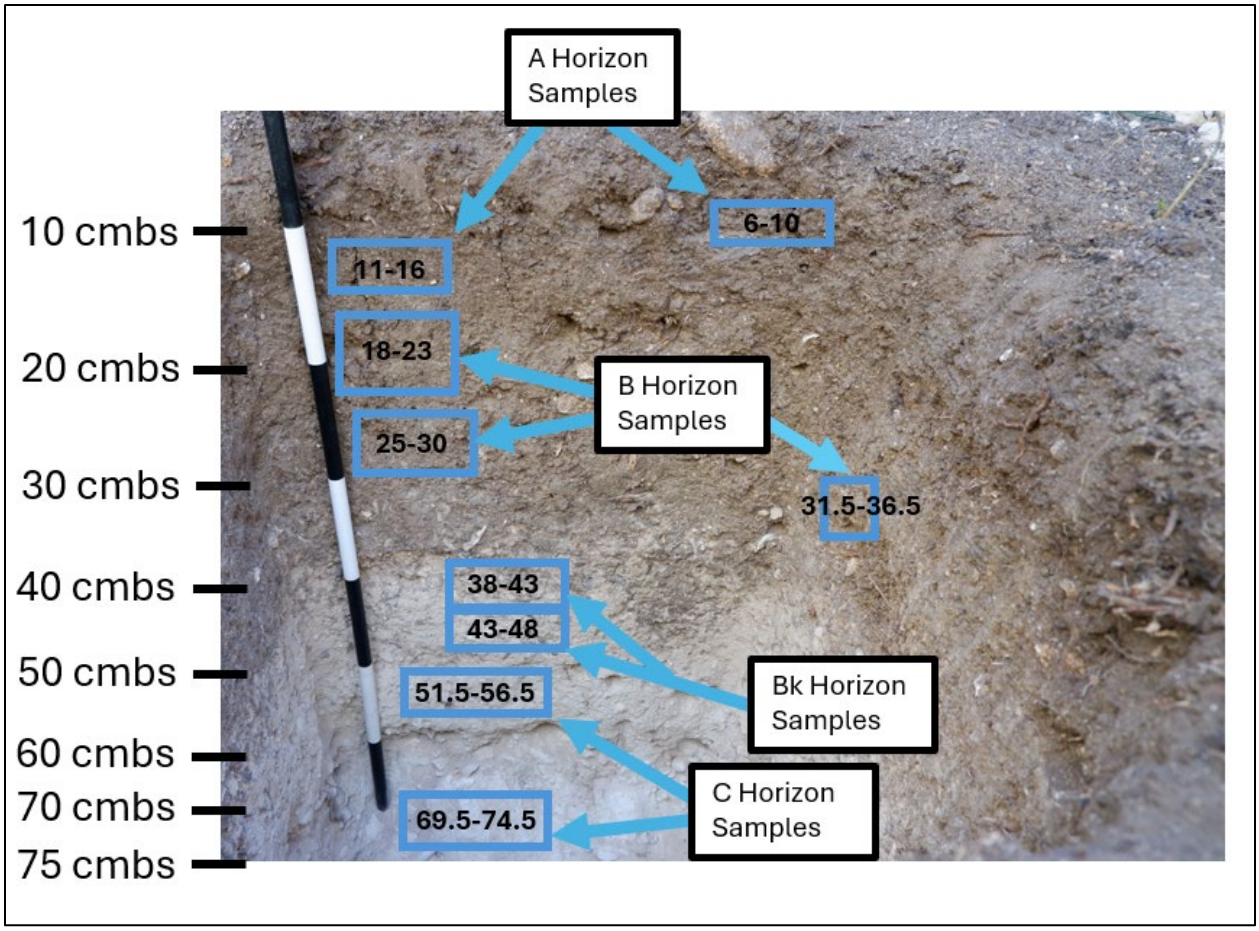

Figure 85. Typical shovel test profile wall sampling strategy, showing locations of bulk samples taken from Shovel Test 9, west wall. Photograph by author, 7/9/22.

Soil samples consisted of 250 mL of soil or less. Soil horizon depths and Munsell colors were recorded during excavations. Field assessments of each stratum's texture were also made, and notes were taken regarding the nature of, size of, and quantity of each. A tarp was placed over each shovel test so that Munsell color tests could be conducted, and digital photographs could be taken, of the exposed soils in indirect sunlight. At least one profile wall for each shovel test was photographed. Once collected, soil samples were double bagged in sealed ziplock brand containers, labeled, and shipped to the Archaeological Research Facility (ARF) at U.C. Berkeley (using USDA certified soils permit #P525-220531-005). All collected samples are presently kept within the ARF's USDA certified quarantined soils laboratory and will be disposed of using the ARF's soil disposal protocol or transferred to another USDA certified laboratory when deemed necessary.

Munsell Color

On a basic level, soil types can be classified by color as an indication of organic matter, iron content, and parent sediment type (Holliday 2004:34). The Munsell colors of the soils encountered during excavations at ELP were recorded at the time of excavation. During excavations, a trowel full of each encountered strata was placed into the viewing windows within pages 7.5 Y/R and 10 Y/R in the Munsell color book, and the soil was matched to the closest

color. All soils' colors were characterized and recorded while the soils were dry and in indirect sunlight.

Lab Tests

Between 2022 and 2024, bulk soils samples collected from ELP were analyzed within the Archaeological Research Facility's (ARF) Soils Lab and Wet Lab. Measurements included pH level, texture, organic carbon and inorganic carbon content, and phosphate concentrations. pH analysis was the first lab test conducted on subsamples taken from selected bulk samples as it is a relatively quick procedure (when using a digital pH meter) and it was hoped that the tests might rapidly reveal specific activity areas on the plantation as well as important aspects of stratigraphic development including the degree of organic decomposition, leaching processes, and potentially even evidence of more recent human interactions with the soil column (Courty et al. 1989, Goldberg and Macphail 2006, Wells 2014). Next, the considerably more time-consuming analysis of the texture of selected soil samples was undertaken. Through PSA of selected subsamples, I sought to gain insight into the depositional and *in situ* developmental history of the soils and sediments encountered within the ELP (Butzer 1982, Holliday 2004, French 2003). Concurrently, selected subsamples were subjected to LOI testing to better ascertain the organic matter content of encountered soils. It was intended that readings of the soils' organic matter content would potentially reflect information regarding current and past vegetation cover, anthropogenic inputs, and information about past land use practices (Holliday 2004, Courty et al. 1989, Buol et al. 2011, Hesse and McTainsh 2003). Lastly, phosphorous analysis was conducted on selected subsamples to further aid in the reconstruction of past land use histories, with phosphate known to accumulate in areas of prolonged human activity including settlement, agriculture, or locations of waste disposal (Holliday 2004, Entwistle et al. 2000, Eidt 1977). Chronologies for observed soil sequences were further developed through the radiocarbon dating of pieces of charcoal and land shells found within shovel tests excavated within the Lands Kept in Timber, and the Sugarcane Fields at ELP. No radiocarbon datable material was recovered from shovel tests within the African Village Site. Relative chronologies of each soil/sediment sample were also inferred from stratigraphic relationships. In total 85 bulk samples were tested, with 74 subjected to pH level testing, 69 subjected to PSA, 80 subjected to LOI testing, and 78 subjected to phosphate testing. In addition, eight radiocarbon datable samples were tested from various depths within six of the excavated shovel tests.

Ultimately, the differences/consistencies between soils/sediments were compared against the plantation's known land use history and analyzed for diagnostic signatures of soil stability and erosion (Holliday 2004, Pratt 2015). What follows are brief descriptions of the methods used for each analysis conducted on the collected bulk samples recovered during excavations and an explanation of each test's potential to add interpretive value to our understanding of the local stratigraphy's past developmental history. Full protocols for each method can be found in Appendix B.

pH Testing

Potential of Hydrogen (pH) levels indicate the hydrogen potential of a soil which in turn can reveal past human and natural processes which have added or removed hydrogen ions (H^+) and hydroxyl molecules (OH^-) in soils (Holliday 2004, Pratt 2015, Tricarico 2019, Wells et al. 2018, Courty et al. 1989). The higher the number of OH^- molecules, the more basic (or alkaline) the soil. By using pH tests for each soil encountered across a horizontal area, or within vertical

columns of a shovel test unit's profile, observed patterns and or interruptions, in pH sequences can point towards areas where different human activities or natural processes may have impacted conditions, likely in the more recent past. Through the identification of areas with elevated or depleted OH- molecules, it may be possible to identify circumscribed activity areas or repeated human activities that might have caused these altered levels including land clearing, manuring, inclusion of ash or lime into soils, and other farming practices (Courty et al.1989, Holliday 2004, Entwistle et al. 2000). A profile where B horizons or lower layers exhibit a more neutral or alkaline pH, can suggest the accumulation of bases that were leached from the upper layers. This is common in more stable and mature soils where the soil has had time to reach equilibrium, meaning the pH has stabilized with the addition of weathered material and nutrients from strata above (Banning 2020). This can also take place where local vegetation can create more acidic conditions within an area's topsoil, even in places where local parent material is more basic (Entwistle et al. 2000). A soil profile that exhibits minimal pH variation between strata can also suggest a stable developmental history, where weathering, leaching, or organic matter inputs have not drastically altered the chemical composition of the soil layers. This may also indicate that the soil has developed from homogeneous parent materials, which has contributed to the consistency of the pH throughout the profile (Banning 2020). By contrast a variable pH seen across a soil profile, or lower pH levels found at greater depths, can be indicators of either erosion from, or the deposition of sediments onto, a given area as it alludes to still active processes of leaching, mineral breakdown, movement of acidic compounds deeper into the profile. It can also indicate localized activities related to anthropogenic land uses.

Soil samples were tested for pH levels at Berkeley's ARF. A 5 mL homogenized subsample of each sample was placed into a beaker. Then 10 mL of deionized water was added to the beaker and agitated for 1 minute using a glass stirring rod. After being left to stand for 5 minutes, each sample was re-agitated before being tested by a digital pH and temperature reader. Readings were taken twice, and averaged. While temperature of the sample can impact the pH meter output, all specimen were kept at 27 degrees Celsius during testing, to ensure consistent pH readings between samples. The pH meter was calibrated prior to use, with calibration solutions of known 7.0, 4.0, and 10.0 pH levels. Detailed step-by-step procedures for pH testing are provided in Appendix B-1.

Soil Texture

Determined through particle size analysis (PSA), and gravitation analysis for smaller particles, identifying soil and texture is a common practice in geoarchaeological investigations. PSA quantifies the amount of sand, silt, and clay within each collected soil sample and reveals each soil's type (Gee and Or 2002, Wells et al. 2013, Pratt 2015). Determining soil particle size can help characterize soils and parent materials within fluvial, aeolian, or lacustrine depositional systems, It can also indicate the sediment type and or origin of a soil, can reveal soils as being compacted (potentially by human activity), and can reveal patterns of erosion that would affect site stratigraphy (Holliday 2004, Scudder et al. 1996, Timpson and Foss 1993 Courty et al. 1989, Goldberg and Macphail 2006, Waters 1992). The analysis of soil texture can prove useful in understanding the transport and depositional history of a soil's parent material, help identify periods of stability and relative instability (i.e. erosion or deposition) and can indicate the degree to which pedogenic processes have been able to take place (especially weathering) (Goldberg and Macphail 2006:336, Holliday 2004:34, Scudder et al. 1996:18, Garrison 2016).

Soil textures at ELP were examined by first drying out the selected subsamples. This was achieved by leaving samples in opened ziplock bags for several days, until all visible moisture was removed from the sample and the samples felt dry to the touch. Next 50 g of each sample was weighed out, and then placed into a mortar, where the larger clods within each sample (consisting of aggregated soil grains of various sizes) were broken down until the subsample consisted strictly of individual grains of soil. Next, the 50 g samples of soil were mechanically separated based on size of grain size, using a series of sieves and a mechanical shaker (See Appendix B-2.1). For this process the sieves were stacked in a sequential order, going from largest screen aperture at the top, to smallest aperture and, ultimately, the pan at the bottom. The stack of sieves was then placed into the mechanical shaker and shaken for 10 minutes. Soil particles caught by sieves of 8 mm, 4 mm, 2 mm, 1 mm, 0.25 mm, 0.125 mm, 0.063 mm, and the pan, were weighed separately and these totals were then compared against the total weight of the original soil subsample that had been added to the sieve stack. Sample materials measuring between 2 mm and 0.063 mm were identified as sand. Materials measuring 0.0629 mm and smaller represent a silt-clay fraction.

As clay particles are too fine to be separated from the silt fraction via screens, PSA for the sample fraction smaller than 0.063 mm sample was conducted using a gravitation test (hydrometry). Hydrometry (sometimes called gravimetry) is a grain size separation method based on an application of Stoke's law, which describes the settling velocity of various particle sizes in a fluid (Gee and Bauder 1986, Courty et al. 1989, McManus 1988, Goldberg and Macphail 2006, Garrison 2016). Effectively larger particles settle faster than smaller ones, with specific sizes of particles settling out of solution after specified durations of time. In this way, Stokes law makes it possible to determine at which point all silt particles have fallen out of solution, while virtually 100% of the clay particles remain suspended in the water column. Gravitation tests for this project were started by taking the volumetric measurement of the fraction of grain particles smaller than 0.063 mm which remained at the conclusion of the sieve and mechanical shaker testing. Then this subsample was added into a graduated vial with 1 mL of soil dispersing agent. The vial was then filled with water until the 45 mL mark was reached. The sample and reagents were then mixed with a glass stirring rod and then shaken for at least two minutes to ensure that 100% of the grain particles were suspended in the solution. Next the vial was allowed to sit upright for a duration of 30minutes allowing the heavier grain particles (i.e. all silt present in the sample) to settle out of solution. Then, using a syringe, all water was extracted from the vial, and the remaining materials were allowed to dry out completely. A volumetric measurement of the remaining sample materials was then taken, to determine the volume of the original sample that was silt. Through subtraction, the percentage of the original sample that was clay could also be deduced. The relative percentages of each particle class were recorded, and then taken as values that could be input into the USDA's Soil Texture Triangle to determine each soil's composite texture. Detailed step by step procedures for both the Shaker Screen particle size analysis and the Gravitation based particle size analysis are provided in Appendix B-2.2.

Loss on Ignition Testing

Loss on ignition (LOI) testing is as an effective method for accurately estimating organic and inorganic carbon content in a soil (Dean 1974, Heiri et al. 2001, Garrison 2016). Soil organic carbon and inorganic carbon contents can provide a look into the organic inputs (such as waste deposited by flora, fauna, or decomposing organisms) that have been introduced into a soil being

studied, and can also speak towards the measure of the carbonic influence of local parent materials on, or the level of weathering that has taken place on, materials within, a studied soil (Dean 1974, Goldberg and Macphail 2006, Heiri et al. 2001). Understanding these key aspects of a soil can speak toward the stability of current and past land surfaces. A stable land surface is generally high in organic carbon, where the topsoil has been undisturbed and been subjected to a great deal of organic inputs, resulting in high organic carbon concentrations, which help to form a thick A horizon. Organic matter can contribute to the development of stable soil aggregates, can improve water retention, and can enhance biological activity. Consequently, high soil organic carbon content levels in the O and A horizons of a soil profile can be indicative of a balanced cycle of organic matter inputs and decomposition and can signify long-term ecological stability in a soil as well as low erosion rates (Goldberg and Macphail 2006). However, interruptions in the inclusion of organic inputs into a soil or disturbances to a soil, due to either human activities (such as ploughing) or erosional or depositional episodes, can also hinder the decomposition of organic inclusions, impeding soil development, and potentially result in soils with higher inorganic carbon contents, and the development of shallow A horizons.

Low organic carbon content in the upper levels of a profile can also suggest instability, potentially because of erosion, tillage, or changes in land use which can result in the loss of organic material (Blum 2014, Tricarico 2019:149). When soils are disturbed organic matter can be lost, reducing the soil's ability to resist further degradation through processes such as erosion, compaction, and nutrient leaching (Banning 2020, Tricarico 2019, Conforti et al. 2013). While the O and A horizons of a profile might be expected to be relatively rich in organic carbon in stable settings, as organic materials are regularly deposited at the ground surface, organic carbon content is expected to decrease with increases in depth in locations where soils have had time to develop *in situ*. By contrast, high organic carbon contents found at greater depths within a profile point towards disturbances in regular pedogenic processes (e.g. instability) likely in the form of sediment deposition and or erosion (Banning 2020, Tricarico 2019).

LOI testing involves the heating of soil samples to incrementally increasing temperatures to remove (by burning off) water, organic carbon, and inorganic carbon contents from the sample, while revealing the percent of the sample which consisted of water, organic carbon, inorganic carbon, and noncarbon materials. To perform LOI testing, subsamples of 2 g were taken from the larger bulk samples collected from various depths within excavated shovel tests. Each 2 g sample was then gently disaggregated using a mortar and pestle to ensure that no clasts or peds were present before testing, ensuring that only individual grain sizes would be measured by the test, and placed into a weigh boat of a fixed weight. The mass of the sub-sample was then measured and recorded. Next, each 2 g subsample was then heated to 105°C for 12 hours in order to remove any moisture present, and to ensure a constant mass throughout the sample (Heiri et al. 2001). After each subsample's reweighing (and the recordation of this new dry mass), the subsamples were then heated to a temperature of 550°C, the temperature at which organic carbon oxidizes, for 4 hours (Heiri et al. 2001). Afterwards the subsamples were weighed again, and these values were compared to each subsample's previously recorded dry mass to calculate the amount of organic carbon lost through the process. Lastly, each subsample was then heated a final time at 900°C for at least 2 hours. At this temperature inorganic carbonate converts into carbon dioxide releasing it into the air (Heiri et al. 2001). The amount of inorganic carbonates present was then calculated by reweighing the sub-sample and comparing its weight against the previously recorded weight of the sample's dry mass. LOI testing is appreciated as an effective

method for accurately estimating organic and inorganic carbon content (Heiri et al. 2001). Step by step procedures for the LOI testing performed for this project can be found in Appendix B-3.

Phosphorous Testing

Phosphorous (P) in a soil can be a strong indicator of past human activity and can potentially even suggest specific types of past human land use (Goldberg and Macphail 2006:346). Human waste, food waste, and human burials all contain high levels of phosphates (Holliday and Gartner 2007:301, Garrison 2016:152, Courty et al. 1989, Wells 2006). Phosphates are chemical compounds which are created during the decomposition of organic matter including soft tissue, bones, and plant remains suggesting that areas with high phosphate concentrations may have been areas of dense human activity in the past, where a significant number of plants and animals might have been processed and consumed (Wells 2014). Alternatively, animal manure as well as other fertilizers are also known to contain high levels of phosphorus, which can point toward an area's past use for agricultural activity (Holliday 2004:304, Garrison 2016, Wells 2006, Pratt 2015:91). Phosphorus is also a particularly powerful tool for the study of past land uses because it has a particularly long lifespan, potentially remaining in soils for thousands of years after their deposition. This lifespan makes phosphorus levels a relatively easy to detect and dependable signature of past human activities.

Phosphorous concentrations are also a good indicator of current soil health due to phosphorous's role in plant seed formation and photosynthesis. Phosphorous is also responsible for several other key processes and systems within plants, including the metabolism of sugars, plant energy storage and transfer, cellular division, cell enlargement, and the transfer of genetic information. Phosphorus is also known to promote healthy root growth, early shoot growth, and enhances the quality of fruit, vegetables and grain crops. This is because adequate phosphorus levels in soils enable plants to more efficiently use water, and available nitrogen. Phosphorous is also thought to assist with disease resistance in some plants, and helps plants cope with cold temperature and moisture stress (Raghothama 2005).

There are many different ways in which phosphorous levels can be measured in a soil sample (Holliday 2004, Garrison 2016). Four main types of phosphorous testing include colorimetric analysis, extraction methods, sequential extraction methods, and instrumental techniques, each with their own strengths and limitations. The colorimetric analysis involves reacting soil extracts with a reagent to produce a color change, the intensity of which can then be measured through colorimetry to determine the phosphate concertation (Holliday 2004:207 – 208). This method provides total phosphorus concentrations of tested soils, providing relatively quick and inexpensive and reliable results. However, this test does not distinguish between organic and inorganic phosphorus which can limit interpretive value in the understanding of past human activities (Holliday 2004). Fortunately, this limitation can be at least somewhat mitigated through the contextualization of tested samples against the known land use history of the study area, which is the case for the present study.

Extraction methods of phosphorus analysis use specific chemical solutions (acids and bases) to isolate different forms of phosphorus (including organic, inorganic or total phosphorus) (Holliday 2004, Garrison 2016, Wells 2006). This additional information can be valuable, especially in study areas where little is known about past land uses, as the presence or preponderance of organic phosphorous and or inorganic phosphorous can aid in the identification

of specific activities in the past including the creation of organically rich middens, or the inclusion of fertilizers (Holliday 2004:208 – 209). Extraction methods, however, are more time-consuming, and can be more costly.

Sequential extraction methods involve the application of a series of reagents to isolate and quantify distinct phosphorous pools in a tested soil (Holliday 2004:209 – 210, Garrison 2016). Labile phosphorous (also known as available phosphorus) is the fraction of phosphorus in soil that is easily accessible for plant use and chemical reactions. It includes phosphorus dissolved in soil water and that has been weakly adsorbed onto mineral surfaces. Occluded phosphorous (or unavailable phosphorous) is phosphorous that has been chemically bound within soil minerals, such as iron or aluminum oxides, or encapsulated within soil aggregates. This form of phosphorus is inaccessible to plants and microbial biota without significant chemical or physical alteration. This method can be particularly useful in understanding long-term site formation processes as it provides the detailed insight into phosphorus forms and their associations with specific past environmental histories and human activities. This method is labor-intensive and expensive.

Instrumental methods such as Inductively Coupled Plasma Spectroscopy (ICP) or X-Ray Fluorescence (XRF) can be used to measure total phosphorus and other elements in soils (Holliday 2004). Though not able to distinguish organic vs inorganic phosphorus, or available or unavailable phosphorous concentrations, these tests are nondestructive and highly accurate. The instruments used in these tests however, are expensive and require specialized expertise to operate.

The present study employed a form of colorimetric analysis to examine the phosphorus concentrations in local soils. This method was chosen to efficiently take a wholistic look at the phosphate concentrations present across the ELP and to complement understanding of the ELP's historic land uses, which was available to contextualize the geochemical and geophysical findings from the current study. Making use of compiled information from archival, cartographic, photographic, and archaeological sources, observable phosphate levels from these tests will ultimately be interpretated against a robust understanding of the types of, and likely locations of, past anthropogenic activities on the plantation. The specific method and reagents chosen for use were adapted from those used in the laboratory of Dr. Christian Wells at the University of South Florida. This method consists of the breaking down of the bonds between P molecules and their hosts in a soil using Melich II acid, and the reduction of molybdo-phosphoric compounds to create a blue-colored sample solution, the shade of which is related to the phosphorous content of the sample being tested (Holliday and Gartner 2007:309, Wells 2014, Pratt 2015: 91). For the present study, 2 g of each soil sample selected was placed into a testing tube with 20 mL of a diluted Mehlich II acid solution (consisting of 10 mL of concentrated Mehlich II acid put into 100 mL of Type II deionized water). The tube was then capped and shaken for five minutes. This process extracted all phosphorus from the soil sample. Then, the liquid in the tube was transferred to a sample cell, using a funnel and a Whatman ashless circle filter paper (<.2 microns), to prevent the soil grains and other inclusions from entering the sample cell. After filtration a Phos Ver 3 powder pillow, containing ammonium molybdate, was added to the sample cell and the cell was shaken to help it dissolve. The ammonium molybdate produces a yellow phosphor-molybdate in the presence of phosphates, however, through a reduction reaction with the Mehlich II acid, the solution turns to blue molybdenum compounds.

The sample cell was then placed into a Hach brand DR 890 portable colorimeter to quantify the shade of blue present within the cell, and speak towards concentration of phosphates (P, P2O5, and PO4) present within the solution in milligrams per liter (mg/L) on a scale of 0 to 2.75. If the quantity of total phosphorus present within the sample exceeded 2.75 mg/L, the colorimeter indicated that the phosphorus levels exceeded the testing limits of the device, and these high phosphorus levels were noted in the results. Colorimeter testing results produced results in mg/L, which readily translate to parts per million (ppm) at a ratio of 1:1. Detailed procedures for the phosphate colorimeter testing performed for this project can be found in Appendix B-4.

Radiocarbon Dating

Radiocarbon datable materials (shell and charcoal) were identified at various depths in several of the 27 shovel test units excavated and were collected and stored in pieces of aluminum foil for shipment along with collected bulk samples. Radiocarbon datable materials help us establish absolute chronologies for the stratigraphic development of ELP (Levin and King 2016). While radiocarbon datable materials found in soils can help reveal periods of stability, by aiding in the identification of a specific time period in the past during which a profile depth may have served as a location's active ground surface, radiocarbon datable materials found in strata that have been buried beneath subsequently deposited sediments, can also help pinpoint the chronology of local stratigraphic instability, identifying the time after which depositional event(s) must have taken place (Birkeland 1999). Admittedly radiocarbon dates from snail shells are less ideal than those from charcoal for establishing absolute chronologies (Banning 2020, Taylor 2014, Holliday 2004). This is due to their capacity to move within the soil column due to bioturbations in the soil after deposition, and during the snail's active life. Land snails are known to move within the soil column while alive in response to environmental factors including moisture, temperature, or the availability of food (Ramey et al. 2021, Osborne and Wright 2018). From a geoarchaeological perspective, this movement can lead to the collection of radiocarbon dates from snail shells that do not truly reflect the shell's date of deposition on a past ground surface (Banning 2020, Taylor 2014). Instead, these dates represent a broader range of soils that may have been reached by the snail prior to the organism's death. Nonetheless, in the absence of charcoal, snail shells can still offer some chronological information to a geoarchaeological investigation. Though it is possible that a snail has moved into an older part of the soil column during its active life, a snail shell would still provide archaeologists with a likely *terminus ante quem* for the soil in which they were found, in that, they can speak towards the youngest a specific stratum may be (as a snail would not be able to travel to a soil horizon and die within it, prior to its having existed).

At the ARF eight pieces radiocarbon datable materials were selected, cleaned, and prepped for shipment to the Keck Carbon Cycle AMS Facility located within the Earth System Science Department of UC, Irvine for radiocarbon analysis. Samples tested included shells or pieces of charcoal collected from ST 4, ST 8, ST 9, ST 11, ST Uphill Pond 2, and ST Uphill Pond 1 (Figure 2 in Appendix A). Results from these tests were calibrated using Oxcal v. 4.4.4, an online calibration software developed and updated by Bronk Ramsey as recently as 2021 and based on atmospheric data from Reimer et al. 2020 (Ramsey 2001, Reimer et al. 2020).

Results

The results from the testing of the soils examined within the shovel test units excavated on the grounds of the ELP are presented below. These 27 shovel tests were excavated along two

transects, one traversing from south to north from within the plantation's former African Village Site down to ELP's primary hillslope and towards the plantation's northern boundary, and a second starting close to the plantation's southwestern boundary and extending to the northeast, to the south of the plantation's sugar factory ruins (Figure 86). The lines for these two transects were chosen to ensure that a wide variety of topographic and land use proveniences were examined through shovel test excavations. While shovel tests within Transect 1 examined soils in areas that had been previously occupied by an African Village and lands that had been left relatively undeveloped, Transect 2 examined soils in an area where sugarcane was cultivated for close to 200 years (Figure 86 and Figure 86). The depth and Munsell color of each strata encountered during excavations of all 27 shovel test units were recorded during excavations (Figure 87).

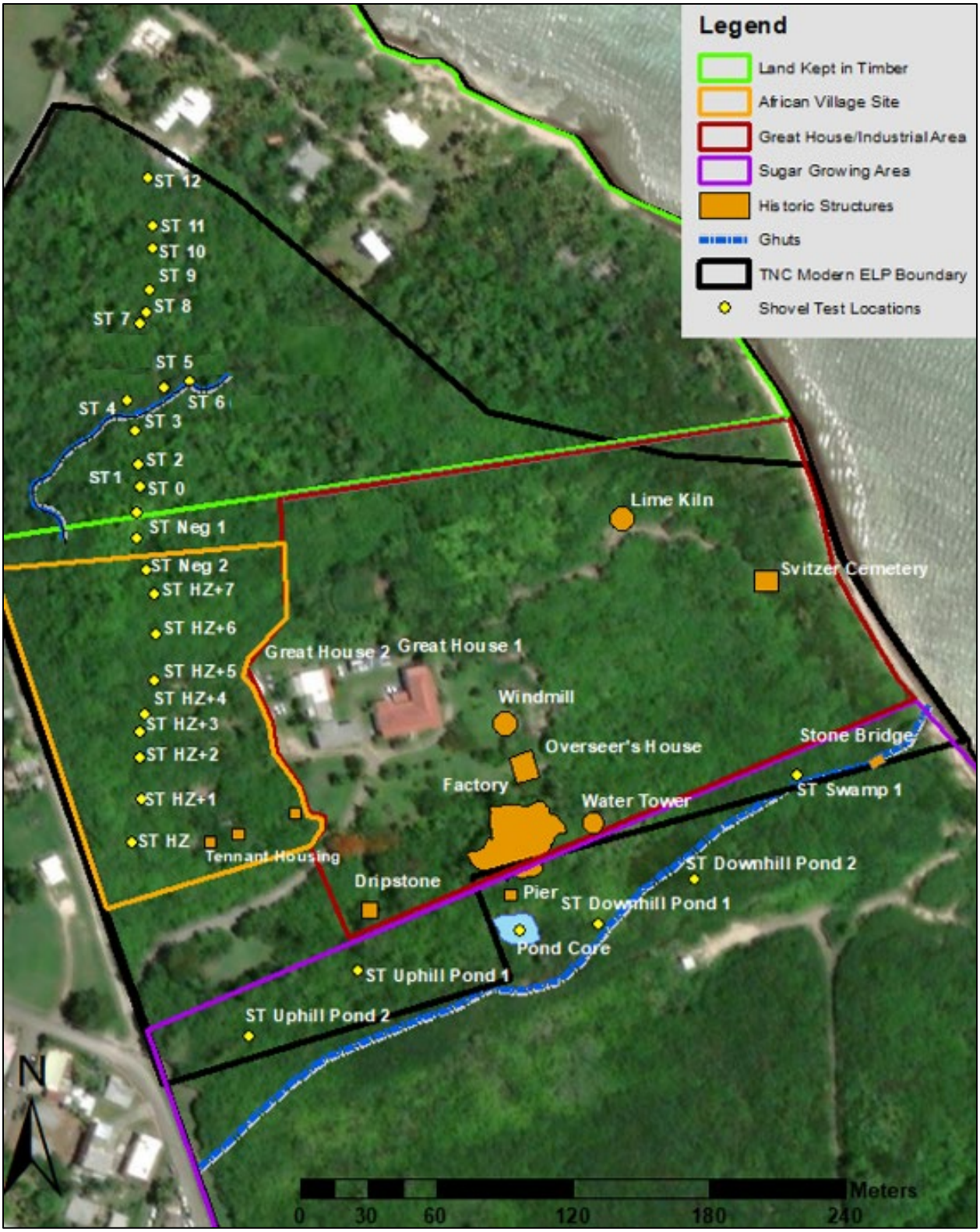

Figure 86. Locations of geoarchaeological shovel tests for the Summer 2022 field season and key features of the Estate Little Princess Plantation. Map created by author, Spring 2024.

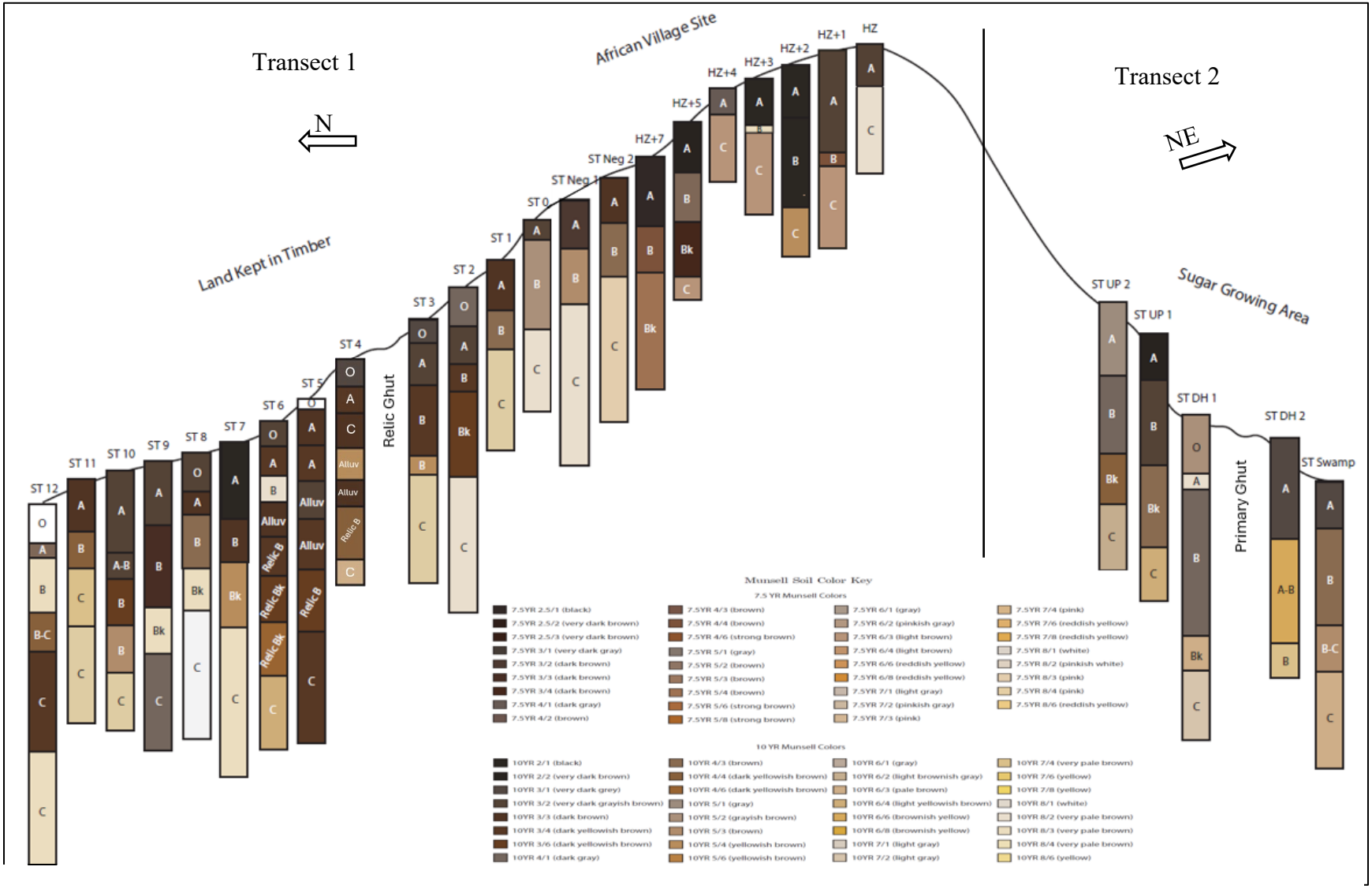

Figure 87. Shovel test unit locations, relative depths, Munsell color of encountered strata, and USDA soil characterization. Figure created during Undergraduate Research Apprenticeship Program at UC Berkeley, Fall 2023, with help from Kathleen Hulguin.

Samples from 14 of the excavated shovel tests were selected for additional testing, including ST HZ, ST HZ+1, ST HZ+5, ST HZ+7, ST 3, ST 4, ST 8, ST 9, ST 11, ST Uphill Pond 2, ST Downhill Pond 1, ST Downhill Pond 2, and ST Swamp 1. A complete list of shovel tests excavated and the types of tests conducted on soils from specific shovel tests can be found in Table 8. The 14 shovel tests chosen for additional testing were selected based on several criteria. Of paramount importance was that at least one shovel test from each of the three primary land use proveniences (the African Village Site, Timberlands, and Sugar Growing Area) was exposed to the full suite of lab tests (Figure 86 and Figure 87). Within Transect 1, soils collected from ST HZ and ST HZ+1 were subjected to lab tests in order to examine soils that had been occupied by enslaved Africans and laborers. Samples from ST HZ+5 and HZ+7 were tested as they were thought to lie within the transition area between the boundaries of the African Village Site and the lands left in Timber. These two shovel tests, along with ST 3 (also extensively tested) also comprised the middle of the ELP's primary hillslope, a topographic provenience on the plantation worthy of study as it would speak to the continuation or suspension of trends in soil conditions further downhill from the hillslope's crest and African Village Site. Further down Transect 1 alluvial deposits were readily observed during excavations within ST 4, ST 5, and ST 6. With the profile of these three shovel tests looking quite similar, ST 4 alone was selected for additional testing, as it proved to be the closest shovel test to the apparent source of the alluvium (the ELP's relic ghut) (See Figure 84, Figure 86, and Figure 87). Rounding out the shovel tests selected for additional testing within Transect 1 ST 8, ST 9, and ST 11 were chosen because they were excavated within the toe of the ELP's primary hillslope, and thus they can be understood to reveal conditions on the flattest portion of the plantation tested, and in a location where little development has taken place over the course of the plantation's history. As for the shovel tests within Transect 2, all soils excavated within the Sugar Growing Area (the entirety of Transect 2) were fully tested. This decision was made based on a stated primary interest goal of the project, which is to examine the long-term impacts of sustained sugarcane agriculture.

Table 8. Shovel test naming conventions, and descriptions of additional tests performed on bulk samples. pH stands for potential of hydrogen testing, PSA stands for particle size analysis (to determine soil texture), LOI stands for loss on ignition testing.

Transect 1 (Shovel Tests Listed from South to North)	**Additional Testing? / Justification**	**Lab Tests**	**Transect 2 (Shovel Tests Listed from West to East)**	**Additional Testing? / Justification**	**Lab Tests**
ST HZ	Yes / Within African Village Site	pH PSA LOI Phosphorous	ST Uphill Pond 2	Yes / Area kept in sugarcane cultivation for extended period of time	pH PSA LOI Phosphorous Radiocarbon
ST HZ+1	Yes / Within African Village Site	pH PSA LOI Phosphorous	ST Uphill Pond 1	Yes / Area kept in sugarcane cultivation for extended period of time	pH PSA LOI Phosphorous Radiocarbon
ST HZ+2	No Deemed Redundant	N/A	ST Downhill Pond 1	Yes / Area kept in sugarcane	pH PSA

Transect 1 (Shovel Tests Listed from South to North)	Additional Testing? / Justification	Lab Tests	Transect 2 (Shovel Tests Listed from West to East)	Additional Testing? / Justification	Lab Tests
	due to testing of ST HZ, and ST HZ+1			cultivation for extended period of time	LOI Phosphorous
ST HZ+3	No Deemed Redundant due to testing of ST HZ, and ST HZ+1	N/A	ST Downhill Pond 2	Yes / Area kept in sugarcane cultivation for extended period of time	pH PSA LOI Phosphorous
ST HZ+4	No Deemed Redundant due to testing of ST HZ, and ST HZ+1	N/A	ST Swamp 1	Yes / Area kept in sugarcane cultivation for extended period of time	pH PSA LOI Phosphorous
ST HZ+5	Yes/Close to Suspected Boundary of African Village Site	pH PSA LOI Phosphorous			
ST HZ+6	No / Deemed Redundant due to testing of ST HZ+5 and HZ+7	N/A			
ST HZ+7	Yes / Close to Suspected Boundary of African Village Site	pH LOI Phosphorous			
ST NEG 2	No / Deemed Redundant due to testing of ST+7 and ST 3	N/A			
ST NEG 1	No / Deemed Redundant due to testing of ST+7 and ST 3	N/A			
ST 0	No / Deemed Redundant due to testing	N/A			

Transect 1 (Shovel Tests Listed from South to North)	Additional Testing? / Justification	Lab Tests	Transect 2 (Shovel Tests Listed from West to East)	Additional Testing? / Justification	Lab Tests
	of ST+7 and ST 3				
ST 1	No / Deemed Redundant due to testing of ST+7 and ST 3	N/A			
ST 2	No / Deemed Redundant due to testing of ST+7 and ST 3	N/A			
ST 3	Yes / Close to Relic Ghut (just to the north) and within middle of ELP's Primary Hillslope	PSA LOI Phosphorous			
ST 4	Yes / Contains Alluvium from Relic Ghut Flooding Event and within middle of ELP's Primary Hillslope	pH PSA LOI Phosphorous Radiocarbon			
ST 5	No / Deemed Redundant as within same provenience as ST 4	N/A			
ST 6	No / Deemed Redundant as within same provenience as ST 4	N/A			

Transect 1 (Shovel Tests Listed from South to North)	Additional Testing? / Justification	Lab Tests	Transect 2 (Shovel Tests Listed from West to East)	Additional Testing? / Justification	Lab Tests
ST 7	No / Deemed Redundant due to testing of ST 3 and ST 4 which were also mid-slope	N/A			
ST 8	Yes / Lies at toe of ELP's primary hillslope	pH PSA LOI Phosphorous Radiocarbon			
ST 9	Yes / Lies at toe of ELP's primary hillslope	pH PSA LOI Phosphorous Radiocarbon			
ST 10	No / Deemed Redundant due to testing of ST 9 and 11	N/A			
ST 11	Yes / Lies at toe of ELP's primary hillslope, tested to confirm findings in ST 9	pH Radiocarbon			
ST 12	No / Deemed Redundant due to testing of ST 9 and 11				

Attributes of the soils collected from the 14 selected shovel tests that were examined included: soil texture (through particle size analysis testing), pH levels, organic and inorganic carbon content (through LOI testing), and or phosphate levels. The fourteen shovel tests chosen for additional testing were selected to take a closer look at the geophysical and geochemical conditions in three distinct areas of the plantation. In addition, eight radiocarbon datable

materials were recovered from six of the shovel test units which possessed excellent stratigraphic integrity, making it so that the results from the additional lab testing of the soils from these shovel tests would also be aided by absolute chronologies, and would support a broader understanding of the chronology of the ELP's pedologic and depositional history (including ST 4, ST 9, ST Uphill Pond 2, ST Uphill Pond 1). Tables containing the raw data, field observations, and the results of all lab tests performed on collected soils from the 14 representative shovel tests along with shovel test unit profile photographs that were taken at the conclusion of the excavation of each shovel test, and charts depicting the tested geochemical and geophysical properties of soils within each shovel test can be found in Appendix C. Radiocarbon test results from samples collected from ST4, ST 8, ST 9, ST 11, ST Uphill Pond 2, and Uphill Pond 1are provided in Appendix D, with the individual results from these tests discussed in detail within the narrative descriptions provided within this chapter for each selected shovel test. Lastly, a comparative table which allows for the ready comparison between the results for each lab test conducted for all 14 tested shovel tests is provided in Appendix E.

Indicative of soil conditions within several different proveniences on the plantation, the results from the analyses conducted on these 14 shovel tests provide us with a strong understanding of the current conditions of this former sugar plantation's soils and help us gain insight into past activities and land uses which have contributed to the conditions we see on ELP today.

Results from Selected Shovel Tests within Transect 1

Transect 1 consisted of twenty-two shovel tests, intended to examine portions of the former plantation which had been used in the past as an African Village Site, as well as a portion of the plantation that was thought to have been left in Timbers and relatively undeveloped. These shovel tests were placed in a line to the west of the ELP's great houses, extending from the highest point on the plantation (which was found to lie in close proximity to still standing residential structures associated with the African Village Site), to the north (Figure 84, Figure 86, and Figure 87). Starting from the south and moving to the north, these shovel tests consisted of ST HZ, ST HZ+1, ST HZ+2, ST HZ+3, ST HZ+4, ST HZ+5, ST HZ+6, ST HZ+7, ST Neg 2, ST Neg 1, ST 0, ST 1, ST 2, ST 3, ST 4, ST 5, ST 6, ST 7, ST 8, ST 9, ST 10, ST 11, and ST 12.

The soils encountered within ST HZ, ST HZ+1, ST HZ+5, ST HZ+7, ST 3, ST 4, ST 8, ST 9, ST 11, were tested for soil texture (through particle size analysis), pH, organic and organic carbon content (through LOI testing), and Phosphorous. The decision to test the soils found in these specific shovel tests and not others was based on a desire to closely examine several specific locations on plantation, while also seeking to avoid producing redundant or repetitive results for tests run on the soils found in nearby shovel tests which might have occupied identical topographical or land use proveniences. ST HZ and ST HZ+1 were tested to examine the area that had been occupied by African slaves and laborers. Samples from ST HZ+5 and HZ+7 were tested because this portion of the plantation was thought to form the transition area between the boundaries of the African Village Site and the Lands Left in Timber (Figure 84, Figure 86, and Figure 87). ST HZ+5, ST HZ+7 and ST 3 were also extensively tested as they lie within the midslope of the ELP's primary hill, giving them a unique topographic provenience from ST HZ and ST HZ+1, which lie at the hill's crest. ST 4 was tested to examine soil characteristics in the vicinity of the ELP's relic ghut. Lastly, ST 8, ST 9, and ST 11 were chosen for testing not only because they are thought to lie within a portion of the plantation which was left relatively undeveloped throughout the plantation's period of active use, but also because they lie within the

toe of the ELP's primary hillslope, enabling them to reveal information about the flattest portion of the plantation tested. In addition, radiocarbon datable materials were retrieved from various depths within ST 4, ST 8, ST 9, and ST 11 further enhancing the results of the lab tests run on the soils encountered with Transect 1 with absolute chronological data. Unfortunately, no radiocarbon datable materials were observed within shovel tests excavated within the African Village Site.

Shovel Test (ST) HZ

Shovel Test HZ was excavated at the highest point found at the ELP (approximately 18.45 m above sea level), southwest of the ELP's great houses, approximately 25 m east of the ELP's western boundary line (Figure 84, Figure 86, and Figure 87). During excavations it was revealed that ST HZ consisted of an A Horizon measuring 11 cmbs, which was comprised of a 10 YR 3/2 (very dark grayish brown) sand, underlain by a C horizon which consisted of almost entirely solid limestone which was a 10 YR 8/2 very pale brown. Excavations were terminated after 13 cm of the C horizon revealed no additional changes in soil color or texture. ST HZ did not contain an observable B horizon and the transition between the two strata found in ST HZ were abrupt in both color and texture. Bulk samples were taken from the A and C horizons and were subjected to pH testing, PSA, LOI testing, and phosphate content testing. The results from these tests, as well as excavation notes, a photograph of the west wall profile of ST HZ, and a chart depicting the tested geophysical and geochemical properties of ST HZ can be found in Appendix C-1.

Potential of Hydrogen (pH) levels in the A horizon of ST HZ were 7.95 and rose to 8.5 within the C horizon below it. The organic carbon content of the A horizon within shovel test HZ is relatively high (14.72%) compared to the A horizons found elsewhere on ELP. The organic carbon content within this shovel test's C horizon was found to be significantly less than that of the horizon above it, reaching only 2.45%.

The extent to which the organic content drops off between the A and B horizons in ST HZ matches with the abrupt changes in color and texture observed between ST HZ's A and C horizon. Together, these three indicators suggest a great deal of volatility in the stratigraphy of this area, with soils likely carried away from the location of ST HZ by erosional forces (including rainsplash damage and gravity-based run off). Rainsplash damage can be extremely destructive when soil remains exposed and without vegetation cover for extended periods of time, directly exposing it to rain droplets during precipitation events. Such soil exposure and erosion might be accounted for by this area being in use as a habitation site for enslaved (and later free) laborers and their families, whereby the area was deliberately cleared of vegetation, and kept clear for the construction and use of housing structures, various domestic activities, and pathways.

Phosphate (PO4) readings within the A horizon of ST HZ were found to be extremely high, exceeding 2.75 mg/L, the highest concentration even recordable via the project's Melhich II/Phos Ver 3 based colorimeter testing. This high phosphate level could be linked to the former use of this area as a habitation site, suggesting that food waste as well as human waste may have been introduced into the local stratigraphy over an extended period of time, enabling it to bond with minerals and chemicals found in local soils. Moreover, the presence of very high PO4 concentrations within the A horizon at the highest point on the ELP's primary hillslope suggests

that the movement of soil from this location has been reduced more recently (likely by the development of secondary growth after the laborer's village abandonment) enabling PO4 rich A horizon soils to remain in place rather than erode downhill.

The shallowness of the A horizon, and absence of a B horizon are clear signs of the erosion of soils from this location sometime in the past (Birkeland 1999, Pratt 2015, Garrison 2016). In an undisturbed profile we would expect to see a well developed A horizon, and a B horizon underneath it, formed by the passage of time and the physical and chemical weathering of A horizon materials which would have illuviated down deeper into the soil column, gradually forming a B horizon (Garrison 2016). Absent these key indicators of development in situ, we are forced to acknowledge that these well developed soils may not be here due the A horizon's constant erosion in the past, before these pedogenic processes could take place (Garrison 2016, Holliday 2004, Courty et al 1989). Yet the presence of an organic carbon rich A horizon, and a pH that rises with increases in depth, is consistent with a profile that has more recently begun to retain a larger portion of the organic matter via plant and animal decay and parent material weathering (Garrison 2016). A horizons with high organic carbon content suggests the active deposition of organic materials (from flora and fauna) onto the ground surface. These organic materials also lead to increased pH levels in A horizons as they decompose and their chemical components begin to interact with mineral soil (Birkeland 1999, Bockheim 2014). When pH increases with increased depth down the soil column, this also suggests that the stratigraphy has been stable for at least a time, as the gradual accumulation and mineralization of organic matter and the leaching of these particles into lower strata can only take place if soils are undisturbed (Bockheim 2014).

ST HZ+1

Shovel Test (ST) HZ+1 was excavated approximately 15 m north of, and downslope of ST HZ (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy within ST HZ+1 included an A horizon measuring 32 cmbs, which consisted of 10 YR 3/2 (very dark grayish brown) sand underlain by a thin B horizon (measuring 3.5 cm) which consisted of a 7.5YR 4/4 brown sand. This B horizon was exaggerated on the northern profile wall, where a rotted or removed tree stump extended the B horizon another 8.5 cm into what is elsewhere in the Test Unit covered in a C horizon. This B horizon was underlain by a C horizon which consisted of almost entirely solid limestone, which was a 10 YR 8/2 very pale brown. Excavations were terminated after the exposure of 21 cm of the C horizon revealed no additional changes in color or texture. Abrupt changes in texture and color were observed between the B and C horizons of this profile. Bulk samples were taken from the A and B horizons of ST HZ+1 and were subjected to pH testing, particle size analysis, LOI testing, and phosphate content. The results from these tests, as well as excavation notes, a photograph of the west wall profile of ST HZ+1, and a chart depicting the examined geophysical and geochemical properties of ST HZ+1 can be found in Appendix C-2.

Hydrogen Potential (pH) levels within the A horizon of ST HZ+1 were 8.015 and rose to 8.32 within the B horizon. ST HZ+1 exhibits somewhat lower organic carbon content (10.8%) in its A horizon than other shovel tests in the vicinity (such as ST HZ). The inorganic carbon within ST HZ+1's A horizon was also lower than that of ST HZ (consisting of 19.71% of the soil sample as opposed to 25.16% within the A horizon of ST HZ) suggesting that noncarbon materials made up a large portion of ST HZ+1's A horizon's particle matrix. The B horizon of ST HZ+1 has a lower organic carbon content (9.52%) than the A horizon above it, which coincides with the

expected trend of smaller amounts of organic matter found with increases in depth, as deeper horizons are less directly influenced by organic material inputs at the ground surface (Birkeland 1999).

Phosphate levels (PO4) within the A horizon of ST HZ+1 were extremely high, exceeding the highest concentration even recordable (2.75 mg/L) via Melhich II/Phos Ver 3 based colorimeter testing, and mirroring the phosphate levels found within the A horizon of ST HZ. This trend continued down the profile, with the B horizon also found to contain PO4 levels higher than 2.75 mg/L. These high readings are consistent with what you might find in an area that was used in the past as a human habitation site, where soils would have been exposed to both food waste and human waste, two known and concentrated sources of PO4 (Holliday and Gartner 2007, Birkeland 1999, Wells 2006, Schuldenrein 1996, Eidt 1984). Observance of this PO4 build up within both the A and B horizons suggests that not only has PO4 had an opportunity (i.e. time) to percolate down into the local B horizon, but also that movement of soils from the top of the ELP's primary hillslope has been reduced more recently, enabling PO4 rich A horizon soils to remain in place, further enabling PO4's gradual deposition into the B horizon beneath it.

The trends in pH and organic carbon content with increased depth in ST HZ+1 suggests that the A and B horizons have developed to some extent *in situ*. Increases in pH levels corresponding to increases in depth from the A to B horizon is expected in soils that have had time to develop in place as it is only through a soil column remaining undisturbed over a period of time that organic matter begins to mineralize and gradually accumulate and leach into lower strata (Birkeland 1999, Bockheim 2014). However, it also seems likely that the B horizon's development has started only relatively recently, likely sometime after the abandonment of the African Village, when the area was allowed to return to secondary growth (Cameron and Tomka 1993). With dense vegetation allowed to return to the area, pedogenic processes such as the weathering of parent material, the deposition of acidic and organic humus, the illuviation of clay, and mineral accumulation can begin to form more robust B horizons. The recentness of the development of the B and A horizons in ST HZ+1 is also supported by the low organic carbon content found within the A horizon, as this suggests that the stratigraphy on this portion of the plantation has not yet incorporated a great deal of decaying plant and animal matter (Birkeland 1999). A more distant history of erosion is also evident within ST HZ+1, with the loss of soils both suggested by the clearly hampered development of an extensive B horizon, and the abrupt change in texture and color observed between the B and C horizons within the profile (Birkeland 1999). These characteristics make it seem likely that soils loss, potentially induced by land clearing, village development, and occupation, and encouraged by the area's slope, played a large role in the development of the current profile. Simultaneously, the very high PO4 content found within both the A and B horizon of ST HZ+1 corroborates our historical understanding of local land use, in that these high readings are readily explained by the extended and continuous use of this area as a habitation site, exposing it to the introduction of food waste, and potentially human waste as well (Holliday and Gartner 2007, Eidt 1984).

ST HZ+5

ST HZ+5 was excavated roughly 60 m north of, and downslope of, ST HZ+1 (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy consisted of an A horizon measuring 13 cmbs, which consisted of 10 YR 2/2 very dark brown sand underlain by a thin (13 cm) B horizon which consisted of a 10YR 4/2 dark grayish brown sand. This B horizon was underlain by a 14 cm

thick Bk horizon which consisted of a 7.5YR 3/4 dark brown, loamy sand. Underneath this Bk horizon, a C horizon was discovered, consisting of 7.5 YR pink marl (local parent material). Bulk samples were taken from the A, B, and Bk horizons of ST HZ+5 and were subjected to pH testing, PSA, LOI testing, and phosphate content. The results from these tests, as well as excavation notes, a photograph of the east wall profile of ST HZ+5, and a chart depicting the tested geophysical and geochemical properties of ST HZ+5 can be found in Appendix C-3.

Potential of Hydrogen (pH) in the A horizon of ST HZ+5 was 8.025 and rose to 8.34 in the B horizon. These readings are quite similar to those observed in the A and B horizons of ST HZ+5. The successively increasing pH with increased depth observed in ST HZ+5 points towards development in place amongst the A, B, and Bk horizons (Birkeland 1999, Bockheim 2014).

ST HZ+5 has an organic carbon content of 12.59% in its A horizon, a level comparable to that found in the A horizons of other shovel tests in the vicinity. Similar to the B horizon of ST HZ+1, the B horizon of ST HZ+5 has a lower organic carbon content (9.22%) than the A horizon above it, which coincides with the expected trend of smaller amounts of organic matter further down a soil profile which has had time to develop *in situ* (Appendix E). As organic materials break down in the A horizon, minerals and clay begin to accumulate through illuviation, leaching, and percolation into the soils below, supporting the development of an inorganic-rich B horizon (Birkeland 1999, Garrison 2016). This trend continues into the Bk horizon which has an even lower organic carbon content (8.11%) than the B horizon above it. Interestingly the Bk horizon also contains a substantially lower inorganic carbon content (3.85%) than the B horizon above it (15.9788%) suggesting that the Bk horizon has a large percent of noncarbon based materials within its soil matrix.

Phosphate (PO4) levels within the A horizon of ST HZ+5 mirrored those found within ST HZ and ST HZ+1, exceeding a value of 2.75 mg/L (the highest reachable through the chosen testing method). This trend continued down the profile, with the B and Bk horizons also found to contain PO4 levels above 2.75 mg/L. As is the case for shovel tests excavated further to the south (and further upslope on the ELP's primary hillslope than ST HZ+5) the high PO4 readings within ST HZ+5 are consistent with the understood land use history of human occupation of the area (Holliday and Gartner 2007, Garrison 2016). This occupation would have infused local soils with both phosphate inclusions from food waste and human waste. PO4 build ups within not only the A horizon, but also within both B and Bk horizons beneath it, suggests that PO4 has had more time to percolate down the soil profile into deeper horizons, and that the movement of soils further downslope from this location has been somewhat retarded in more recent times, enabling a PO4 rich A horizon to remain in place (Holliday and Gartner 2007, Wells 2006, Eidt 1984). This more recent stability is likely the result of the abandonment of the village sometime in the early to mid-twentieth century, followed by the return of dense secondary growth in the area (Cameron and Tomka 1993). This more recent soil stability has also likely in turn further enabled PO4 to gradually make its way down the soil column, further contributing to the high PO4 levels seen in the B and Bk horizons within this profile.

ST HZ+5's A, B, and Bk strata possess pH readings that steadily increased with depth, and organic carbon content that steadily decreased with depth. Both of these trends are indicators of soil stability, at least since the development of the Bk horizon (Birkeland 1999, Bockheim 2014, Garrison 2016). The stark contrast in color, however, between the Bk and C horizon observed in

ST HZ+5 suggests that the Bk horizon, and the B stratum above the Bk, may have only started to develop *in situ* more recently, as they show signs of minimal alteration and chemical and particle exchange with one another (Bockheim 2014). This in place development likely began sometime after the abandonment of the African laborer's village, when the area was allowed to return to secondary growth (enabling it to become a more stable landscape) (Cameron and Tomka 1993). A more distant history of erosion is also evident in ST HZ+5, with the loss of local soils strongly suggested by the abrupt change in texture and color observed between the Bk and C horizons within the profile (Birkeland 1999, Pratt 2015, Garrison 2016). Consequently, it seems likely that soil loss, potentially induced by land clearing, village development, and occupation, played a large role in the development of the current profile (Morgan 2009, Boardman and Poesen 2006). This history of intensified land use, particularly in the form of human habitation, would also account for the high PO4 levels recorded in the A, B, and Bk stratum of this shovel test (Holliday and Gartner 2007, Garrison 2016, Wells 2006, Eidt 1984). Despite a history of soil development beleaguered by erosion due to both local slope and anthropogenic land uses, a large amount of phosphate has been introduced into this profile, likely through the introduction of food waste, or human waste, associated with the African laborer's village's former occupation.

ST HZ+7

ST HZ+7 was excavated roughly 30 m north of, and downslope of, ST HZ+5 (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy had an A horizon measuring 18 cmbs, which consisted of 7.5 YR 2/1 black, sand underlain by a thin (12 cm) B horizon which consisted of a 7.5YR 4/4 brown, sand. This B horizon was underlain by a 30 cm thick Bk horizon which consisted of a 7.5YR 5/4 light brown, loamy sand, which contained small limestone inclusions. Underneath this Bk horizon, a C horizon was discovered, consisting of a 10YR 5/4 yellowish brown limestone, a darker tan iteration of the local parent material. Bulk samples were taken from the A, B, and Bk horizons of ST HZ+7. Samples from the A and B horizon were tested for organic and inorganic carbon content and phosphate content. The Bk sample was tested only for pH as insufficient materials were collected to run all the tests. The results from these tests, as well as excavation notes, a photograph of the east wall profile of ST HZ+7, and a chart depicting the examined geophysical and geochemical properties of ST HZ+7 can be found in Appendix C-4.

The pH level within the A horizon of ST HZ+7 was 7.96. In the B horizon the pH rose slightly to 8.11. These readings are similar to those observed within the A and B horizons of ST HZ+5 (Appendix E). The Bk horizon had a pH of 8.36. The successively increasing pH values seen with increased depth observed in ST HZ+7 points towards development in place amongst the A, B, and Bk horizons (Birkeland 1999, Bockheim 2014).

ST HZ+7 exhibits an organic carbon content of 13.89% in the A horizon, a level comparable to that found in the A horizons of other shovel tests in the vicinity. Slightly higher than the B horizon of ST HZ+5, the B horizon of ST+7 has an organic carbon content of 11.99%. This reduction in organic carbon with increases in depth coincides with the expected trend of smaller amounts of organic matter to be found further down stratigraphy (suggesting development in place) (Birkeland 1999). The B horizon was also found to contain a lower inorganic carbon content (11.44%) than the A horizon above it (13.21%) suggesting that the B horizon has a large percentage of noncarbon based materials within its matrix.

Phosphate (PO4) levels within the A horizon of ST HZ+7 were markedly lower than those found within ST HZ, ST HZ+1, and ST HZ+5, with a reading of 0.81 mg/L. This presence of this lower, but still discernable concentration of phosphates has two possible, and likely interwoven explanations. First, with the ST location approximately 105 m north of, and downslope of ST HZ, ST HZ+7 may well lay outside the site boundary of the former African Village. This certainly seems possible, given that ST HZ+7 lies further north than any of the positive shovel tests excavated by the SBA's ELPFS during 2017, 2018, 2019, and 2022 archaeological excavations. As a result, this area may have been exposed to the deposition of some food waste or human waste, associated with the laborer's village, which might have stemmed from occasional use of this space for human activities, but to a considerably lesser extent than the area's covered by ST's excavated further uphill and within the formerly more densely populated and used areas (Holliday and Gartner 2007, Wells 2006, Eidt 1984, Schuldenrein 1996). Second, the presence of phosphates in the area could be attributed to a combination of perhaps some secondary deposits of phosphates (via sediments transported to this location from further uphill during erosion episodes) and due to natural processes of phosphate inclusion, including animal waste, and organic matter inclusions from vegetative growth above the ground surface (Holliday and Gartner 2007, Birkeland 1999, Wells 2006). The PO4 level drops to 0.49 mg/L within ST HZ+7's B horizon, suggesting some transference of P down the soil column. This drop in phosphate concentration also suggests some level of soil development *in situ* between these two strata through the percolation of water and subsequent leeching of phosphorous from the A horizon into lower strata, playing a role in the B horizon's P levels (Holliday and Gartner 2007, Garrison 2016).

The pH readings of ST HZ+7's A and B strata steadily increase with depth, while the carbon content steadily decreases, both indicating stability since the development of the B horizon (Birkeland 1999, Bockheim 2014). The presence of a Bk horizon within ST HZ+7 also suggests that the strata here have developed *in situ* and together, rather than being the result of several depositional episodes. Bk horizons are a subsoil layer where there is a pronounced accumulation of calcium carbonate. These only form when carbonates are redeposited from upper horizons, via illuviation or translocation, which are processes that can only take place within undisturbed soils (Birkeland 1984, Bockheim 2014). The abrupt transition and stark contrast between the Bk and C horizon observed however, suggests a more distant history of volatility, potentially caused by the removal of more weathered parent material and or sediments that might have been deposited in this location, which subsequently moved further downhill (Pratt 2015, Bockheim 2014). Nonetheless, the combined 60 cm of the A, B, and Bk horizons, and the gradual changes observed between these strata within ST HZ+7 allude more to a history of stability, potentially enabled by dense secondary growth now present above the ground surface in this area (Cameron and Tomka 1993). Relatively moderate PO4 levels found within the A horizon of ST HZ+7 and falling PO4 levels observed within the ST's B horizon, also point toward a history of relatively steady soil development *in situ* in this area (Holliday and Gartner 2007, Garrison 2016, Eidt 1984). When compared with the very high levels PO4 levels of ST HZ, ST HZ+1, and ST HZ+5, the PO4 levels within ST HZ+7 also allude to a distinct land use history in this area from that seen within the ST's further uphill (Eidt 1984, Wells 2006). Whereas those higher levels provided a clear sign of intensified human use, the absence of these high PO4 levels here, coupled with the other observed signs of soil stability, suggests that this area was perhaps not occupied as densely, or even at all, but instead, left in timber lands, where natural plant growth, or at least secondary plant growth after initial clearing, was allowed to take place.

ST 3

ST 3 was excavated approximately 75 m north of, and downslope of, ST HZ+7. This location lies firmly within the mid-section of the ELP's primary hillslope, and just south and upslope of a relic ghut found cutting along the contour of the hill (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy within ST 3 consisted of an A horizon measuring 11 cm, which consisted of 10 YR 3/2 (very dark grayish brown), sand underlain by an 18 cm thick B horizon, which consisted of a 10 YR 3/4 dark yellowish brown, loamy sand. This B horizon was underlain by a 5 cm thick transition layer which consisted of a 10 YR 5/4 yellowish brown loamy sand. Beneath this transition a discrete C horizon was found which consisted of a 10 YR 7/3 very pale brown limestone. Excavations were terminated after reaching the now recognizable C horizon consisting of limestone. Discrete bulk samples were taken from various depths in ST 3, with two samples extracted from the A horizon, four samples extracted from the B horizon, one sample extracted from the B to C transition horizon, and three samples extracted from the C horizon. These bulk samples were subjected to PSA, LOI testing, and phosphate content analysis testing. The results from these tests, as well as excavation notes, a photograph of the northeast wall profile of ST 3, and a chart depicting the examined geophysical and geochemical properties of ST 3 can be found in Appendix C-5.

ST 3 exhibits somewhat higher carbon content in its A horizon (19.28% near its top and 16.41% near its bottom) than other shovel tests in the vicinity. The inorganic carbon within ST 3's A horizon was found to be notably higher (25.16% in some tests) than any of the ST's further to the north and uphill of this one, suggesting an overall high carbon content for this area's A horizon. The organic carbon content fell steeply between the A and B horizon in ST 3, ranging from between 6.05 – 6.77% at various depths within the B horizon. We also see within the transition from the B to C horizons an uptick in organic carbon content (to 11.15%). Lastly the C horizon shows a steep drop off in organic carbon content from the layer above it, followed by a steady increase towards the end of excavations. This sequence in organic carbon content down the profile is accompanied by relatively low inorganic content found within the A horizon followed by gradual increases in the B and B to C transition layers, and an at first sudden uptick in the top of the C horizon, before falling off again with depth.

Phosphate (PO4) levels within the A horizon of ST 3 were even lower than those observed within ST HZ+7's A horizon (Appendix E). PO4 levels decreased with depth, reaching 0.46 mg/L in the upper reaches of the A horizon and 0.34 mg/L in its lower portions. This trend in falling PO4 continued into the top of the B horizon (0.23 mg/L), before slightly increasing in the midsection of the horizon (0.31 mg/L), and again falling at the horizon's bottom (0.25 mg/L). Within the B to C transition layer beneath the B horizon, PO4 levels continued to fall with increased depth, 0.15 mg/L. This trend downward with increased depth continued through the readings taken at the top of the local C horizon (with PO4 levels of 0.13 mg/L and 0.12 mg/L recorded within its first 15 cm), but was reversed by a small margin at the lowest examined depth of the C horizon, with a narrow increase of 0.02 mg/L over the bulk sample taken some 5 cm above it.

The A horizon of ST 3 has a high organic carbon content of 19.28%, suggesting potentially recent, and or significant exposure to the deposition of plant and animal matter (Garrison 2016, Holliday 2004, Birkeland 1999). This is quite possibly a result of the more recent (circa mid-twentieth century and onward) dense secondary growth which has taken root in the area

(Cameron and Tomka 1993). A downward trend in organic carbon content within ST 3 was also noted to be sharp at the top of the B horizon and continued down within the middle of the B horizon, before taking a surprising uptick near the bottom of the horizon, and another uptick within the B to C transition layer. This pattern possibly alludes to a volatile developmental history for the B horizon, with the stratum possibly having a different depositional/developmental history than the stratum above it as evinced by an increase in the organic carbon content found at depth (Garrison 2016, Holliday 2004, Birkeland 1999).

The stark and abrupt transitions in color between the A to B and B to C transition horizons found within ST 3 corroborate this hypothesis, suggesting that minimal chemical and particle exchange and chemical and physical weathering between the layers has taken place (Bockheim 2014, Birkeland 1999, Garrison 2016). Interestingly, while the current A horizon is filled with organic carbon inclusions that have accrued at this location more recently and have been captured in place by more recently developing secondary vegetation, rain- and gravity-based erosion have likely beleaguered the earlier development of soil horizons at this location, moving weathered parent materials and organic matter from this place to locations further downhill (Garrison 2016, Pratt 2015). While the large A horizon of ST 3 might be the result of organic matter eroding down to this location from further upslope (i.e. during periods of land clearance and human occupation at the top of the hillslope), the absence of high PO4 levels within ST 3, which is a hallmark of the A and B horizon observed within ST's excavated further uphill (i.e. ST HZ, ST HZ+1, and ST HZ+5), suggests that the upper horizons of ST 3 have had a distinct developmental history from those found at the top of the hill (Birkeland 1999, Garrison 2016, Courty et al. 1989). Furthermore, ST 3's relatively low PO4 levels, combined with other previously mentioned signs of more recent stability within the upper reaches of ST 3's profile, strongly suggest that this area was not deliberately used for agriculture, as it does not appear to be an area where soil nutrients would have been lost through erosion since the development of the B horizon, but is still devoid of relatively high phosphorus levels which if present, might have suggested the area's past exposure to fertilizers (Holliday and Gartner 2007, Wells 2006, Eidt 1984).

ST4

ST 4 was excavated roughly 15 m north of and downslope from ST 3, just south and downslope of the relic ghut that curves around the arc of the ELP's primary hillslope (Figure 84, Figure 86, and Figure 87).The stratigraphy of ST 4 is considerably more complex than any of the shovel tests excavated further uphill on the ELP's primary hillslope. It consisted of an A horizon measuring 7 cm, comprised of a of 10 YR 3/4 dark yellowish brown loamy sand underlain by a thin (9 cm) C horizon which consisted of 10 YR 3/3 brown grains of loamy sand which were lying within large, coarse-grained jagged slate rocks. This C horizon was underlain by 8 cm of alluvium consisting of a 10 YR 5/4 yellowish brown sand. This layer is in turn underlain by another thin alluvial horizon (7 cm) which consisted of a 10 YR/6/2 light brownish gray loamy sand. Beneath this deposit lies what appears to be (based on strong change in color) yet another discrete alluvial deposit measuring 13.5 cm and consisting of a loamy sand (10 YR 2/2) sitting atop larger alluvially deposited, rounded river cobbles. Underneath these river cobbles, lay 6.5 cm of a relic B horizon, marked by an abrupt change to a 10 YR 3/3 dark brown silt loam. This relic B horizon proved to be underlain by a C horizon, consisting of a 10 YR 6/3 pale brown limestone. Bulk samples were taken from the A, C, alluvial layers, relic B, and C horizons of ST 4. These samples were tested for pH, particle size, organic and inorganic carbon content, and

phosphate content. The results from these tests, as well as excavation notes, a photograph of the west wall profile of ST 4, and a chart depicting the examined geophysical and geochemical properties of ST 4 can be found in Appendix C-6.

The pH level within the A horizon of ST 4 was 7.94. In the C horizon the pH level rose slightly to 8.185. These readings are like those observed in the A and B horizons of ST HZ+5 and HZ+7 (Appendix E). The third stratum, an alluvial deposit, exhibits a pH of 8.34, higher than that of the horizon above it, suggesting perhaps some level of development between these two strata, at least on a more recent timescale where rain (a known modifier of pH through its introduction of calcium, magnesium, sodium and or potassium into the soil) has had time to percolate through a more stable stratigraphy (Carroll 1962). The pH of the second alluvial deposit (which lies underneath the first) however, is 7.92, lower than the levels above it, suggesting discontinuity between this stratum and those above it (Birkeland 1999, Bockheim 2014, Garrison 2016). This corroborates the notion that these alluvial deposits have different origins and developmental histories, as the two alluvial layers also exhibit different soil colors (Birkeland 1999, Garrison 2016, Courty et al. 1989). What little mineral soil that could be found within the third alluvial layer, which mostly consisted of river rounded cobbles, had a pH of 7.91, slightly lower than the stratum above it, further suggesting volatility in the stratigraphic column. Beneath this layer, lay a thin relic B horizon, with a slightly higher pH of 7.99, resuming an expected increase in pH with increased depth. Finally, the exposed C horizon in ST 4 was found to have a pH of 8.05, continuing the trend upwards with depth. The continuous increase of pH down the soil column from the deepest alluvial layer down to the C horizon, suggests that these three layers may have had some time to develop *in situ*, with the pH in the relic B horizon likely still influenced by that of the limestone parent material lying underneath it (Birkeland 1999, Garrison 2016, Pratt 2015, Tricarico 2019).

Shovel Test 4's A horizon exhibits an organic carbon content of 10.31%, which is somewhat lower than the A horizons of shovel tests further upslope. This organic carbon content in the A horizon was matched with quite low inorganic carbon content (7.94%) suggesting that a great deal of non-carbonic materials make up the majority of the local A horizon. The small amount of soil found within the C horizon proved to have an organic carbon content of 3.29%, representing a significant drop off from the levels seen in the A horizon. This was matched with a slightly higher inorganic carbon content (8.185%) than that found in the A horizon though, still these figures suggest a very high level of noncarbon materials in the stratum. The first alluvial deposit encountered possessed a considerably greater organic carbon content (6.92%) and a considerably larger inorganic carbon content (19.4%) than the stratum above it.

The hypothesis that this stratum is an alluvial deposit is corroborated by these strong differences, with the layer likely transported by the relic ghut located to the south of, and uphill of, this shovel test (Birkeland 1999, Garrison 2016, Karkanas and Goldberg 2018). The second alluvial layer, which was also separated from the layer above it by a stark contrast in color, exhibited a organic carbon content of 7.13%, and an inorganic carbon content of 6.5%, with ratings higher and lower, respectively, than the stratum above it, in both cases, auguring against trends that might suggest interrelated development *in situ* in a pattern further suggesting a lack of any developmental relationship with the layers above it (Birkeland 1999, Garrison 2016, Karkanas and Goldberg 2018). The relic B horizon exhibited an organic carbon concentration of 7.45% and an inorganic carbon concentration of 16.03%, containing more organic material than the

layer above it, but also considerably more inorganic materials as well. Lastly, the C horizon contained a lower organic carbon concentration, and a higher inorganic carbon concentration than the layer above it (6.47% and 29.45% respectively), suggesting that there may have been some development in place between these two layers (Watts 1990). The gradual transition in color between these two layers further suggests a more prolonged developmental history shared between these two layers (Birkeland 1999, Bockheim 2014).

Phosphate (PO4) levels within the A horizon of ST 4 were markedly lower than those found within ST HZ, ST HZ+1, and ST HZ+5, and matched those found within the lower portions of the A horizon of ST 3 with a reading of 0.25 mg/L. Within the C horizon of ST 4, PO4 levels fell by a significant margin, to 0.04 mg/L. This same PO4 level persisted into the layer of alluvial deposited cobbles underneath the C horizon. Within the alluvial layer (stratum IV) beneath these cobbles, the PO4 level rose to 0.25 mg/L which may well be indicative of the native PO4 levels in the location from which this stratum was derived further upstream. The second alluvial layer, largely comprised of cobbles, contained a lower concentration of PO4 (0.19 mg/L). The relic B horizon buried beneath this lowest alluvial layer had an even lower PO4 concentration (0.04 mg/L), a trend which was interrupted within the C horizon encountered beneath the relic B, where PO4 levels hit 0.07 mg/L.

The recovery of a radiocarbon datable land snail shell from the first few centimeters of the relic B horizon of ST 4 (18 cmbs) enhances our understanding of the relative ages of the ST's horizons alongside the geochemical and geophysical data already collected. Calibrated using OxCal v 4.4.4. which follows Ramsey 2001, and adjustments for atmospheric data from Reimer et al. 2020, this shell was dated to 577 AD ±26 years with a 95.4% probability certainty (see Appendix D Table D-1 for details on radiocarbon dating results for the materials pulled from ST 4). While the potential for a snail to move through the soil column during its life span can complicate the interpretation of radiocarbon dates taken from a shell, the calibrated date of 577 AD still provides us with a potential *terminus ante quem* for the relic B horizon in which it was found (Banning 2020, Holliday 2004, Ramey et al. 2021, Osborne and Wright 2018). If true, this relic B horizon would predate the ELP's period of active use as a sugar plantation (from the 1740s through the mid-twentieth century) and that this horizon was likely well buried by the three alluvial deposits above it prior to the European occupation of the island St. Croix. As a result, we can infer that the geophysical and geochemical signature of this relic B horizon is not a result of its being used for European, nor Afro-Cruzan agriculture. Instead, this horizon is the product of natural pedogenic processes with the C horizon below it, and or potentially prehistoric land uses, possibly including slash and burn agriculture (Hardy 2008). We see no direct evidence for prehistoric agricultural land use however, as no charcoal was encountered within the relic B horizon (which might have suggested slash and burn agricultural), and phosphate concentrations in this stratum proved to be quite low.

Traces of a volatile history are revealed in Shovel Test 4 strata. This volatility appears to be brought on by depositions and erosion caused by flooding and spillover from the ghut immediately uphill and to the south of the ST. Consisting of layers of river worn cobbles, geochemically and geophysically discrete soils, which are separated in most cases by stark and abrupt transitions in color and texture, the three alluvial layers in ST 4 may have been deposited during intense weather events which caused sediments from further upstream to be transported down to this space, or in some cases, during moderate intensity rainstorms following a large

scale land clearing event upslope. The events would have had to be quite significant to a) bring about the movement of river worn cobbles (some measuring more than 6 cm in length, and 4 cm in height and width) and b) cause the water level within the ghut to exceed its northern bank, which at the time of recording, measured well over 1.5 m off the ground surface. Equally interesting is the absence of a B horizon between the A and C horizons found at the top of the soil profile. While a relic B horizon lies beneath the deepest of three alluvial layers, which shows signs of *in situ* development with a C layer beneath it, the A to C transition at the top of the profile suggests that the soil column was forced to "restart" its development, using ghut born sediment as parent material, and that some level of erosion in the area is likely to have continued in the more recent past, resulting in the lack of the development of a B stratum.

The A horizon's thinness and the presence of numerous, large, subangular, granitic rocks (3 – 4 cm diameter) within the C horizon below the A horizon suggest that these strata have developed together *in situ*, and likely for only a relatively short period of time. Furthermore, the low PO4 levels (0.04 mg/L) found within the relic B horizon (which we have dated to roughly 577 AD) give us a good idea of what natural, or at least, pre-European PO4 levels might have looked like on ELP. In turn, they help us interpret the relatively low PO4 levels we find much closer to the ground surface within ST 4, where the modern C horizon (which also possess the low PO4 concentration of 0.04 mg/L) is overlain by a relatively thin A horizon, which possess a higher, but still moderate (when compared with ST's further up hill) concentration of PO4 (0.25 mg/L). This modern A horizon then, has either gained its PO4 concentration through the accretion of plant and animal detritus since the deposition of the modern C layer, or has received influxes of sediments richer in PO4 via forces of erosion from further uphill. If the latter were the case however, and sediments were being deposited in this area from further uphill than the relic ghut, then we might expect to see considerably higher PO4 levels, as soils at the top of the hillslope have concentrations exceeding 2.75 mg/L of PO4. Therefore, it is likely that the modern A horizon is the result of *in situ* development, borne of the weathering of the alluvial cobbles beneath it, and the deposition of plant and animal matter at the ground surface, perhaps sometime after the abandonment of the African Village, and or the drying of the relic ghut just upslope of this ST.

ST 8

Shovel Test 8 was excavated roughly 60 m north of, and downslope of, ST 4 close to the toe slope of the hill (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy consisted of a thin A horizon measuring 6 cm, which consisted of 10 YR 3/2 very dark greyish brown sand underlain by a thin (14 cm) B horizon which consisted of a 10 YR 4/3 brown, which at its top was a loamy sand, but at its bottom, was a sand. This B horizon was underlain by an 11 cm thick Bk horizon which consisted of a 7.5YR 5/4 light brown loamy sand which contained white, presumably carbon, striations. Underneath this Bk horizon, a lengthy B to C transition layer (3 cm) was recorded, which was characterized by a somewhat mottled 10 YR 8/3 very pale brown and a 10 YR 4/4 yellowish brown, which was a loamy sand at its top, but a sand in its middle and at its bottom. Beneath this stratum excavators encountered a C horizon consisting of a 10 YR 8/4 very pale brown iteration of the local marl/parent material. Bulk samples were taken from various depths of the A, B, and Bk horizons of ST 8, and were tested for pH, particle size, organic and inorganic carbon content, and phosphate content. The results from these tests, as well as excavation notes, a photograph of the west wall profile of ST 8, and a chart depicting the examined geophysical and geochemical properties of ST 8 can be found in Appendix C-7.

The pH level in the A horizon of ST 8 was 8.08. In the B horizon the pH rose gradually with depth throughout the layer (8.27 in the upper portion, and 8.35 in the lower portion). The Bk horizon had a slightly higher pH (of 8.42), while the Bk to C transition layer exhibited a still higher pH in its upper levels (8.46), before showing a slightly varied pH in its middle (8.39) and lower portions (8.42). The successively increasing pH values seen with increased depth observed in ST 8 (barring the slight uptick within the middle portion of the Bk to C horizon layer), points towards development in place amongst the A, B, Bk, and C horizons as the area is known to have more basic, limestone parent materials (Watts 1990, Tricarico 2019, Pratt 2015).

The A horizon within ST 8 exhibited an organic carbon content of 11.51%, a level quite similar to those found within the A horizons elsewhere on the ELP's primary hillslope. This organic carbon level was matched with a comparable inorganic content of 11.9%. The B horizon of ST 8 consisted of progressively lower organic carbon contents (7.71% in the upper portion and 7.17% in the lower portion), and an inorganic carbon content which increased with depth (12.27% in the upper portion and 13.95% in the lower portion). These measurements, especially in conjunction with the carbon contents identified within the A horizon, suggest *in situ* development between these two strata (Watts 1990, Birkeland 1999, Garrison 2016, Karkanas and Goldberg 2018). The upper reaches of the Bk horizon broke with the trend in decreasing organic carbon content, containing 7.9%, though still containing an increase in inorganic carbon content, with a level rising to 14.86%. Deeper within the Bk horizon, organic carbon content falls (6.61%) and inorganic carbon rises sharply (20.07%). The increased presence of inorganic carbon in this layer came as no surprise however, due to the white flecking and gradual changes in color observed within the Bk horizon (signs of the presence of heighted levels of calcium carbonate). Trends in decreased organic carbon with depth, along with increased inorganic carbon along with increased depth, continued throughout the Bk to C transition layer.

Phosphorous (PO4) levels within the A horizon of ST 8 proved to be only slightly higher than those found within ST 4, with a concentration of 0.37 mg/L. Within ST 8's B horizon, PO4 levels at first abruptly fell (to 0.27 mg/L right beneath the stratum break), and then gradually fell (6 cm deeper reaching 0.21 mg/L) with increases in depth. Within the Bk layer, there was a small spike in PO4 levels (to 0.23 mg/L), but PO4 levels again gradually dropped with increased depth, hitting a level of 0.19 mg/L near the bottom of the stratum. Within the C horizon, PO4 levels continued to drop, again abruptly at the stratum break (to 0.09 mg/L) and then gradually with increases in depth, with a concentration of 0.08 mg/L at the lowest depth recorded.

A radiocarbon datable land snail shell was recovered from a depth of 18 cm below the ground surface, near the top of the B horizon observed within ST 8. Calibrated using OxCal v 4.4.4., this shell dates to, 5,519 BC ±41 years, ±42 years with a 90% probability certainty (See Appendix D Table D-2 for details on radiocarbon dating results for the materials pulled from ST 8). As a snail is able to move up and or down a soil column during its lifespan, it is important to qualify the interpretative value of the shell from ST 8 provides (Banning 2020, Holliday 2004, Taylor 2014, Ramey et al. 2021, Osborne and Wright 2018). Even still, the presence of a snail shell dating to this range of years, speaks towards the extremely long-time depth of the soil formation which has taken place in the area. Even with its diminished interpretive value the shell likely provides us with an approximate *terminus ante quem* for the ST's B horizon, which predates the Danish colonial period by roughly 7,000 years. The age of this datable material found within the B horizon of an ST at the toe of the ELP's hillslope implies the presence of an A horizon in this

area with a very long time depth, suggesting in turn, due to this A horizon's thinness (just 6 cm) that very little soil deposition or very slow soil development has taken place in this area. Being at the toe of the ELP's primary hillslope, if there had been significant erosion to this location from further uphill the resulting sediments would have been deposited here. If this were the case however, we would expect to see a thicker A horizon, and one less geophysically and geochemically related to the B horizon beneath it. Instead, we see evidence of strata which have developed *in situ*, forcing us to consider a painfully slow local soil development rate of as low as .0024 cm per year over a 7,362 year period.

Shovel Test 8's A, B, Bk, and Bk to C transition strata possess pH readings that steadily increase with depth, and organic carbon content that steadily decreases with, along with inorganic carbon content that steadily increases with depth. These are indicators of stability and stratigraphic development *in situ* in an environment with more basic parent material like the ELP (Tricarico 2019, Pratt 2015. Watts 1990). The very presence of a Bk horizon, as well as a larger transition layer between the Bk and the C horizons, also suggests that these strata have developed *in situ* together (Birkeland 1999, Garrison 2016, Holliday 2004). While the sudden uptick in organic carbon content within the top of ST 8's Bk horizon does present an anomaly, the otherwise consistent trends in carbon content within the horizons of ST 8 (with organic carbon decreasing with depth, and inorganic carbon increasing with depth) point towards a history of stability, with soils developing *in situ* over a more extended period of time (Garrison 2016).

The geophysical and geochemical signatures of ST 8 included incrementally decreasing organic carbon, pH, and PO4 levels observed with increasing depth, along with gradual physical transitions (in terms of texture and color) between observed soil horizons. These attributes point toward a long history of local soil development *in situ* in this area brought on by natural pedogenic processes (Garrison 2016, Holliday 2004, Birkeland 1999, Bockheim 2014). Coupled with similar evidence found within shovel tests close to ST 8, including ST 9 (excavated roughly 15 m to the north and slightly downslope of ST 8) and ST 11 (excavated roughly 45 m to the north and slightly downslope of ST 8), which also suggested histories of stable soil development *in situ*, it is likely that the very old radiocarbon datable material found just beneath ST 8's A horizon points towards a slow overall rate of soil development in the toe area of the ELP's primary hillslope (Appendix E). Lying at the toe of the slope of the ELP's hillslope, we might expect to see more evidence that local soils developed from deposited sediments which might have come from further uphill.

We may not be seeing evidence of those past depositional events because the ghut just south of ST 4 and uphill of ST 8 captured the majority of sediments that would have otherwise eroded further down the slope. Dense vegetation may have also been allowed to thrive at this portion of the slope, and for tens of meters above it, helping to prevent soils from eroding downhill onto, and or, from, this location further downhill. In the absence of evidence suggesting the deposition of sediments from further uphill, and with no evidence observed of soils being removed from this location and transported further downslope (with only a gradual descent to beach sand to the northern coast of the island, and large gradual transition layers between each of the observed strata in ST 8), it seems likely that this area has been left unfettered by anthropogenic modifications such as tilling, fertilizing, or occupation during the colonial period (Garrison 2016). Instead, the soils here have been allowed to gradually and naturally develop in tandem with the flora and fauna that have occupied its ground surface. This narrative would prove

consistent with the land use history understood through the local historical record, which has suggested that this area was kept in Timber (either as primary growth or secondary growth after initial cleaning, tropical forest) throughout the colonial and US periods of the island's history.

ST9

Shovel Test 9 was excavated roughly 15 m north of, and slightly downslope of, ST 8 within the toe slope of the hill (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy consisted of an A horizon measuring 10.5 cm, which consisted of 10 YR 3/2 very dark greyish brown sand (which transitioned to a loamy sand near its bottom) underlain by a B horizon measuring 21 cm deep which in its upper reaches consisted of 10 YR 3/3 dark brown sand, and near its bottom changed to a sandy loam. Beneath this layer, a Bk horizon measuring 12 cm was exposed, consisting of a 10 YR 8/3 very pale brown. Below the Bk layer, an easily recognizable C horizon was encountered, noted by the layer's solid color of 10 YR 3/3 very pale brown consisting of marl, which came off the wall in sand sized grains. Bulk samples were taken from various depths in the A, B, Bk, C horizons of ST 9, and were tested for pH, particle size, organic and inorganic carbon content, and phosphate content. These samples were tested for pH, particle size, organic and inorganic carbon content, and phosphate content. The results from these tests, as well as excavation notes, a photograph of the west wall profile of ST 9, and a chart depicting the examined geophysical and geochemical properties of ST 9 can be found in Appendix C-8.

The pH level within the upper reaches of the A horizon of ST 9 was 8.02. However, the pH fell slightly to 7.98 within the lower reaches of the A horizon. In the top of the B horizon the pH rose slightly to 8.05, and then continued to steadily rise throughout the B horizon reaching 8.17 in the midsection of the horizon, and 8.30 by the bottom. Within the Bk horizon pH rose gradually with depth throughout the layer (8.37 in the upper portion, and 8.47 in the lower portion). Finally, within the C horizon, the upper portion was found to possess a pH of 8.51, with a slight increase to 8.6 noticed with increased depth. The successively increasing pH values seen with increased depth observed in ST 9, (barring the slight uptick found within the upper portion of the B horizon) points towards interrelated development in place amongst the A, B, Bk, and C horizons within this shovel test.

The upper portion of the A horizon within ST 9 exhibited an organic carbon content of 10.25%, while the lower portions of the A horizon revealed a lower level of organic carbon of 9.86%. Both of these levels are quite similar to those found within the A horizons elsewhere on the ELP's primary hillslope. These organic carbon levels in the upper and lower reaches of the A horizon were matched with higher inorganic contents of 16.07% and 16.29% respectively. The upper and middle portions of the B horizon of ST 9 consisted of progressively lower organic carbon contents (7.60% in the upper portion and 6.12% in the middle portion), before demonstrating a slight uptick to 6.59% within its lower reaches. Inorganic carbon readings followed suit, with increases in the upper and middle reaches of the horizon (to 16.85% and 18.37% respectively), before falling slightly in the lower reaches to 18.13%. Within the Bk horizon organic carbon levels steadily fell (6.45% in the upper region and 5.76 in the lower), while inorganic carbon content levels steadily increased from those found in the B horizon with readings of 19.51% in the upper reaches of the horizon, and 26.32% in the lower reaches. Within the C horizon, these same trends continued throughout the layer, with organic carbon content falling from 4.21% in the upper portion of the horizon tested to 3.68% in the lowest reaches sampled, and inorganic carbon rising from 8.51% to 8.6% at the lowest reaches sampled.

Phosphate (PO4) levels in the A horizon of ST 9 were quite similar to those found within the A horizon of ST 8 with upper portions of the stratum possessing a concentration of 0.43 mg/L and lower portions of the stratum possessing a concentration of 0.45 mg/L. PO4 levels within ST 9's B horizon were decidedly lower than those within the A horizon, with a concentration of 0.26 mg/L near the stratum's bottom, and with the PO4 concentration hovering within 0.03 mg/L of this level throughout the horizon. Within the upper portions of the Bk horizon, PO4 levels spiked (to 0.34 mg/L) before falling sharply to 0.12 mg/L near the bottom of the layer. Within ST 9's C horizon PO4 levels hovered at, or within 0.03 mg/L of, this same 0.09 mg/L PO4 level throughout.

A radiocarbon datable land snail shell was recovered from the bottom of the B horizon observed within the ST (35 cm below surface). Cognizant of a snail's ability to move up and down a soil column while alive we must be mindful of the shell's interpretive value (Banning 2020, Holliday 2004, Taylor 2014, Ramey et al. 2021, Osborne and Wright 2018). Laboratory provided results suggested that shell dates to 5,758 BC ± 57 years (See Appendix D Table D-3 for details on radiocarbon dating results for the materials pulled from ST 9). Similar to the snail shell found within the B horizon of ST 8, the shell found with ST 9 suggests a very long-time depth of the soil formation which has taken place in the area which was characterized by stability (i.e. soil retention). Likely providing us with an approximate *terminus ante quem* for ST 9's B horizon, together with the radiocarbon datable sample taken from the B horizon of ST 8 (and ST 11, as will be discussed during that shovel test's analysis), the soils at the toe of the ELP's hillslope, have been developing *in situ* for an extend period of time. It is plausible that higher rates of soil deposition at the base of this sloping hill are to be expected if intensive clear cutting and or repeated sugarcane planting had taken place further up this hillslope. Given that the surface of ST 9 lies between 2.59 m and 4.18 m above sea level, and just 150 m from the sea, with dense secondary growth stands between the ST and the ocean (Figure 84, Figure 86, and Figure 87), if there had been erosion from this location, we would have expected to observe mineral rich alluvium lying atop beach sand stratigraphy found just 80 m downslope of and to ST 9's north. In the absence of any of these indicators of volatility, the processes which have created the profile seen at ST 9 appear to have been very slow.

The characteristics of the stratigraphy found within ST 9 strongly suggest a stable developmental history, with gradual changes in color, pH, organic carbon, and inorganic carbon observed down the entire profile (Garrison 2016, Holliday 2004, Watts 1990, Tricarico 2019, Pratt 2015). While there is a slight break from a universal trend of decreases in organic carbon and increases inorganic carbon levels with increased depth seen at the bottom of the B horizon, this small anomaly is not mimicked in the pH readings taken from this portion of the profile, nor is it reinforced for an interpretation of volatility through any kind of abrupt, sudden, or stark change in soil color or texture within either the remainder of the B horizon above it, nor the Bk horizon beneath it (Garrison 2016, Birkeland 1999, Bockheim 2014). Indeed, the transitions between each of the strata present within ST 9 are gradual, taking place over several centimeters.

Shovel Test 9's A, B, Bk, and Bk to C transition strata possess pH readings that steadily increase with depth, and organic carbon contents that steadily decrease with depth, along with inorganic carbon content that steadily increases with depth. These three trends, especially in conjunction with one another, serve as indicators of stability and stratigraphic development *in situ* (Holliday 2004, Watts 1990, Tricarico 2019, Pratt 2015). The very presence of a Bk horizon, as well as a

larger transition layer between the Bk and the C, also suggests the stratigraphy has developed *in situ* together in this area (Garrison 2016). While the sudden uptick in organic carbon content within the top of ST 9's Bk horizon does present an anomaly, the otherwise consistent trends in carbon content within the horizons of ST 9 (with organic carbon decreasing with depth, and inorganic carbon increasing with depth) point toward a history of stability, with soils developing *in situ* over a more extended period in this area. Similarly, while there were small interruptions in the downward trend of PO4 levels found with increased depth throughout ST 9's profile, overall PO4 levels did decrease between each successively deeper stratum, and PO4 levels hovered around similar values within different depths within each individual stratum. Much like ST 8 the data collected from ST 9 point towards a long and slow history of uninhibited natural development *in situ*, consistent with our understanding of this area being allowed to stay in Timber (either kept in primary growth or secondary growth after initial colonial events) (Holliday and Gartner 2007, Wells 2006, Eidt 1984, Appendix E). This conclusion is corroborated by the absence of more evidence for soil depositions in the area, given that it lies at the toe of the ELP's primary hillslope. It seems likely that traces of past sediment depositions are absent both because the ghut just south of ST 4 and uphill of ST 9, captured the majority of sediments that would have otherwise eroded further downslope, and also that the dense vegetation in this area, and in the area just upslope of it, helped prevent soils from eroding downhill onto, and further downhill from, this location (Figure 86 and Figure 87).

ST 11

ST 11 was excavated roughly 30 m north of, and slightly downslope of, ST 9 well within the toe of the slope of the ELP's largest hill, approaching the northeastern coastline of the island (Figure 84, Figure 86, and Figure 87). The stratigraphy encountered within ST 11 consisted of an A horizon measuring 13.5 cm deep consisting of a 10 YR 3/3 dark brown sand, underlain by a thin B horizon, measuring 9.5 cm deep and consisting of a 10 YR 4/4 dark yellowish-brown sand. This B horizon was underlain by 15 cm of a C1 horizon, consisting of a 10 YR 7/4 very pale brown iteration of the local marl/parent material with a notable amount of caliche inclusions, and a soil matrix which was considerably lighter than that of the level above it. Finally, this C1 horizon was underlain by a C2 horizon, very similar to the layer above it in texture, but ever so slightly lighter in color. Very similar to the profile revealed in ST 9 (merely replacing a Bk horizon with a C1 horizon), in terms of color, texture, depths, and (gradual) transitions, bulk samples were taken from the A, B, C1, and C2 horizons of this shovel test, but were only tested for pH to confirm a similar depositional and developmental history between ST 11 and ST 9. The results from the test conducted on soils from ST 11, as well as excavation notes, a photograph of the south wall profile of ST 11, and a chart depicting the examined geophysical and geochemical properties of ST 11 can be found in Appendix C-9.

The pH in the A horizon of ST 11 was 8.41, a reading consistent with, though slightly higher than, that recorded in the A horizon further south on the plantation. In the B horizon the pH rose slightly to 8.50. Within the C1 horizon, the pH fell slightly (to 8.41), in a fashion similar to the slight decrease seen at the bottom of the B horizon within ST 9 (Appendix E). Within the C2 horizon however, the pH level continued to fall (to 8.33), suggesting that perhaps some other unrecorded characteristic of the soils in the area may be the dominant factor in the determination of local pH levels.

A radiocarbon datable land snail shell was recovered from the B horizon of ST 11 (collected from the bulk sample covering the depths of 13.5 cmbs – 23 cmbs). The dates from this shell were 10,624 BC, ±42 years with a 95.4% probability certainty (See Appendix D Table D-4 for details on radiocarbon dating results for the materials pulled from ST 11). Again, while the radiocarbon dates taken from a snail shell must be qualified, the approximate date given to us by this shell for the local B horizon still speaks to the extremely long time depth of soil formation in the area (Banning 2020, Holliday 2004, Taylor 2014, Ramey et al. 2021, Osborne and Wright 2018). Coupled with the evidence suggesting a stable soil developmental history for these soils *in situ*, suggested by the geochemical and geophysical signatures of ST 9 and ST 11, as well as the radiocarbon dates retrieved from snail shells in ST 9 and ST 8 it is possible that this very old radiocarbon datable material lying so close to the surface points toward a slow overall rate of stratigraphic development in the area (Appendix E). This is potentially a result of rain-based erosion carrying away soils as they begin to develop, or perhaps simply reflecting a very slow rate of soil development in the area due to heat and slow pace of biological processes that might break larger pieces of organic or inorganic carbon, and or parent material, into smaller particle sizes. These two interpretations may not be mutually exclusive, as slight and gradual erosion from this location caused by intense or frequent rainstorms, could perhaps even be part of the natural processes that retarded the rate of soil development in the area.

Results from Shovel Tests within Transect 2

Transect 2 consisted of five shovel tests, intended to examine an area of the ELP known to have been kept in sugarcane for nearly 200 years. These shovel tests were placed in a line to the south of the ELP's sugar factory, extending from the plantation's southwestern boundary toward the northeast (Figure 84, Figure 86, and Figure 87). From southwest to northeast, these shovel tests consisted of ST Uphill Pond 2, ST Uphill Pond 1, ST Downhill Pond 1, ST Downhill Pond 2, and ST Swamp 1. The soils encountered within all five shovel tests within Transect 2 were tested for pH, soil texture (through PSA), organic and inorganic carbon content (through LOI testing), and Phosphorous. The decision to run the full suite of tests on the samples taken from each of the shovel tests within Transect 2 was made as it was a specified goal of the project to examine the present-day soil conditions within areas that were kept in sugarcane throughout the eighteenth, nineteenth, and early twentieth centuries. In addition, radiocarbon datable materials were retrieved from various depths within ST Uphill Pond 2, and ST Uphill Pond 1further enhancing the results of the lab tests run on the soils encountered with Transect 2 with absolute chronological data.

ST Uphill Pond 2

ST Uphill Pond 2 was excavated at the western most portion of the project's second transect, which runs from the west near the western boundary of ELP, to the northeast, close to the ELP's boundary with the coast and Caribbean Sea. ST Uphill Pond 2 is roughly 25 m north of the ELP's primary ghut (Figure 84, Figure 86, and Figure 87). ST Uphill Pond 2 consisted of an A Horizon measuring 19 cm deep, which consisted of 10 YR 5/1 gray sandy clay loam, underlain by 20 cm of B horizon which consisted of 10 YR 4/1 dark gray consisting of either a sandy clay loam or a loamy sand. Underneath this B horizon lay 13 cm of a Bk horizon consisting of a 10 YR 5/4 yellowish brown sandy loam, which turned to a sand at depth, followed by a C horizon that consisted of an iteration of the local limestone colored 10 YR 6/2 light brownish gray, and which broke off the profile wall with the consistency of a sandy clay loam. Observed transitions between strata were gradual in color change, taking place over several centimeters. Bulk samples

were taken from the A, B, Bk, and C horizons of ST Uphill Pond 2 and were subjected to pH testing, PSA, LOI testing, and phosphate content testing. The results from these tests, as well as excavation notes, a photograph of the north wall profile of ST Uphill Pond 2, and a chart depicting the examined geophysical and geochemical properties of ST Uphill Pond 2 can be found in Appendix C-10.

The pH level in the A horizon of ST Uphill Pond 2 was 8.01 and steadily fell with increased depth through the B, and Bk horizons, reaching 7.88 by the bottom of the B horizon, and 7.805 by the bottom of the Bk horizon. The recorded 7.865 pH level found within the C horizon of ST Uphill Pond 2 represents a slight increase from the bottom of the Bk horizon, but not to an extent that significantly bucks the trend of gradually reducing pH levels with increases in depth seen throughout the rest of the ST.

The organic carbon content of the A horizon within ST Uphill Pond 2 (13.53%) is relatively high compared to the A horizons found elsewhere on ELP (especially when compared with the organic carbon content found in the A horizons of ST 8 and ST 9) (Appendix E). The organic carbon content found within the top of this shovel test's B horizon was found to be notably less (9.98%) with organic carbon content levels continuing to fall in the middle of the B horizon, before an uptick at the bottom of the B horizon (to 10.25%). These drops in organic carbon content coincided with what is, at first, a drop off (down to 8.64% from 10.24% in the A horizon) in inorganic carbon content at the top of the B horizon, followed by an uptick to 8.31% within the middle section of the horizon, before a dramatic fall to 6.35% at the bottom of the horizon. Within the Bk horizon, organic carbon content levels continued to fall, reaching 8.27% by the bottom of the horizon, while inorganic carbon content levels dramatically fell within the top of the Bk horizon to 3.24% and continued to fall with increases in depth. Finally, the organic carbon content and inorganic carbon content of the C horizon both rose from levels seen in the Bk horizon, with values of 11.61% and 12.74%, respectively.

The PO4 concentration within the A horizon of ST Uphill Pond 2 was 0.62 mg/L. This level was noted to be higher than those observed within the northern portion of the northern shovel test transect (ST 8 to ST 11), but considerably lower than those seen at the top of the ELP's primary hillslope (ST HZ through ST HZ+5). Within the B horizon beneath the A, PO4 concentrations at first fell sharply to 0.27 mg/L, and then hovered within 0.3 mg/L of that level throughout the stratum's depth. Within the ST Uphill Pond 2's Bk horizon PO4 levels followed the same pattern, with an at first steep drop off to 0.13 mg/L followed by levels hovering within 0.01 mg/L of that within the stratum's deepest reaches. Within the single bulk sample collected from ST Uphill Pond 2's C horizon the PO4 concentration rose to 0.18 mg/L, which may have accounted for the slight uptick in PO4 seen in the lowest reaches of the ST's Bk layer.

Two radiocarbon datable land snail shells were recovered from the B horizon of ST Uphill Pond 2, collected from different depths within the middle of the stratum. One sample was collected at 20 cm below the ground surface, and the other at a depth of 28 cm. The shell from 20 cmbs dates to 1285 AD (±24 years) with a probability certainty of 95.4%. The shell from 28 cmbs dates to 74 AD (±48.5 years) with a probability certainty of 95.4%. (See Appendix D Table D-5 and Table D-6 for details on radiocarbon dating results for the materials pulled from ST Uphill Pond 2). Acknowledging the qualifications required when using snail shells for radiocarbon dates, the two shells from the top of the B horizon still provide information about the history of soil

development in the area (Banning 2020, Holliday 2004, Taylor 2014, Ramey et al. 2021, Osborne and Wright 2018). Coupled with the evidence of relatively deep soil horizons, and gradual geochemical and geophysical transitions between each observed strata, both of which point toward long term soil development *in situ* these radiocarbon dates help paint the picture of a landform that has been relatively stable since long before the sugar planting era (Garrison 2016, Holliday 2004, Birkeland 1999, Bockheim 2014).

The presence of gradual textural and color transitions between the A, B, Bk, and C horizons within ST Uphill Pond 2 also strongly suggests the *in situ* development of local stratigraphy (Garrison 2016, Karkanas and Goldberg 2018). It is still possible however that sporadic episodes of topsoil erosion may have played a role in the development of these soils. This history is reflected in the organic carbon and PO4 content levels seen throughout ST Uphill Pond 2's strata as well, where decreases were not uniform, but generally matched a trend of decreases in organic carbon content and PO4 concentrations with increases depth. With only evidence of little, or occasional and small amounts of erosion in this location, the slow rate of soil development suggested by the two radiocarbon dates within ST Uphill Pond 2 may simply be a reflection of the slow pace of soil formation processes in the area such as chemical and physical weathering which would be responsible for breaking down larger pieces of organic or inorganic carbon, and or parent material, into smaller particle sizes and form the soil's matrix (Holliday 2004).

ST Uphill Pond 1

ST Uphill Pond 1 was excavated roughly 30 m northeast of, and slightly downslope of, ST Uphill Pond 2 (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy consisted of an A horizon measuring 12 cm, which was a 10 YR 2/2 very dark brown sandy clay loam underlain by a B horizon measuring 22 cm deep which consisted of a 10 YR 3/2 very dark grayish brown sandy clay loam. Beneath this layer, a Bk horizon measuring 21 cm was exposed, consisting of a 10 YR 4/3 brown sandy clay loam, which in its lowest reaches turned to loamy sand. Below the Bk layer, an easily recognizable C horizon was encountered, consisting of marl of a 10 YR 6/4 light yellowish brown color, with grains that came off the profile wall as a sandy clay loam. Bulk samples were taken from various depths in the A, B, Bk, C horizons of ST Uphill Pond 1, and were tested for pH, particle size, organic and inorganic carbon content, and phosphate content. The results from these tests, as well as excavation notes, a photograph of the northeast wall profile of ST Uphill Pond 1, and a chart depicting the examined geophysical and geochemical properties of ST Uphill Pond 2 can be found in Appendix C-11.

The pH level within the A horizon of ST Uphill Pond 1 was 8.12. At the top of the B horizon the pH fell slightly to 8.09, rising in its midsection to 8.13, before falling again to 8.055 at its bottom. Within the Bk horizon pH steadily fell with increased depth throughout the layer (7.93 in its upper portion, and 7.86 in its lower portion). Finally, the C horizon was found to possess a pH of 7.89. The nearly continuously falling pH values seen with increases in depth almost throughout Uphill Pond 1 (barring only a slight uptick found within the midsection of the B horizon) points towards *in situ* and interrelated development amongst the A, B, Bk, and C horizons within this shovel test, however, these findings suggest that some other factor, perhaps the chemical make up of the area's precipitation, plays the dominate role in determining local pH levels, as the local parent material is an alkaline limestone (Garrison 2016, Bockheim 2014, Carrol 1962).

The A horizon within ST Uphill Pond 1 exhibited an organic carbon content of 13.25%, a level similar to that found within the A horizon of ST Uphill Pond 2. This organic carbon content coincided with a fairly low inorganic carbon content reading of 6.77%. Though the upper portions of the B horizon showed a stark drop off in organic matter content (9.05% compared with the 13.25% found in the A horizon) organic carbon content steadily increased throughout the rest of the B horizon, hitting a level of 9.52% by its bottom. These organic carbon readings coincided with a fall in inorganic carbon readings, starting at 8.24% at its top, before reaching 6.55% at its bottom. Within the top of the Bk horizon the organic carbon content increased to 10.66%, before falling to 10.54% in the lower reaches of the horizon. These readings coincided with steady decreases in inorganic carbon readings, falling to 5.56% in its upper reaches, and 4.84% at its bottom. Within the C horizon both the organic carbon content and inorganic carbon content levels increased dramatically from those found in the B horizon, with 12.09% organic carbon content and 13.78% inorganic carbon content observed.

Phosphate (PO4) levels within the A horizon of ST Uphill Pond 1 proved to be markedly lower than those found within the A horizon of ST Uphill Pond 2, measuring only 0.09 mg/L (Appendix E). The PO4 concentration rose sharply within the upper layers of the B horizon though, to a level of 0.43 mg/L, and then hovered within 0.06 mg/L of this concentration throughout the remainder of the layer's depth. Within the upper reaches of ST Uphill Pond 1's Bk horizon, the PO4 again fell dramatically (to 0.27 mg/L), and then gradually fell to 0.2 mg/L within the stratum's lower depths. Within ST Uphill Pond 1's C horizon, PO4 concentrations were 0.23 mg/L, still quite close to the concentration found at the bottom of the Bk horizon above it.

The characteristics of the stratigraphy found within ST Uphill Pond 1 suggest a history of soil development *in situ*. Consisting of relatively deep stratum (save for the moderate sized A horizon) with gradual transitions (in texture and color) between each stratum, and strata containing steadily decreasing pH levels, inorganic carbon content levels, and for the most part decreasing PO4 concentrations with increases in depth, many of the geophysical and geochemical signatures of this shovel test strongly suggest a stable and gradual developmental history (Garrison 2016, Holliday 2004, Bockheim 2014, Holliday and Gartner 2007). There are however, some anomalies which are difficult to account for, with pH levels steadily falling, rather than rising (as would be expected in an area with alkaline limestone parent material), nearly steady increases in organic carbon content between the midsection of the B horizon and the C horizon, and marked increases in organic carbon and inorganic carbon content observed within the C horizon (when compared with the lower portions of the Bk horizon above it) (Garrison 2016, Birkeland 1999, Bockheim 2014). Seemingly the parent material in this area is of a higher organic carbon content and inorganic carbon content than those found elsewhere in the southeastern portion of the ELP. This factor would then also account for the increased organic carbon content found with increased depth throughout the B and Bk horizons, and in its own way, point toward steady soil development *in situ*, with the B and Bk horizons clearly including significant amounts of weathered parent material that has made its way up into these horizons.

Two radiocarbon datable pieces of charcoal were recovered from ST Uphill Pond 1, one piece was collected from the top of the B horizon (at 15 cm below the ground surface) and the other was collected from the middle of the Bk horizon (at 47 cm below the ground surface). The

charcoal collected from the 15 cmbs dates to 1870 AD (±68 years) with a probability certainty of 71.90%. The charcoal collected from 47 cmbs dates to 256 BC (±48 years) with a probability certainty of 95.4% (See Appendix D Table D-7 and Table D-C8 for details on radiocarbon dating results for the materials pulled from ST Uphill Pond 1). Likely dating from the known period of sugar planting on ELP, the radiocarbon datable charcoal from the top of the B horizon offers interesting information about the history of soil development during the plantation era. Found within a B horizon with a relatively high PO4 concentration (when compared with those found in the B horizons of STs within the northern reaches of Transect 1) the radiocarbon date taken from the piece of charcoal from the 15 cmbs suggests that past land uses in this area have resulted in relatively well-maintained phosphate levels. Far from any known habitation area, these higher phosphate levels could be the result of the deliberate adding of soil amendment or manure to facilitate sugar cultivation when this B horizon was the active ground surface during the ELP's active period of planting (Holliday and Gartner 2007, Wells 2006, Eidt 1984).

The considerably older piece of charcoal was found 32 cm beneath the first. Coupled with the evidence of relatively deep soil horizons, as well as gradual transitions between each observed stratum, the age of this charcoal at this depth strongly suggests a very slowly developing and relatively stable landform in the area (Banning 2020, Garrison 2016, Birkeland 1999, Bockheim 2014). While it is possible that some occasional top soil erosion beleaguered the pedogenic processes in the area, by removing loose soils at the top of the soil column, the presence of gradual transitions between the A, B, Bk, and C horizons within ST Uphill Pond 1 suggest that *in situ* development and stability, rather than the constant erosion or deposition of new materials in this area, dictated the formation of the local stratigraphy.

ST Downhill Pond 1

ST Downhill Pond 1 was excavated roughly 120 m northeast of, and slight downslope of, ST Uphill Pond 1 (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy consisted of a relatively thin A horizon measuring 11 cm, which consisted of a 10 YR 5/2 greyish brown sandy clay loam underlain by a very thin (4 cm) B horizon which consisted of a 10 YR 8/2 very pale brown, loamy sand. This B horizon was underlain by a well-developed 38 cm thick Bk horizon which consisted of a 10YR 4/1 dark gray sandy clay loam which contained white, presumably carbon, striations. Underneath this Bk horizon, a short C1 horizon was exposed measuring 9 cm which was characterized by a 10 YR 6/3 pale brown sand. Beneath this stratum excavators encountered a C2 horizon consisting of a 10 YR 7/2 light gray loamy sand. Bulk samples were taken from various depths within the A, B, Bk, C1, and C2 horizons of ST Downhill Pond 1, and were tested for particle size, organic and inorganic carbon content, and phosphate content. The results from these tests, as well as excavation notes, a photograph of the west wall profile of ST Downhill Pond 1, and a chart depicting the examined geophysical and geochemical properties of ST Downhill Pond 1 can be found in Appendix C-12.

The upper reaches of the A horizon within ST Downhill Pond 1 exhibited a moderate organic carbon content (as compared with other A horizons across the plantation) of 10.94%, which was coupled with a relatively high inorganic carbon content of 17.54%. Deeper within the A horizon, the organic carbon content rose to 12.95%, while inorganic carbon content dropped to 16.76%. Within the B horizon organic carbon content continued to rise slightly (to 13.06%) while inorganic carbon levels continued to fall. Within the ST's deep Bk horizon, there is a slight decrease in organic carbon (to 12.99%). Thereafter, organic carbon content levels proved to be

erratic throughout the remainder of the stratum, with both increasing and decreasing values with increased depth, with levels reaching as high as 11.95%, as low as 8.73%, and reaching a level of 9.72% at its bottom. These changes in organic carbon levels within the Bk horizon coincided with an initial decrease in inorganic carbon from the level found within the B horizon, followed by slight fluctuations, up and down within the remainder of the depth of the Bk horizon, reaching a peak of 14.35%, a low of 13.09%, and a value of 13.82% at the stratum's bottom. Within the C1 horizon organic carbon levels initially rose (to 10.68%) before falling to 9.39% near its bottom. These levels were matched by an initial fall in inorganic carbon content (to 12.10%) and large rise to 16.20% at the stratum's bottom. Within the single bulk sample collected from ST Downhill Pond 1's C2 horizon organic carbon content fell to 8.71% while inorganic carbon levels rose to 19.75%.

Phosphate (PO4) levels within the A horizon of ST Downhill Pond 1 were higher than those found within the A horizon of ST Uphill Pond 2, with a concentration of 0.27 mg/L in its upper reaches, and a concentration of 0.24 mg/L near its bottom (as compared to the A horizon within ST Downhill Pond 1's PO4 concentration of 0.09 mg/L) (Appendix E). Within Downhill Pond 1's B horizon, PO4 levels slightly fell (to 0.21 mg/L), though this B horizon proved to be extremely thin (4 cm total). Perhaps more representative of this area's capacity to support plant growth are the PO4 levels within the ST's far larger Bk horizon, with levels spiking to 0.48 mg/L within the Bk horizon's upper reaches, and then generally, gradually falling with increased depth for the next 38 cm. Within the first C horizon encountered, PO4 levels were surprisingly higher, reaching levels of 0.2 mg/L close to the Bk/C transition, and hitting levels of 0.32 mg/L near its bottom at 65 cm below surface. The small portion of the C2 horizon exposed through excavation revealed considerably lower PO4 levels, with concentrations of 0.09 mg/L.

The geochemical and geophysical signatures of ST Downhill Pond 1 point toward a complex history of development, involving *in situ* soil formation interrupted by periods of volatility, possibly in the form of erosion and deposition, or possibly in the form anthropogenic tilling or the addition of soil amendment (Wells 2006, Eidt 1984, Holliday and Gartner 2007). Geochemically, portions of the soil column within ST Downhill Pond 1 hint at periods of steady soil development *in situ*, with portions exhibiting both gradual decreases in organic carbon and PO4 content and increases in inorganic carbon content (as is the case between depths 37 cmbs and 51 cmbs) (Garrison 2016, Holliday 2004). Yet other portions of the shovel test allude to periods of disturbance and volatility, with increases in organic carbon content and PO4 concentrations with increased depth, and decreases in inorganic carbon levels (such as those observed at 27 – 32 cmbs and 47 – 52 cmbs), which suggest the interruption of regular pedogenic processes that were either naturally occurring (i.e., rainsplash damage and sheet erosion) or anthropogenically induced (through the tilling, and or removal or amendment of local soils) (Garrison 2016, Holliday 2004, Birkeland 1999, Bockheim 2014). Geophysically, the presence of an extensive (38 cm) Bk horizon, as well as very gradual transitions between each of the strata present within the ST, point towards a history of *in situ* development (Garrison 2016). Conversely, ST Downhill Pond 1's only moderately sized A horizon (11 cm) and extremely thin B horizon (4 cm) suggest a more volatile history, whereby these strata have not had significant undisturbed time to develop. These characteristics in the profile point toward soil loss, perhaps in the more recent past. Such a narrative would hint at a drastic change in the land use in this area, which might have caused an abrupt and meaningful change in how local soils were developed.

ST Downhill Pond 2

ST Downhill Pond 2 was excavated roughly 30 m northeast of, and slightly downslope of, ST Downhill Pond 1 (Figure 84, Figure 86, and Figure 87). The exposed stratigraphy consisted of an A horizon measuring 26 cm, which consisted of a10 YR 3/1 very dark gray sandy clay loam in its upper reaches and transitioned to a loamy sand and eventually a sand with increased depth. This stratum was underlain by an extremely gradual A to B transition layer measuring 27 cm deep which consisted of a 10 YR 6/6 brownish yellow sand which gradually shifted to a 10 YR 3/1 very dark gray sandy clay loam towards its bottom. Beneath this layer, 9 cm of a B horizon consisting of a 10YR 7/4 very pale brown sandy clay loam was observed before excavations were terminated. Bulk samples were taken from various depths in the A, A to B transition, and B horizons of ST Downhill Pond 2, and were tested for particle size, organic and inorganic carbon content, and phosphate content. The results from these tests, as well as excavation notes, a photograph of the west wall profile of ST Downhill Pond 2, and a chart depicting the examined geophysical and geochemical properties of ST Downhill Pond 2 can be found in Appendix C-13.

The upper portion of the A horizon within ST Downhill Pond 2 exhibited a slightly above average organic carbon content (for soils found on the ELP) of 13.38%, while the remainder of the A horizon revealed a gradual reduction down to 11.48% at its bottom. These values were mirrored by somewhat high inorganic carbon content levels in the A horizon's upper reaches (16.63%), and gradual reductions in inorganic carbon content throughout the remainder of the stratum. Within the A to B transition layer, organic carbon levels first rose slightly (to 11.63%) but then gradually fell with increases in depth, while inorganic carbon levels at first slightly fell (to 11.70%) but then steadily rose to 21.0% by the bottom of the horizon. Within the B horizon, organic carbon content levels rose to 12.37% while inorganic carbon levels slightly decreased to 20.41%.

PO4 levels within the A horizon of ST Downhill Pond 2 were higher than those found within ST Downhill Pond 1, with concentrations within the highest portion of the horizon of 0.40 mg/L, and concentrations falling slightly with increased depth, hitting 0.36 mg/L by its mid-section, and ultimately reaching 0.27 mg/L within the last few centimeters of the horizon. Within the A to B transition horizon beneath the A, PO4 concentrations fell to 0.17 mg/L and remained constant throughout the stratum. Within the top of the B horizon (the last portion of the profile examined through excavation), PO4 concentrations fell sharply to 0.09 mg/L.

The stratigraphy found within ST Downhill Pond 2 point towards a complicated history of development, including periods of development *in situ*, and periods of volatility. Strata characteristics are similar to those found within ST Downhill Pond 1 (Appendix E). These traits consist of the presence of a fairly large (26 cm) A horizon, which exhibits gradual decreases in organic carbon content, PO4 concentrations, and corresponding increases in inorganic carbon content. The ST also possesses a large A to B transition layer, in which changes in color and texture take place quite gradually over 27 cm. These attributes strongly suggest a history of soil stability in the area and point towards the stratigraphic development of horizons *in situ* (Garrison 2016, Holliday 2004). The PO4 levels throughout the remainder of the ST's profile also suggest a history of relative stability and development *in situ*, with PO4 levels gradually falling with increased depth throughout the soil column (Holliday and Gartner 2007). There are also signs of stratigraphic volatility or interruptions in the pedogenic processes. Higher PO4 levels within the A horizon of ST Downhill Pond 2 suggest the introduction of phosphates in the area either

through the erosion of topsoils from further upslope, or through anthropogenic activities, such as the dumping of waste and the inclusion of soil amendment or manure (Holliday and Gartner, Wells 2006, Eidt 1984). Other signs of volatility within this shovel test include rises in organic carbon content at the tops of both the A to B transition layer and the B layer, which corresponded with decreases in inorganic carbon content. These readings suggest that some other factors, beyond the weathering of parent material, and the deposition of new organic matter on the top of the ground surface, have helped to govern the development of this profile (Garrison 2016, Holliday 2004, Pratt 2015, Tricarico 2019).

ST Swamp 1

ST Swamp 1 was excavated near the eastern boundary of ELP, just 35 m west of St. Croix's northeastern coast (Figure 84, Figure 86, and Figure 87). It is located roughly 60 m northeast and slightly downhill of ST Downhill Pond 1, within 5 m of the ELP's primary ghut. ST Swamp 1's A Horizon measured 12 cm deep and consisted of 10 YR 3/1 very dark sandy loam. This stratum was underlain by a B horizon measuring 25 cm deep which consisted of 10 YR 4/3 brown sand within its upper reaches and transitioned to a sandy clay loam around its mid-section. Underneath this B horizon lay a B to C transition layer measuring 12 cm thick and consisting of 10 YR 5/3 brown sandy clay loam, followed by a C horizon which consisted of a 10 YR 6/3 pale brown sandy clay loam. Transitions between strata were gradual (with one of the horizons recorded as a transition between the B and C horizon). Bulk samples were taken from the A, B, B to C transition, and C horizons and were subjected to pH testing, PSA, LOI testing, and phosphate content testing. The results from these tests, as well as excavation notes, a photograph of the west wall profile of ST Downhill Swamp 1, and a chart depicting the examined geophysical and geochemical properties of ST Swamp 1 can be found in Appendix C-14.

Potential hydrogen (pH) levels within the upper levels of the A horizon of Swamp 1 were 8.08 but increased to 8.155 by the bottom of the stratum. Within the B horizon pH levels steadily, but gradually, fell reaching a level of 7.86 by the stratum's bottom. Within the B to C transition layer, and within the C horizon beneath it, pH levels steadily rose, first to 7.975 within the transition layer, and then to 8.17 in the C horizon.

The organic carbon content of the A horizon within shovel test Swamp 1 is lower than that of ST Downhill Pond 2 (10.69% vs Downhill Pond 2's 13.38%). Similarly, the inorganic carbon content within the A horizon of ST Swamp 1 (12.92%) is markedly lower than that found in STs Downhill Pond 1 and 2 (17.54% and 16.63% respectively) (Appendix E). Within the B horizon organic carbon levels first fell to 9.01% and then rose slightly to 9.13% near the horizon's bottom, while inorganic carbon content levels fell throughout the stratum, hitting levels of 12.24% and then 9.04% near the layer's bottom. Within the B to C horizon, observed organic carbon levels fell slightly (to 8.93%) while inorganic carbon content rose to 13.42%. Within the C horizon the trends continued, with a slight decrease in organic carbon content from the layer above it (to 8.81%) and a more dramatic increase in inorganic carbon content to 22.74%.

Phosphate (PO4) levels within the A horizon of ST Swamp 1 were markedly higher than those found within ST Downhill Pond 2, or anywhere else in the southern shovel test transect, with a concentration of 0.92 mg/L. Within the B horizon, PO4 levels fell from those found in the A horizon, but still contained higher concentrations than any other B horizon in the southern shovel test transect, reaching levels of 0.73 mg/L in its upper reaches, and 0.33 mg/L close to its bottom.

Within the B to C transition horizon which was observed, PO4 concentrations fell considerably to 0.17 mg/L. PO4 concentrations proved to stay constant throughout portions of the C horizon which were sampled and tested.

Like the profiles found within ST Downhill Pond 1 and Downhill Pond 2 the geophysical and geochemical characteristics of the stratum found within ST Swamp 1 suggest a complex developmental history. Signs of stability and soil development *in situ* include the presence of an, A, B, and B to C transition horizon (which measured 22 cm deep), gradual transitions in color and texture between each of these horizons, and the gradual drop in PO4 levels seen with increased depth throughout the soil profile (Bockheim 2014, Birkeland 1999, Holliday and Gartner 2007, Eidt 1977). Signs of volatility within this shovel test are numerous. They include fluctuating pH, organic carbon content, and inorganic carbon content levels observed throughout the A, B, and B to C transition layers, which suggest the interruption of regular pedogenic processes (Garrison 2016, Holliday 2004). These processes might have included erosion from the area to points further downslope (or even the Caribbean Sea), sediment deposition onto the area (derived from eroded soils located upslope), or anthropogenic modification, through tilling, aeration, soil amendment, or manuring, in the vicinity of this shovel test. The presence of relatively high PO4 levels at the top of this ST, as well as relatively high PO4 levels (when compared to those seen in other ST's along the southern transect) throughout the entire soil profile however, would seem to suggest a more recent history of sediment deposition, or anthropogenic modifications, rather than one of erosion moving soils from this area, as phosphates would likely be washed away along with soils during such events (Holliday and Gartner 2007, Eidt 1984).

Chapter 11. Discussion: Unpacking The Soilscape Legacies at the Estate Little Princess

Having collected bulk samples from virtually every stratum encountered within the projects two transects, the soils of the ELP were subjected to a wide variety of testing at the Archaeological Research Facility at UC Berkeley. Using a suite of tests similar to those used by Wells and his colleagues Pratt and Tricarico who examined the soilscape legacy of sugar planting at Betty's Hope plantation in Antigua, the soils collected at the ELP were tested for Munsell color, pH, grain size, texture, organic and inorganic carbon content (via LOI testing) and phosphate concentrations. This analysis was conducted to identify detectable aspects of conditions of soils on the plantation today that could be linked to plantation era activities and land uses including occupation, leaving lands deliberately in timber or bush, and sugarcane agriculture. In so doing this work sought to more fully understand the "soilscape legacy" of human activity on the ELP during its nearly 200 years of use as a sugar plantation by looking at the "long-term socioecological consequences of human interactions … [observable within] soil bodies that have been physically and chemically altered as a direct result of human behavior" (Wells 2013:23 – 24). What follows is a discussion of the geophysical and geochemical properties of the soils of ELP as they compare with the area's known colonial era history to help us understand the enduring legacies of various forms of land use on the ELP during the plantation's active period.

Interpreting the Results from Soils and Sediment Analysis from the ELP

Transect 1

Topographic evidence collected via LiDAR and pedestrian survey of the plantation's grounds as well as geophysical and geochemical evidence from the shovel test units excavated along the primary hillslope of ELP, spanning from the hill's zenith to the toe of the slope in the north suggest the presence of four distinct soil proveniences within this portion of the landscape (Figure 86). These four provinces include areas covered by: ST HZ north through ST Neg 2 which lie along the top of the estate's primary hill, ST Neg 1 through ST 3 which occupy the middle portion of the hillslope and a small portion of the hillslope which lies just uphill from a relic ghut, ST 4 through ST 6 which contain evidence of the deposition of sediments from the ghut and hillside further uphill, and ST 7 through ST 12 which are located considerably further downhill of the relic ghut and occupying the toe of the slope of ELP's primary hill (Figure 84, Figure 86, and Figure 87 show ST names and locations along Transect 1). The first stratigraphic provenience (observed within ST HZ through ST Neg 2) encompassed a portion of the ELP that was developed and occupied as an African laborer's village. The other three soil proveniences examined within the northern transect occupied an area deliberately kept in timber or secondary growth throughout the historic period.

The African Village

The stratigraphic profiles revealed within shovel tests ST HZ through ST Neg 2 (at the top of the ELP's primary hill) contained several geochemical and geophysical signatures which allude to a volatile history of development, including shallow and underdeveloped A horizons (ST HZ, ST HZ+5, and ST HZ+7), stark contrasts in color, texture, and carbon content found between adjacent strata (as is the case in ST HZ, ST HZ+1, ST HZ+7), and in some cases the absence of, and or a noticeable underdevelopment of B horizons (as is the case in ST HZ, ST HZ+1, ST HZ+5) (Figure 84, Figure 86, and Figure 87) (Appendix C, Appendix D, and Appendix E)

(Garrison 2016, Holliday 2004, Bockheim 2014, Birkeland 1999). The volatility suggested by the characteristics in the soils on this part of the plantation alludes to erosion having taken place down from this location on the ELP's primary hillslope to the north and northeast of the hill's zenith. Natural factors likely contributing to this past erosion include gravity and precipitation on occasions intense enough and or frequent enough to pry loose top soils and carry them downhill. These natural factors would be constant forces at work in any location where the soil has potential energy and where exposed earth would be subjected to rainsplash damage and transport downhill through sheet wash of collected rains.

The historical record of ELP suggests that the clearing of this portion of the ELP's primary hillslope took place no later than the second half of the eighteenth century. At that time it was cleared and developed for use as an African laborer's village. At first, a small village was built in the 1740s by the plantation's first Danish owners, Fredrick Moth and Peter Heyliger (Wright et al. 1980). The *First Danish Map over St. Croix*, (Croneberg and Jeagersberg 1750) depicts ELP's boundaries and plantation holdings (including mills, residential structures, the laborer's village, and acres in cane cultivation). It shows a laborer's village as lying to the east of the plantation's structures and an animal mill, rather than atop the ELP's primary hill slope (Figure 88). This map also clearly depicts the top of ELP's primary hillslope as not in sugar cultivation or development, with the only developed sugarcane fields depicted well to the south of any structures on the plantation.

Figure 88. Eighteenth century depictions of St. Croix and the Estate Little Princess. On the left, First Danish Map over St. Croix, by Johan Cronenberg and Johan Jaegersberg, 1750, on the right, Peter Oxholm's 1799 Map of St. Croix. Maps are on file at the Danish National Archives Rigsarkivet. Blue outlines of ELP added by author.

In 1756 Peter Heyliger Jr., Peter Heyliger's son, and his wife, Fredrick Moth's youngest daughter, Alette Moth, inherited ELP, and continued to make improvements to the plantation, constructing the plantation's first great house in 1759, and a wind driven sugarcane mill in 1766 (Wright et al. 1980). While paper documentation detailing the clearance and development of the top of ELP's primary hill for the purposes of an African laborer's village are notably absent from available historical records (Staples 1998, Tyson 1993, Tyson N.D., Vaughn 1977), this clearing and construction effort were evidently undertaken during Peter Heyliger's tenure as plantation owner and manager (1756 – 1804) as a 1799 map of the island which depicts ELP, *Peter Oxholm's 1799 Map of St. Croix*, shows that by the time of the map's creation the ELP's hill zenith was cleared of forest and bush, and developed into a residential area for laborers, with three columns and five rows of small rectangular structures (15 in total) (Figure 88).

Archaeological and photographic evidence from ELP strongly suggest that this location for the African laborer's village was contiguously occupied from its initial construction through the mid or even late 1900s. Recent and ongoing archaeological excavations and artifact analyses conducted by the SBA's ELPFS, which have taken place within and in the vicinity of this African laborer's village support this understanding of the area's use through the identification of material culture found on and beneath the ground surface in this area. SBA leaders have directed shovel test and test unit excavations in the vicinity of still extant laborer dwellings and have used these excavations to define and characterize the extent of the historical African laborer's village on ELP. Subsequent artifact analysis has identified material culture dating throughout the nineteenth century and early twentieth centuries, as well as the several structural remains and post holes (Dunnavant et al. 2018b, Flewellen et al. 2019, Flewellen et al. 2022).

Artifacts recovered from shovel probes and test units have dates of production and use associated with the Danish Caribbean era of enslavement and tying the African Village at ELP into a broader international trade network (1733 through 1848). These finds include a Danish coin, creamware sherds, north midlands slipware ceramic sherds, Afro-Crucian ceramic sherds, sherds of Moravian slipped ware vessels (manufactured in Pennsylvania), and pipestems, with production ranges dating from the 1670s through the early 1800s (Flewellen et al. 2019:7, Flewellen et al. 2022:14, Majewski and O'Brien 1987, DAACS 2018, Lenik and Heindl 2014). Whiteware sherds, bottle glass, window glass, and metal artifacts dating to the mid to late nineteenth century and early twentieth centuries were also commonly encountered during archaeological excavations expanding the known dates of the village's occupation. Artifacts and structural evidence suggest that the top of the ELP's primary hillslope was developed and used as an African laborer's village from a period close to the start of the Danish occupation in St. Croix (1733), through the 1900s.

Several photographs taken during the Svitzer era of ELP (1879 and 1933) also confirm the use of the laborer's village through the first several decades of the 1900s. While the precise dates of these photographs are unknown, the presence of Emil Svitzer, owner of ELP from 1879 through his death in 1922, depicted as an adult male in these photographs gives them a firm date range of production. In one of the photographs (Figure 89) Emil Svitzer is on a horse, and within a cane field located to the south of the ELP's factory. To the northwest of Emil's location however, we see no fewer than 18 small rectangular structures occupying the ELP's primary hillslope (Figure 89). Figure 90 and Figure 91, two photographs found within the same Svitzer era photo series, also give us glimpses of the nature and condition of the laborer's village around the turn of the

twentieth century, showing us views of village structures from the southeast and south respectively. Within these photographs the structures appear to be oriented with their longest sides spanning from north to south on the primary hill slope. The structures appear to be A-frame in design, comprised of brick and or limestone rock rubble, covered in plaster. Entrances appear to be constructed on either the east or north facing walls, and the roofs appear to be made of corrugated metal.

Figure 89. Photograph showing Emil Svitzer on a horse within a cane field ready for planting, (located to the southeast of the ELP's Cane Factory), facing northwest. Photograph by unknown, taken circa 1890. Image from TNC's ELP photograph collection, compiled by Dr. George Tyson from the vertical files at the St. Croix Historical Landmarks Society Archive at Whim Plantation.

Figure 90. Photograph showing the African laborer's village located to the west of the ELP's First Great House. The view is from the second story balcony of the First Great House, facing northwest. Photograph by unknown, circa 1890. Image from TNC's ELP photograph collection, complied by Dr. George Tyson from the vertical files at the St. Croix Historical Landmarks Society Archive at Whim Plantation.

Figure 91. Photograph showing plantation laborers standing in front of the African laborer's village (left), Lands Kept in Timber (center), and First Great House (right). Photograph taken from a location to the west of the First Great House, facing north. Photograph taken from a location to the west of the First Great House, facing north. Photograph by unknown, taken circa 1890. Image from TNC's ELP photograph collection, compiled by Dr. George Tyson from the vertical files at the St. Croix Historical Landmarks Society Archive at Whim Plantation.

These photographs also depict a larger number of structures than the number depicted within *Peter Oxholm's 1799 Map of St. Croix*, suggesting that the area had likely been further developed since the area's initial clearance and development during the eighteenth century. Also visible from these photographs are rows of palm trees planted and kept to the west of the village houses, perhaps demarcating the plantation's western boundary. Figure 90 and Figure 91 also reveal that the space between the great house and the village was kept clear and unplanted at the time of the photograph, while Figure 91 depicts the village area as a discrete patch of entirely cleared area, well north of the cane fields themselves, and immediately adjacent west of a patch of dense hardwood vegetation which is understood to have occupied the remainder of the plantation grounds from the north and northwestern boundaries of the village area. Lastly, this photograph also depicts two horse drawn carts in the foreground of the village area, likely used for carrying cane and personnel around the plantation grounds and to the nearby town of Christiansted to the east.

Use of the top of the ELP's primary hillslope as an African laborer's village would have had a tremendous impact on the soils and soil systems which had previously occupied the vicinity.

Initial clearance of the plantation is thought to have taken place sometime in the 1730s or 40s, and the deliberate clearing and prepping of this portion of the hillslope is likely to have taken place between 1750 and 1799. With the removal of stabilizing vegetation, plant roots, and severe disruption and loosening of local topsoil, these clearing events would have undoubtedly made local soils more susceptible to erosion. These initial clearances of the area would have been extremely damaging to local soils, consisting of the removal or uprooting of larger hardwoods, as well as the removal of smaller shrubs and ground plants and their more sprawling root systems. This clearing would have prompted universal exposure of the entire area's top soils, making them particularly susceptible to rainsplash damage and subsequent sheet erosion during any storm of even moderate intensity or duration. Human impacts to the soils would have persisted through subsequent excavations in the area associated with the development of the foundations for the village's structures, and the continued maintenance of the area to keep it clear of secondary growth, as well as its continued use as a dwelling and activity space for its occupants.

These construction-related excavations in the area, to depths that would have reached local parent material at the top of the ELP's hillslope, would have promoted the exposure of a great deal of previously subterranean soils to rain damage and erosional forces. Moreover, the contiguous occupation of this portion of the hill would have had several impacts on local soil development. First, it would have been continuously kept clear of secondary growth to allow for ease of use as a place of occupation, cooking, walking, and even gardening (Berleant-Schiller and Pulsipher 1986). This would have kept local soil exposed to the open air and the forces of precipitation and erosion. Walking, or the traversing of the land by horse and or horse drawn carriage, in particular, would have also had the additional effect of compacting the topmost exposed layers of local soil. While this impaction would have offered some form of initial protection against rain and sheet erosion to the affected soils, it would have also created a "slick" surface layer of soils which would have more readily enabled sediments deposited onto these soils to continue moving downhill during rain events, as more compact soil matrixes are characterized by a heightened level of impermeability.

Since the abandonment of the African laborer's village in the early to mid-twentieth century the top of the ELP's primary hill has been allowed to return to secondary growth. A major hurricane struck the island in 1928 and is noted to have destroyed the roof of the ELP's first Great House (Wright et al. 1980). Given the severity of the storm, it is also quite likely to have done significant damage to the structures of the laborer's village as well. Lacking in funds to muster repairs from this storm the plantation largely lay in ruin for the next decade. In the late 1940s ELP was purchased by Clayton and Opal Shomaker, who decided to use the grounds of the former plantation as a vacation home. They soon remodeled the great houses so that they might occupy it, and installed a chlorinated pool with a pump into the southeastern portion of the sugar factory ruins (Wright et al. 1980). All the while, the area formerly occupied by the laborer's village fell further into ruin, with brush, sansevieria, and small hardwoods establishing secondary ground cover and ecosystems in the area. The Shoemaker family enjoyed the property in this way until 1977 when the family donated the central 25 acres of the former planation (within which the village site sits) to The Nature Conservancy (TNC), a US based nonprofit, for use as the organization's Virgin Islands headquarters (Harty 2003). Since that time, the TNC has also largely left the laborer's village area untouched, save for the maintenance of a narrow nature trail which runs past several of the still extant village structures before looping to the north and northeast portions of the TNC's property, and the more recent excavations of the SBA's ELPFS.

The relatively high phosphate (PO4) concentrations (which often exceeded the 2.75 mg/L limit of the phosphate testing method used for this project) found within the soils tested at the top of the ELP's primary hillslope combined with the area's known land use history paint the picture of a heavily anthropogenically influenced landscape (Holliday and Gartner 2007, Wells 2006, Eidt 1984, Schuldenrein 1996). While it is certainly likely that the natural forces of rainsplash damage and gravity are likely to have played a role in this apparent history of erosion, several pieces of geophysical and geochemical data collected from soil samples from the African laborer's village area point towards significant levels of anthropogenic induced volatility. These include the presence of an underdeveloped A horizon, the presence of stark contrasts in color, texture, and carbon content found between adjacent strata, and the absence of, or underdevelopment of, a local B horizon (Garrison 2016, Holliday 2004, Bockheim 2014). The soils tested in this portion of the plantation were also found to possess relatively high levels of phosphates. Such phosphate concentrations are understood to be good indicators of human activity, as humans are likely to impact soil phosphate levels through the introduction of human waste, food refuse, and manure fertilizer (in the case of house gardens) (Holliday 2004:304).

Within STs HZ, HZ+1, ST HZ+2, and HZ+5 PO4 concentrations throughout the soil column consistently surpassed the highest concentration of PO4 (2.75 mg/L) detectable by the Hach colorimeter (Appendix E). These were by far the highest readings found within any of soils tested across the entire plantation. While the land clearance and development of the local area likely amplified rain and gravity based localized erosion, it is difficult to know what amount of this erosion could be directly attributed to the area's past uses. From the ELP's history we know that this portion of the plantation was not used for agricultural purposes, which rules out the possibility that the area's high phosphate concentrations are the result of heavy or repeated manuring or fertilizing. Furthermore, the markedly lower phosphate concentrations found in shovel tests excavated within undeveloped lands to the north of the hill crest rules out the idea that local flora or natural ecosystem processes dictated the hill crest's abundance of phosphates. As a result, the only factor that might have contributed to the high phosphates readings found in the vicinity of ST HZ, ST HZ+1, and ST HZ+5 was the area's continuous occupation by African laborers and their families who, through the repeated preparation and consumption of fruits, vegetables, meats, and other foods, deposited food waste and human waste in this area over an extended period of time. Surviving as the result of the area's occupation by African laborers the heightened PO4 levels detected within even tested C horizon materials near the hill's zenith are a clear demonstration of the soilscape legacy of the African laborers and their families who continuously occupied the village's structures for well over 100 years.

The Timberlands

Further north, and downslope of the African laborer's village, is the second provenience identified on the ELP's primary hillslope area. Here soil profiles are characterized by: the deposition of sediments from further upslope, signs of the erosion of soils from this location to points further downslope, and evidence of the long-term development of soils *in situ*. Located just north of the ELP's relic ghut, this area is bounded by ST NEG 1 and ST 3 (Figure 84, Figure 86, Figure 87). The evidence for volatility within this area includes noted increases in organic carbon content, and or inconsistent rises and falls in inorganic carbon content within the B and B to C transition horizons of STs excavated in this location as well as the observation of stark contrasts in soil color and texture observed amongst adjacent strata within excavated STs (Garrison 2016, Holliday 2004, Appendix C, Appendix D, and Appendix E). These signs

strongly suggest that these strata are developed from deposited sediments, which were originally transported by sheet erosion from further uphill. Above these depositional layers, within ST 3, and within shovel tests located within approximately 100 m to the south (and upslope) of ST 3 we also see signs of soil profiles that are the results of increased landform stability, especially when compared with the profiles found within the African Village area. Characteristics within the upper layers of these soils which suggest relative stability include the presence of B horizons, and in some cases even the presence of relatively well developed and relatively large (in terms of depth) A, B, and even Bk horizons in observed profiles (Figure 87). Furthermore, the A and B horizons within ST 3 were found to possess PO4 and organic carbon content concentrations which gradually decrease with increases in depth. These attributes suggest that while the mineral soil comprising these strata may have once been transported here via erosion, and that while each of these strata may have been subjected to levels of rain-based sheet erosion after their initial deposition, some level of *in situ* development (representing stability) over time has taken place in this portion of the hillslope (Bockheim 2014, Birkeland 1999). This stability may have quite possibly been a more recent phenomenon, with the current A horizon perhaps having taken shape sometime after the abandonment of the African Village Site, when fewer soils uphill of this area would have been exposed to the forces of rainsplash damage and sheet erosion which would have resulted in their deposition onto this area.

Further north than, and downslope of, the northern bank of the relic ghut (which runs through the hillslope of ELP) lies the third distinct soil provenience found within the project's northern transect (Figure 84, Figure 86, Figure 87). This area, spanning from relic ghut to as far north as the recorded location of ST 6 contains evidence of the deposition of sediments, most likely resulting from ghut overflow prompted by heavy storms, or sheet erosion from further uphill (Figure 84, Figure 86, Figure 87). The stratigraphy in this area, as evidenced through the extensive analysis of the soils found within ST 4, reveals a volatile history consisting of depositions from, and erosion caused by, flooding and spill over within the ghut just uphill of it (Karkanas and Goldberg 2018). Consisting of layers of river rounded cobbles, geochemically- and geophysically- distinct soils with different parent material sediments, these strata are separated in most cases by stark and abrupt transitions in color and texture. As a result, the three alluvial layers observed within ST 4 can be thought to have been deposited during intense weather events, or moderate weather events following large scale clearing activities further upslope, such that sediments from further upstream in the first case, or sediments from further uphill in the second, would have been transported down to this space (Garrison 2016). In some cases, as evidenced by the soils themselves, which reflect development based on separate sedimentary deposits, the culprit weather events would have had to have been quite severe to move river rounded cobbles and cause the water levels within the ghut (heavy with sediment load) to flood out of the ghut's 1.5 m tall northern bank.

It is also quite possible that a large portion of sediment materials eroded from the top of the primary hillslope and found its way into the (now relic) ghut located just south of ST 3 (Figure 84, Figure 86, Figure 87). If this were the case, then a large amount of that sediment would have been redirected down to the southeast (following the curvature of the ghut bank around the hill's topography) and potentially out to the shoreline and the Atlantic Ocean (Figure 86). Only during rain events where the ghut would have overflowed, would sediments have made it down to the area occupied by ST 4, ST 5, and ST 6. This supposition is supported by the total absence of sedimentary deposits observed within ST 7, ST 8, ST 9, ST 10, ST 11, and ST 12, suggesting

that all sediments transported from further uphill were carried out to the sea or redirected just north and downhill of the relic ghut.

The relic B horizon found beneath the deepest alluvial deposit within ST 4 also provides an understanding of the landscape at this point along the hillslope prior to the deposition of the three alluvial strata above it. A radiocarbon datable shell from the top of this relic B horizon dated to 577 AD ±26 years (Appendix D Table D-1). While the potential for a snail to move through the soil column during its life span complicate the interpretive value of this snail shell, the calibrated date of 577 AD still provides us with a potential *terminus ante quem* for the relic B horizon in which it was found (Banning 2020, Holliday 2004, Ramey et al. 2021, Osborne and Wright 2018). Predating the ELP's period of active use as a sugar plantation (1733 – mid-twentieth century) by over 1,000 years, this relic B horizon has likely not served as the local ground surface since prior to European occupation of the island St. Croix. While possible that it was once occupied by precontact cultures who traversed and settled the island, this stratum did not yield any direct evidence for prehistoric land use, as there were no lithic materials, soil midden, nor extensive charcoal (which might have suggested the use of slash and burn agricultural techniques) encountered within the relic B horizon (Hardy 2008). Nonetheless, this horizon was found to exhibit higher organic carbon content and higher PO4 concentrations than the strata above and below it, supporting the narrative that this layer has a distinct developmental history from the alluvial layer above it, but potentially a connected one with the C stratum beneath it, with the changes observed in organic carbon content, inorganic carbon content, PO4 concentrations, and pH levels between the relic B and C strata suggesting a history of development *in situ* (Garrison 2016, Holliday 2004, Bockheim 2014).

Another attribute of the third distinct soil provenience found within the project's northern transect is the absence of a robust B horizon, and in some locations, an A to C transition, entirely devoid of a B horizon, found at the top of the soil profile. While a relic B horizon was demonstrated to lie beneath the deepest of three alluvial layers within ST 4 and ST 5, the A to C transition at the top of these profiles suggests that at one point the soil column "restarted" its development, using ghut born and deposited sediments as parent material. Moreover, it seems possible that some level of erosion from the area has also likely continued into the more recent past, resulting in the lack of the development of a B stratum. The thinness of the A horizon, and the presence of predominantly large (3 – 4 cm diameter) and still subangular (relatively unweathered) granitic rocks within the local C horizon, also suggests that these strata have developed together *in situ* over a relatively short time (Garrison 2016, Holliday 2004).

The timberland's modern A horizon's PO4 content (0.25 mg/L) is notably higher than the PO4 levels seen in the relic B horizon (0.04 mg/L) (and presumably locally developed soil), but still considerably lower than the PO4 levels observed within the African laborer's village area at the top of the hill. Instead, the PO4 levels found in the A horizon here most closely match those found within the A and B horizons within the portion of the hillslope just upslope (and south) of the relic ghut, suggesting that there may be some commonalities between the observed stratigraphy of the two areas. It is possible that these observed PO4 concentrations are more directly linked to the recent accretion of plant and animal detritus in the area since the alluvial deposition of the modern C horizon has taken place, but it would also be conceivable that the two proveniences (both downslope of the African Village area) have received influxes of relatively PO4 rich sediments via forces of erosion from further uphill (Holliday and Gartner 2007, Eidt

1977). If the latter were the case however, and sediments were being deposited in this area from further uphill, then we might expect to see considerably higher PO4 levels, with topsoil at the zenith of the hillslope exceeding concentrations of 2.75 mg/L (Appendix E). Therefore, we instead must consider the former and acknowledge that the modern A horizon is the result of *in situ* development, borne of the weathering of the alluvial cobbles beneath it, and the deposition of plant and animal matter at the ground surface. Such an interpretation supports the idea that in the more recent past, quite likely after the abandonment of the African laborer's village, the hillslope has seen additional stability, with less erosional deposits seen both upslope and downslope of the plantation's relic ghut (Cameron and Tomka 1993).

Finally, even further north than ST 6, past the point where sediments from past overflows of the ELP's relic ghut had been deposited, we encountered the fourth provenience of soils within the project's northern transect. This provenience, which was recorded as spanning as far south as ST 7 and at least as far north as ST 12 lies at the toe of the ELP's primary hillslope (Figure 84, Figure 86, Figure 87). This provenience contained soils which indicated signs of relative stability, with various indicators pointing towards soil development *in situ*, and a relative lack of soil deposition onto the area. Signs of relative soil stability found within these shovel tests included: organic carbon content levels, pH levels, and PO4 concentrations which generally dropped with increases in depth, gradual transitions (in color and or texture) between observed strata, and well-developed strata with STs usually possessing Bk or other B to C transition layers of relatively large size (Garrison 2016, Holliday 2004, Bockheim 2014, Birkeland 1999, Appendix C, Appendix D, Appendix E). If sediments from further upslope had been deposited in this area, then ST 7, ST 8, ST 9, ST 10, ST 11, and ST 12, would have had much thicker A and B horizons, and strata with considerably starker contrasts in color and texture (Tricarico 2019, Pratt 2015). Instead, here we see gradual and steady transitions between well developed and geochemically and geophysically related strata, strongly suggesting that the area has not seen constant, nor the significant, deposition of sediments which might have eroded downhill from the African Village area, relic ghut, and or midrange of the hill's slope.

A radiocarbon datable land snail shell recovered from the observed B horizon within ST 11 also provides insight into the history of the land in this portion of the ELP. Found no deeper than 23 cm below the ground surface, the snail shell dated to 10,624 BC ±42 years. Like the other snail shells recovered in ST 4, ST 8, and 9, this one was likely moved through the soil column during the snails active life (Banning 2020, Taylor 2014, Holliday 2004, Ramey et al. 2021, Osborne and Wright 2018). This snail shell lying so close to the current ground surface within an area where shovel tests have yielded evidence suggesting relative stability of the local landform, encourages an understanding of an overall, extremely long time depth of soil formation in the vicinity, likely measuring in the thousands of years. It is possible that this soil formation has a very slow rate of stratigraphic development. This could potentially be a result of rain-based erosion carrying soils away from this area, just as, or before, they began to develop *in situ*, but perhaps is indicative of a very slow local rate of pedogenic processes (i.e. the weathering of parent material) in the area due to climate (i.e. heat) or a slower pace of the decomposition processes of local biota.

While these two interpretations may not be mutually exclusive (as moderate and gradual erosion from this location caused by intense or frequent rainstorms, well could have played a role in the development of this area's stratigraphy), the degree of slope at this portion of the hill is

considerably more temperate than that found in the soil proveniences further to the south, and the area exhibits well developed strata, separated by gradual transitions. These details push us towards an overall characterization of the toe of the hillslope as an area with a stratigraphy that has gradually developed *in situ* over the long term (Garrison 2016, Holliday 2004, Birkeland 1999, Bockheim 2014). This stability also seems to have continued into the present, with PO4 concentrations found within the A and B horizons of ST 8 and ST 9 similar to those found with the A and B horizons found within almost all shovel tests north of the African Village area (Appendix E). Interpreted within these other areas of the plantation's primary hillslope as the result of the *in situ* development of A horizons (borne of the weathering of the materials beneath it and the intermixing of deposited plant and animal detritus at ground surface) the same pattern in PO4 concentrations observed here, would suggest a similar understanding of the developmental history of the A horizon in this area as well (Holliday and Gartner 2007, Eidt 1977, Wells 2006). Seemingly the plant growth in the area, which includes sansevieria, subtropical forest, and sporadic small hardwoods, which have occupied the entirety of the ELP's primary hillslope since shortly after the abandonment of the African laborer's village, has played a dominant role in the development of the hillslope's A horizon (Cameron and Tomka 1993).

Various signs of relative stability are observed within the northern half of the project's northern transect (spanning from ST NEG 1 to ST 12) (Figure 86 and Figure 87). These included more robust A, B, Bk or B to C transition horizons, consistently decreasing organic carbon content, pH, and phosphate concentrations with increases in depth, and steadily increasing inorganic carbon content with increases in depth, coupled with considerably lower PO4 concentrations (as compared to those found within soils within the African laborer's village area) which strongly suggest a markedly different land use history for the middle and lower reaches of the ELP's primary hillslope (Garrison 2016, Holliday 2004, Birkeland 1999, Bockheim 2014, Holliday and Gartner 2007, Wells 2006). Whereas PO4 concentrations within the African Village Site consistently hit a level of 2.75 mg/L, PO4 levels within these more northern shovel tests never exceeded concentrations beyond even 0.45 mg/L (Appendix E). While the more northern reaches of the ELP's hillslope were clearly subjected to some levels of sediment deposition (comprised of sediments from further upslope or from sediments carried to the area by the ELP's relic ghut), and were clearly exposed to some level of rain and gravity based erosion (based on the signs of erosion found within the B and C horizons of ST NEG 1 through ST 6), the soils in this area must be understood to have enjoyed a level of stability beyond that seen at the top of the ELP's primary hill.

While there are some signs of volatility present within the second, third, and fourth soil proveniences found within the project's northern shovel test transect, (consisting of the areas between ST Neg 1 and ST3, ST 4 and ST 6, and ST 7 and ST 12, respectively), these three proveniences are more clearly unified by their categorically lower concentrations of PO4 than those found within the African laborers village, and the various signs of *in situ* soil development which they display (Garrison 2016, Bockheim 2014, Wells 2006, Eidt 1984). Profiles found within ST Neg 1 through ST 6 also proved to include soils which had developed from previously deposited materials that had eroded downhill to this location from locations further uphill. This phenomenon is readily explained by the abundance of loosened materials which would have been present and susceptible to rain-based erosion during the occupation of the African laborer's village site further upslope. Against this backdrop of deposition from further upslope however, the observed stability along the slope of the ELP's hill are of particular interest, especially in

areas just downslope of the African Village and hill zenith (including ST Neg 1 to ST 3) where extensive erosion took place in the past due to land clearance, development, and continuous human occupation.

Through a review of the historical record, it becomes clear as to how and why we see signs of stability within the stratigraphy of the slope of ELP's primary hill. From deed records we know that ELP was first developed for sugarcane planting by Frederick Moth and Peter Heyliger in 1749 (Wright et al. 1980, Tyson N.D.), but it is not until 1750 when we get our first glimpse of the plantation's spatial layout. Within the *First Danish Map over St. Croix*, by Croneberg and Heagersberg (1750), the area to the north of all extant structures on ELP is distinctly depicted as undeveloped and still in woods (Figure 88). A similar depiction is also clear within Peter Oxholm's half-century later prepared *1799 Map of St. Croix* (Figure 88), whereby areas to the north of the ELP's depicted properties are again portrayed as undeveloped, uncultivated, and further north, as lying in bush or forest.

In 1804, ELP was purchased by Cornelius D. Battelle, a private investor. Under Battelle's ownership ELP annexed 125 acres of the nearby Estate Golden Rock (EGR), located to the ELP's southeast (Wright et al. 1980, Tyson N.D.). This move increased the ELP's total acreage, and acreage kept in cane by roughly 50%. With EGR's sugarcane fields clearly depicted as adjacent to those maintained on ELP within both the *First Danish Map over St. Croix* and Peter Oxholm's *1799 Map of St. Croix,* it would stand to reason that following this annexation in the early 1800s agricultural production was consolidated and continued to be focused strictly to the south of the ELP's structures, and in between the sugar processing buildings and equipment kept on ELP and EGR at the time of the annexation (Figure 88).

The ELP's next major addition of agricultural lands would not come until after Emil Svitzer took over the estate in 1879 (Staples 1998). Between 1886 and 1889 Emil expanded the ELP's holdings to include an additional 106 acres of the southeast adjacent EGR (GDWII 1892, 1905). These increased holdings, still located well south of any of ELP's extant structures, gave Svitzer the capacity to deploy his large labor force to work and develop these newly acquired fields to the south. As a result, ELP soon reached its highest ever levels of acres kept in sugarcane, with an increased from 97 to 130 acres noted between 1879 and 1889, and a steady rise upwards before hitting its zenith in 1893 with a total of 229 acres kept in sugarcane in that year (GDWII 1892, 1905).

Several photographs dating to the Svitzer era of the plantation (1879 through 1933) also provide us with glimpses into the conditions of the area to the north, west, and east of the African laborer's village during that time, suggesting that in contrast to space found elsewhere on the plantation, this was an area that seemingly went unkempt, largely left in timberlands, brush, or bush. Though focused in on the African laborer's village, one photograph also shows a row of palm trees, likely delineating the nearby roadway (Little Princess Road), off in the distance to the northwest, presumably also depicting the northwestern boundary of the village itself (Figure 9290). Another photograph, Figure 92, is particularly revealing as it depicts the area adjacent east of the laborer's village as covered in hardwoods. This third image from the Svitzer era gives us a view of what vegetation within the northeastern portion of the plantation would have looked like around the turn of the twentieth century (Figure 92). Based on the caption on this photograph, and an understanding of the ELP's Palm Grove location from the papers of the

granddaughter of Emil Svitzer, this photograph depicting “Emil Svitzer (On Horseback) and Guests in the Little Princess Palm Grove” suggests it was likely taken roughly 100 m to 150 m south by southeast or possibly due east of the current study’s ST 12 (Staples 1998). The palm trees in the background of this picture suggest a somewhat manicured landscape, with the palms forming a “grove” which, under Svitzer family ownership, ran along the eastern boundary of the plantation, separating the ELP from the eastern coastline with approximately 25 m of palm trees (Staples 1998). In the foreground of this photograph however, we also see where the palm grove meets the more unkempt flora of the northern half of the plantation. Though it is difficult to make out individual plant species in this photograph, small brush plants, and what looks to be a Seagrape tree (to the left) are prominent in the image.

After the Svitzer period, there is little written or depicted regarding land uses for the area examined through excavations at ST 3 through ST 12, effectively speaking volumes about its relative disuse. When Clayton and Opal Shomaker purchased the plantation in the 1940s, they did much to refurbish the great houses, and estate records detail the Shomaker’s clearing of the area to the south and east of the great houses (Figure 86). Throughout the Shomaker’s ownership of the plantation, there is no documentation suggesting that they did anything to clear or otherwise manage the area to the north of the great houses and to the north and east of the (then former) African laborer’s village. All that is known from this time is that the area occupied by the ruins of the laborer’s village went largely unmanaged, causing it to be reclaimed by the brush, bush, and smaller hardwoods that had persisted to the north and northeast of the village throughout the plantation’s active use.

Figure 92. Photograph entitled “Emil Svitzer (On Horseback) and Guests in the Little Princess Palm Grove” facing east. Photograph by unknown, taken circa 1879 or later. Image from TNC’s ELP photograph collection, compiled by Dr. George Tyson from the vertical files at the St. Croix Historical Landmarks Society Archive at Whim Plantation.

After the Shoemakers donated the plantation to the TNC in 1977, the northern reaches of the plantation remained relatively untouched. The nonprofit focused on the refurbishment of the great houses, the installation of solar panels, development of a waste-water recycling pond, and the construction of a coral reef lab and nursery to the northeast of the great house complex (Harty 2003). With the small exception of a narrow nature trail which runs through the northern and eastern reaches of the former plantation, the TNC to this day has never clear cut the plantation's northern portion (Richard Gideon, personal communication, 2022).

Ultimately the historic record suggests that the portion of the plantation to the north and east of the African laborer's village was left in timber or bush, or at the very least, left largely uncleared and undeveloped since the start of the Danish Period (1733) through the present. This narrative is strongly corroborated by the geochemical and geophysical signatures observed within the shovel tests examined in this area. As revealed through the significantly, and universally, lower PO4 levels found in this portion of the ELP's primary hillslope (when compared with those found within the African laborer's village) this area was certainly not occupied or developed to the same extent as the African laborer's village (Wells 2006, Eidt 1984). Furthermore, this area overall appears to have been a far more stable landscape than that of the African laborer's village, as the stratigraphy here showed numerous signs of stability and soils development *in situ* (consisting of the presence of B horizons, in some cases the presence of well-developed B, Bk, or B to C transition horizons, gradual changes in color and texture between strata, and organic carbon content levels, pH levels, and PO4 concentration levels which generally dropped with increases in depth) despite lying on the slope of a hill (Garrison 2016, Holliday 2004, Birkeland 1999, Bockheim 2014).

There are two main reasons why this portion of the ELP might have been deliberately left in timber, bush, or secondary growth throughout the Danish colonial period (1733 – 1917). The first reason is that timber on St. Croix was valuable. Though St. Croix was largely in a dense tropical forest of mahogany and cedar when the Danish took possession of the island, the rapid and widespread adoption of sugarcane monoculture on the island, encouraged the clearcutting of these forests to make room for large, open, tillable tracts for sugarcane planting. Portions of the island outside of plantations were also cleared to make way for roads, cities, houses, and churches. Wood was still plentiful in the 1730s and 40s and was even harvested on island for use in the construction of tall ships (Lawaetz 1980:90). As more of the island underwent development in the latter half of the eighteenth century and throughout the nineteenth century, timber continued to become scarcer. As a result, planters, and even outright prospectors, would purchase large parcels, sometimes with interests strictly in the timber on the estate (Lawaetz 1980). Once the profitable and or useful trees had been felled and sold off, many investors would simply sell the estate to someone who sought to use the cleared land to grow sugar. In other cases, more long-term investors would clear the land entirely, save for the larger trees, and then use the remaining timber to build the structures needed to run a sugar estate. Even if planters would use some of the timber on lands they purchased, it was so valuable that wood surpluses were often sold off at a tremendous profit, sometimes to purchasers from other neighboring islands including St. Christophe, Montserrat, Nevis, St. Martin, Tortola, and other islands where timber was even more scarce. According to some estimates, planters at this time could receive a price ten, twenty, or even thirty times more for the timber on some of these estates, than the

initial cost of the estate (Lawaetz 1980:90). It is likely some planters opted to delay this windfall, and instead chose to leave surplus lumber in the ground, keeping the trees as an asset that could be held on to as an investment for future sale. With timber serving as a much-desired commodity on island, it is quite possible that the northern portion of ELP was deliberately kept in timber by plantation managers to either provide a future windfall, or to help secure lumber in times of need for construction projects on the estate itself.

The second reason why the northern portion of the ELP might have been deliberately left in timber, bush, or secondary growth throughout the estate's sugar planting era might be so that resources within this forested area could be harvested. While enslaved and later freed African laborers on the plantation were perhaps given small plots for gardens, and provided with some form of rations, or later after emancipation, payment to purchase their own foodstuffs, some plantation lands may have been deliberately left undeveloped to provide fertile hunting and foraging grounds which could be used to supplement laborers' subsistence (Hosbey and Roane 2021, Roane 2018, Berleant-Schiller and Pulsipher 1986). Suitable mammalian fauna for hunting that were present on island during the historic period included white-tailed deer (*odocolleus virginlanus*), feral goats (*capra aegagrus hircus*), and hogs (*sus scrofa domesticus*). Supplemental nutrition might have also been found amongst edible flora known to grow in St. Croix which might have been allowed to persist in a patch of undeveloped land, including genip (*melicocca bijugata*), papaya (*carica papaya*), seagrape (*coccoloba uvifera*), mangos (*mangifera indica*), soursop (*annona muricata*), banana figs (*ficus pleurocarpa*), breadfruit (*artocarpus altillis*), tamarind (*tamarindus indica*), and avocado (*persea americana*). In this way, the maintenance of timberlands, bush, or at least a segment of undeveloped land, might have served an important role on ELP. Providing an additional source of foodstuffs for the population living within the plantation's African Village, land set aside for this purpose would have supplemented regular rations. During periods of European colonial conflict in the region, timberlands such as those found on ELP would have potentially offered sources of much needed nutrition to enslaved and later freed laborer populations which might have otherwise been subject to starvation due to wartime shortages. This certainly would have been the case during the Napoleonic Wars (1801 – 1815), where Denmark was allied with France against Britian. As a result of these conflicts, the Danish West Indies were occupied by Great Britan twice, once in 1801 – 1802, and 1807 – 1815 (Sheridan 1973).

Transect 2

The Lands Kept in Sugarcane

The stratigraphy observed within the shovel tests excavated within the southern transect for this project (ST Uphill Pond 2 through Swamp 1) contained signs which alluded to a history of stability and soil development *in situ* (Figure 84, Figure 86, and Figure 87) (Appendix C, Appendix D, and Appendix E). Generally, areas marked by erosion exhibit abrupt and stark contrasts between strata, which would have been caused by the water or wind-based movement of topsoil and more recently deposited sediments further down slope before the percolation of rainwater through the soils could encourage the movement of finer grain particles and soil/sediment borne chemicals down the soil column (Garrison 2016, Holliday 2004). In this way profiles that endured significant levels of erosion are expected to have both abrupt transitions between strata, and a great deal of heterogeneity between adjacent strata (Karkanas and Goldberg 2018). On the contrary, the strata examined in ST Uphill Pond 2, Uphill Pond 1, Downhill Pond

1, Downhill Pond 2, and ST Swamp 1, all exhibited gradual transitions between each stratum, as well as only gradual changes in soil color, inclusions, and texture, between strata. Several of these shovel tests also revealed profiles consisting of relatively large A, B, Bt, Bk, and C horizons (when compared with strata observed within the project's northern transect), which were separated by gradual transitions (Appendix E). In some cases, these transitions took place over the span of 5 cm or more (and in some instances even exceeding spans of 10 cm or more), which enabled for the bulk sampling of the transitions themselves. These large and gradual transitions suggest that the strata here have developed *in situ* because they are clearly well-formed interfaces which lie between distinct strata (Garrison 2016, Birkeland 1999, Bockheim 2014). This demonstrates that the soil column here has been given sufficient time to meaningfully and noticeably interact with, and develop, with each other, through either particles and inclusions of deposited sediments having had time to seep into strata below, and or, other pedogenic processes (such as the chemical and physical weathering of parent material and the percolation of grain particles and water-soluble molecules). While some level of sheet erosion, caused by rainwater traversing down the area's subtle slope (which tilts downward to the northeast), may have transpired over the span of this stratigraphy's evolution, the transitions between the strata found in the southern portion of ELP do not exhibit signs of a particularly volatile past.

Phosphate concentrations within observed soils in all STs tested in southern transect also suggested that this portion of the plantation was a relatively stable environment, with PO4 levels which generally decreased with increases in depth down the soil column (Appendix E). This suggests longer term pedogenic processes have taken place here, which would have required a stable environment over a longer term. Translocation, water percolation, and leeching of phosphates from higher strata have determined the PO4 concentrations within successively deeper strata in this area (Garrison 2016, Holliday 2004, Birkeland 1999, Bockheim 2014, Holliday and Gartner 2007). The phosphate concentrations found within the southern transect also suggested that this portion of the plantation was relatively nutrient rich when compared with areas of the plantation tested to the north of the African laborer's village. With observed B horizon phosphate levels within ST Uphill Pond 2 (0.27 mg/L), ST Downhill Pond 1 (0.21 mg/L), and Swamp 1 (0.73 mg/L) at least as high, or higher than those observed within the B horizons examined within the plantation's timberlands, soil conditions in this portion of the plantation appear to, at present, be relatively phosphate rich and likely more capable of supporting sustained agriculture than those found in the northern portion of the ELP (Appendix E).

Two sets of radiocarbon dates provided by land snail shells and charcoal found within ST Uphill Pond 2 and ST Uphill Pond 1, also inform the histories of soil development within the southern transect. Two land snail shells collected from ST Uphill Pond 2, one from 20 cmbs within the B horizon and one from 28 cmbs, just slightly lower in the B horizon dated to 1261 AD ±24 years and 74 AD ±48.5 years respectively. Cognizant of a snail's ability to move throughout a soil column while alive we must be cautious in our interpretation of these radiocarbon dates (Banning 2020, Holliday 2004, Taylor 2014, Ramey et al. 2021, Osborne and Wright 2018). Nonetheless, when coupled with other evidence within ST Uphill Pond 2's profile, which included relatively deep soil horizons, and gradual geochemical and geophysical transitions between each observed strata, these radiocarbon dates paint the picture of a relatively stable landform with a long time depth of soil formation processes. While it is possible that some sporadic episodes of topsoil

erosion played a role in the development of these soils by removing loose soils at the top of the horizon, thereby retarding the processes of soil development in the location, the presence of gradual textural and color transitions between the A, B, Bk, and C horizons within ST Uphill Pond 2 strongly suggest the slow *in situ* development of local stratigraphy.

The two radiocarbon samples collected from ST Uphill Pond 1 were both pieces of charcoal. One piece of charcoal was retrieved from 15 cmbs (within the top of the B horizon) and dated to 1870 AD (±68 years), and the other was found at a depth of 47 cmbs and dated 256 BC (±48 years). With only 32 cm separating pieces of charcoal deposited approximately 1,614 years apart amidst well developed, B and Bk horizons with a gradual transition between them, the radiocarbon dates contribute to an interpretation of a very slowly developing soil profile and a relatively stable landform. While it is possible that erosion took place here in the past, and that it even might have played a role in the retardation of local soil development (potentially leading to apparently slow rate of soil growth we are seeing in the profile), these erosive events do not seem to have ever been intense enough or long enough in duration to entirely disrupt natural pedogenic processes.

Cartographic, photographic, and other archival evidence reveals that the area examined through the excavation of shovel tests in the southern transect was part of a much larger area of the plantation which was kept in sugarcane, likely since the earliest days of Danish rule over St. Croix. Sugar planting had been the intended purpose of ELP since its founding by its first Danish owners, Fredrick Moth and Peter Heyliger in the 1740s. By the mid-eighteenth century, maps of the island show fields on ELP kept in sugarcane, which included virtually all plantation lands south of the estate's great house (Figure 88). Oxholm's 1799 *Map of St. Croix* also depicts the location of sugarcane fields on ELP nearly 50 years later, showing organized and mapped out acreage used for sugarcane planting to the south of the plantation's later built L-shaped sugar factory (Figure 88).

Photographs from the Svitzer era (1879 – 1933) also depict this portion of the plantation as being kept in sugarcane. In Figure 89, which consists of a plantation overview taken from a point well south of the ELP's sugar factory (and potentially even, taken from the mill or other structure located on the Estate Golden Rock Property to the ELP's adjacent southeast) facing northwest, the current study's southern shovel test transect is depicted in the background as covered in rows of mature sugarcane stocks (Figure 89). In Figure 93, which is a photograph taken from a point to the northwest of Figure 89, and facing the northeast, towards the plantation's factory, the southern transect area is again depicted, showing soils formed into managed furrows where sugarcane plants have either been recently harvested, or where they will likely be planted again soon. Lastly, the photograph in Figure 94 is taken from an angle quite like that of Figure 93 but also perhaps 200 m or so closer to the plantation's sugar factory. This photograph also shows the area examined by the southern transect as covered in mid-growth stage or mature sugarcane plants, sometime between 1879 and 1933.

Figure 93. Photograph entitled "Estate Little Princess #1980 DEEP VII," facing northeast, from southwest of ELP's Sugar Factory. Photograph by unknown, likely taken circa 1879 or later. Image from TNC's ELP photograph collection, compiled by Dr. George Tyson from the vertical files at the St. Croix Historical Landmarks Society Archive at Whim Plantation.

Figure 94. Photograph entitled "Estate Little Princess #1981 DEEP VII," facing northeast. Photograph by unknown, likely taken circa 1879 or later. Image from TNC's ELP photograph collection, compiled by Dr. George Tyson from the vertical files at the St. Croix Historical Landmarks Society Archive at Whim Plantation.

Island wide sugar production records, and compiled estate papers (including probate records and tax records) which document the ELP annual acreage kept in sugarcane during the mid to late nineteenth and early twentieth centuries, show increases upon, or at least maintenances of previous years' sugar production levels (GDWII 1892, 1905, Staples 1998, Tyson N.D.) support the idea that sugarcane cultivation continued within the area examined in the southern transect throughout the Svitzer period, with little interruption. With noted numbers of acres kept in sugarcane cultivation, starting at 100 acres in 1862, and increasing to as many as 229 acres in 1893, it is likely that all previously developed areas kept in sugar, and especially those closest to the plantation's sugar factory (such as those within the present study's southern transect) were continuously put to use each year to ensure profitable rates of sugar production, perhaps right up until the plantation's closure in the early-twentieth century.

While the area kept in sugarcane on ELP, like the African laborer's village and the timberlands, has been reclaimed by local secondary growth since the cessation of sugar cultivation on site, this area's known land use history enables us to interpret the geophysical and geochemical properties observed within these soils as outputs of nearly two centuries of sugarcane planting. The younger of the two radiocarbon samples collected from St Uphill Pond 1 (taken from 15 cmbs) in particular, provides us with an approximate date for the B horizon in the area around 1870 AD, which lies well within the period when this area was actively and intensively kept in sugarcane. The B horizon in which this radiocarbon datable piece of charcoal was found, was noted to possess both heterogeneity with, and gradual transitions between, both the A horizon above it and the Bk horizon below it, both of which are signs of relative stability and soil development *in situ* (Garrison 2016, Holliday 2004, Birkeland 1999, Bockheim 2014). Perhaps most significantly, this dated B horizon within ST Uphill Pond 1 was also noted as having a relatively high PO4 concentration (when compared with those found in the B horizons of STs within the northern portion of the northern transect), suggesting that the soils that were used for sugar planting may well today be an even more nutrient rich environment for future plant growth than those areas examined on plantation within ands kept in timber (Holliday and Gartner 2007, Wells 2006, Eidt 1984). While it is possible that ST Uphill Pond 1's B horizon possesses relatively high PO4 levels as a result of the anthropogenic addition of soil amendment or manure during the plantation era, or that these heightened PO4 concentrations are a result of the area's subsequent occupation of secondary growth following the abandonment of the sugarcane fields, the fact remains that this B horizon appears to have a history of relatively stable development *in situ* over an extended period of time, and that its present day phosphate concentrations (a good indicator of soil nutrient health) are greater than those found in other B horizons examined in the northern reaches of the ELP.

Final Thoughts

The goal of this geoarchaeological investigation was to examine the stratigraphic conditions of the ELP and to interpret these conditions against the plantation's known land use to understand the long-term impacts of sugar planting and other land uses on the ELP. Following in the footsteps of Dr. Christian Wells and his colleagues who have conducted similar investigations at Betty's Hope plantation in Antigua, this article describes the methods employed in, and the results found through, several lines of investigation on the soils of the ELP to help develop a spatial and temporal understanding of local sediment aggradation, soil development, stability, degradation, and, in some cases, nutrient accretion and depletion as a consequence of human activities across the plantation (Wells et al. 2017, Wells et al. 2018, Waters 1992:91, Pratt

2015:86, Tricarico 2019). By comparing the present-day conditions of the soils observed within different land use areas on the ELP, we are now well situated to consider the comparative long-term ramifications of using portions of the ELP for three different land uses: the construction, maintenance of, and habitation of the African laborer's village, the keeping and managing of timberlands, and the intensified agricultural pursuit of sugarcane cultivation.

Overall, the soils within the African laborer's village can be said to have developed amidst a history of volatility. Through its initial clearance, sometime in the 1730s or 40s, the development of permanent structures (with stone foundations) by at least 1750, and the continued occupation and maintenance the top of the ELP's primary hillslope until the middle of the twentieth century, the soils within this portion of the plantation were continuously exposed to the forces of rainsplash damage, sheet erosion, and topsoil compaction (i.e. through human and animal foot traffic) which would have led to the additional, and more easily achieved erosion of loose soils in the future. These anthropogenic impacts on the soils in this area have left its stratigraphy with little to no observable B horizon. The recent return of secondary growth to the area (after the village's abandonment), has however, started to repair this damage, adding an organic rich, and now far more stable, A horizon over this once occupied area. It is also clear that over the span of its extended use as a laborer's village, its occupants introduced large amounts of phosphates into the soils, through the deposition of food waste and potentially human waste. The legacy of this land use lives on today, with the soils tested here showing the highest PO4 concentrations (higher even, than this study's analytical equipment could detect) found anywhere on the plantation.

To the north and east of the African Village, soils underneath lands that were kept in timber, or at least left undeveloped and in bush, demonstrated signs of stability, and long-term development *in situ*, as well as some evidence of the deposition of sediments from further uphill. While perhaps subject to some timber harvesting and clearing efforts during the plantation's initial development, and on occasions large construction projects and or African Village expansion, the soils in this area have been left to largely develop via natural pedogenic processes such as the chemical and physical weathering of parent material and of organic and inorganic matter that accretes at the ground surface. The exceptions here, are the soils developed from previously deposited sediments found within the portion of the plantation just downslope of either the African laborer's village or the relic ghut observed on the side of the primary hillslope (Figure 84, Figure 86, and Figure 87). In the former case (ST 0 to ST 3) we see anthropogenically induced (or at least encouraged) deposits of materials eroded from the African Village area. Since the mid-twentieth century, dense secondary growth has retaken the African Village site uphill, resulting in the cessation, or at least dramatic reduction of the deposits of loose sediments further down the hillslope. In the latter case (ST4 to ST 6), we see evidence of intense rainstorm (perhaps even hurricane) and or flooding induced depositional events. Here there are no fewer than 3 distinct alluvial deposits on top of a relic B horizon dated via radiocarbon to 577 AD ±26 years) which suggests that this area was subject to these kinds of sedimentary depositions throughout its development since the end of the sixth century. The relic ghut which lies just south of, and upslope of ST 4 was observed to have been dry for some time as well, with twentieth century residential development noted just upstream of ST 4 to the west of the ELP's property line.

Observed phosphate levels within the estate's former timberlands were found to be considerably lower than those found in the African laborer's village, and do not suggest a history of deliberate soil amendment or manuring, nor one of human occupation (Appendix E). If the phosphate levels and organic carbon content levels observed within the relic B horizon of ST 4 can be considered to serve as an indicator of "" or "natural" soil conditions, prior to the establishment of the plantation, it is noteworthy that the B horizon observed across the timberlands portion of the plantation appears to be relatively nutrient rich, with considerably higher PO4 concentrations and higher organic carbon content levels, than those observed within the relic B horizon, implying a net gain achieved throughout the plantation's active use, in the form of increases in concentrations of phosphate, nitrogen, and sulfur, elements necessary for healthy plant growth.

By far the most significant finding of this study pertains to the observed conditions of the soils found in the area of the plantation that was kept in sugarcane for nearly 200 years. Since the early 1900s historians, archaeologists, and natural scientists have suggested that sugar planting is the cause of the poor environmental conditions currently seen throughout the Caribbean (Ragatz 1928, Crosby 1972, Mintz 1986, Grove 1996, Watts 1990, Meniketti 2015, Fox 2016, Pratt 2015). While many of these scholars hold, "little doubt that the effect of sugarcane on the environment… has been overwhelming negative," the results from the present geoarchaeological investigation at the ELP do not echo this understanding (Watts 1990:533). The soils examined within the portion of ELP that were known to be kept in sugarcane were among the most stable examined across the plantation. Exhibiting deep strata, gradual transitions between strata, and heterogeneity between strata, the colors and textures of the soils found within the area kept in sugarcane strongly suggested a history of long-term landscape stability and *in situ* soil development. Despite the intensive agricultural activities that we know to have taken place in the area between the early to mid-eighteenth and early twentieth centuries, which included initial clearing, ploughing, furrow construction, harvesting, tilling, and replanting, we see in these soils evidence of the movement of finer grain particles and soil/sediment borne chemicals down the soil's profile, suggesting that these soils remained in the same location long enough to enable the gradual sorting of these particles into deeper portions of the soil column via the percolation of rain water.

Admittedly, this is not to say that the ELP's sugarcane fields experienced no erosion at all during the plantation's active use. Low phosphate concentrations found in the area's A horizon, followed by an increase in phosphates observed within the B horizon, followed by a decrease in the C horizon would be the signature of a stable soil profile. Decreases in the phosphate concentrations observed between the area's A and B horizon, however, suggest that some force has acted upon local soil development to prevent the natural accumulation of phosphates within the B horizon (Appendix E). Similar patterns were also observed in the organic carbon content levels within the A, B, and C horizon of this area, which also suggests a level of volatility in the area's soil development. These signs all allude to some other force or forces having acted upon local soils which resulted in erosion and or the disruption of natural accretions of organic material within the area's B horizon. Against the backdrop of an overall relatively stable developmental history, it is not surprising to see some signs of volatility in the area given what is known about sugarcane planting practices on St. Croix. Consisting of land clearance, tilling, the addition of soil amendment, crop maintenance, sugarcane harvesting, intercrop clearing and tilling, and replanting, the intensive cycle of sugarcane planting had key moments, where local soils would have been quite susceptible to rainsplash damage and subsequent sheet erosion. Just

after harvesting, during intercrop periods, or in the months where new sugarcane was still taking root, would have been times of vulnerability for the soils in the area. Rainstorms during these vulnerable moments, would have had considerably greater ability to transport soils downslope.

It must also be recalled that during the overwhelming majority of the sugarcane plant's lifecycle, young and fully grown sugarcane provide a robust level of ground surface protection, rivaling that provided by natural hardwood growth on the island (Renard et al. 1991). Furthermore, sugar planters on St. Croix are known to have had work crews leave sugarcane "trash" on the fields after harvesting, a practice which would have afforded local soils some level of protection to severe damage from rainsplash and erosion (Chapters 2 through 5). Given the overall stable conditions of the soils found within the area previously kept in sugarcane on ELP, it would seem that rainsplash damage and soil loss due to sheet erosion were issues that were reasonably well managed, even during the plantation era, by the ground cover afforded to soils by both mid-growth stage and mature sugarcane plants, and through the use of "cane trash" during the intercrop periods.

It should also be noted, that while decreases in phosphate concentrations between the A and B horizon were noted within shovel tests ST Uphill Pond 2 through ST Swamp 1, the PO4 concentrations observed within the A and B horizons within these shovel tests are on the whole markedly higher than those found within the soils of the portion of the plantation that was kept in timber (Appendix E). As a result, even though the PO4 concentrations in these shovel tests insinuate that some level of soil disturbance has transpired over the history of the soil's development, the lands kept in sugarcane cannot be said to be stripped of nutrients vital to plant growth. Subjected to year after year of intensified sugarcane monocropping, this area's soils are just as, or even slightly more, nutrient rich than other soils on the plantation which had not been subjected to sugar cultivation, nor any other significant form of anthropogenic manipulation or development throughout the historical period.

Given that current soil conditions observed within the area formerly used to grow sugarcane appear relatively good, with relatively high phosphate levels, well developed B horizons, and a stratigraphy suggesting a relatively stable past, but aware of the terrible reputation sugar plantations have in terms of soil preservation and soil health, we are left to consider the "Abandoning the Garden" hypothesis as the reason why soilscapes in the vicinity of past sugar plantations are in such poor condition across the Caribbean. First posited by Chelsea Fischer in 2005 the "Abandoning the Garden" hypothesis puts forward the idea that "the abandonment of an intensive, anthropomorphized landscape dependent on labor for stability contributes directly to environmental degradation" (Fischer 2005:89). From ethnographic and photographic records, we know that sugarcane planting in St. Croix was an extensive and deliberate long-term investment in, and a development of landesque capital to maximize agricultural production (Chapters 3, 4, 5, 7, and 9).

While the initial clearing of a field for sugarcane planting would have been traumatic to local soils, these be would cane fields were the heavily and intentionally developed. They were ploughed, tilled, and worked into furrows, often by enslaved or free African laborers making use of hand hoes, shovels, and rakes. These furrows measured between 1 and 2 ft (0.30 – 0.61 m) wide, by .5 to 2 ft (0.15 – 0.61 m) in height, and were often placed along local contour lines to help reduce soil loss. Next, sugarcane buds (chopped and cured from last season's harvest)

would be planted within each furrow, and covered with soil. Once sprouted, these sugarcane plants were well looked after, with the rows of plants regularly weeded, and with occasional additions made into the soil in the form of soil amendment or manuring. At harvest time (some 15 – 17 months later), African laborers chopped sugarcane stocks down near their bases and removed the cane tops with machetes. At this time each stock's leaves were also removed. These leaves and stock tops, known collectively as "cane trash" were then deliberately left on the fields to protect the soil (and to keep weeds down) during the intercrop period. Within a few months, the whole process would begin again, and the field would be tilled and ploughed once more, so that the furrows could be rebuilt, and new young and cured cane buds could again be planted. Though perhaps making many demands of the soils in each phase, beyond the erosion encouraged by the initial clearing of a sugarcane field, successfully managed sugarcane fields may have actually retained local soils, and managers may have kept them reasonably well nourished. This would have of course, aligned with the goal of sugarcane plantations in the first place, which was to have healthy and well-maintained fields that would produce the absolute maximum amount of sugarcane per annum.

Stable, if not occasionally improving, sugar production levels are reflected within available historical records from the late nineteenth century and turn of the twentieth century which detail the amount of sugar produced on ELP during that time. *Statistics Concerning Sugar Production in St. Croix from 1862 – 1889* shows that between 1862 and 1889, the average area ELP had in sugarcane amounted to 155 acres (GDWII 1892). The sugarcane planted on these acres yielded some 133 hogshead (39,900 liters) of muscovado sugar, resulting in an average of 0.86 hogshead (258 liters) of muscovado sugar, per acre per year. A second average, taken from just between 1880 and 1889, suggests that the estate owned an average of 149 acres that were kept in sugarcane, which produced an average of 157 hogshead (47,100 liters) of muscovado sugar a year. The resulting average yield per acre kept in sugarcane was considerably higher (1.06 hogshead or 318 liters), showing that sugarcane yields had actually improved on a per acre basis, in the second decade of the study. *Statistics Concerning Sugar Production in St. Croix from 1890 – 1902*, similarly gives us insight into the productivity of the ELP's soils. In 1890 the ELP averaged 1.5 hogshead (450 liters) of muscovado sugar, per acre per year (GDWII 1905). A stark drop off was noted the following three years, in 1891, 1892, and 1893, but these were undoubtedly related to the notably lower rainfalls in 1890 and 1892, which each saw more than 10 inches less of rain per year than St. Croix's annual average (GDWII 1905). Similarly, poor rains were also noted during 1899, where again, more than 10 inches of rain less than the island's annual average fell on ELP. Omitting these years where poor sugar yields are attributable to poor rains rather than soil health, ELP's average sugar yield amounted to 0.94 hogshead (282 liters) per year during the 1890s. Of particular note, the annual average sugar per acre yielded in 1902 (the last year of the study) was among the highest ever recorded, hitting a level of 1.42 hogshead (426 liters) per acre. Altogether, these late nineteenth century records of ELP's sugar production show us that while the yield of muscovado per acre per year did not always rise from year to year on the plantation, a strong, relatively stable, and at times, improving average yield was sustained for some forty years of intensified sugar production. Far from showing signs of degradation and nutrient depletion, yearly per acre yield averages at ELP suggest that when the sugarcane fields were well maintained with reasonably high levels of soil health, along with reasonably high per acre outputs which could be achieved for decades.

These archival findings, combined with the geoarchaeological data found through this study, which suggest that there were relatively stable soil conditions and the development of soils *in situ* within ELP's sugarcane fields during the plantation era, lend credence to the idea that the investments made into the soils on ELP to maximize sugarcane yields effectively created a stable or even sustainable landscape during its period of use. Unfortunately, there is no mention in any available records pertaining to ELP that reveal precisely when and how the sugarcane fields on ELP were decommissioned. Presumably, mature sugarcane was harvested one last time in the late 1920s or early 1930s, and then each field was abandoned, to be taken over by secondary growth. If this were the case, the soils within these sugarcane fields would have been without any ground cover and totally exposed throughout what might have been an extensive interim period, spanning some six months to several years before secondary growth could reach and take hold of a particular field. While intercrop periods for fields within the ELP during the planting era would have lasted no more than a few months (and would have been mitigated by the use of "cane trash" to cover the soils), this extended exposure at the time of the sugarcane fields' abandonment would have made soils particularly susceptible to the forces of solar radiation (i.e. heat) which has the ability to dehydrate and crack soils leading to a loss of soil structure and stability, and precipitation (i.e. rainsplash damage and sheet erosion), which has the ability to pry particles loose from the soil matrix, and transport them down slope in the event of an intense or prolonged rainstorm.

While no direct geoarchaeological evidence of this potentially traumatic abandoning event was encountered during the examination of ELP's soils, it is quite possible that this violent moment in ELP's soil history, is covered up by the modern A horizon found across the entire plantation during this study. Relatively rich in organic carbon content, phosphates, and root matter, and forming a relatively thick stratum, this A horizon, has developed since after the end of the sugarcane era on ELP, having been ushered in by the lush secondary growth that has taken over the plantation since the mid-twentieth century. Consisting of brush and bushes, smaller hardwoods and sansevieria, the plantation's landscape today must be identified as one characterized not just by the land use practices of the eighteenth, nineteenth, and twentieth centuries, but also one that has been heavily defined by the plant cover and above ground conditions of the middle and late twentieth and early twenty-first centuries. While there is some observable degradation of ELP's soils attributable to anthropogenic activities from the plantation's period of active use (especially in the vicinity of the African laborer's village) the overall conditions of the soils today cannot be attributed to plantation agriculture alone. Instead, with its ubiquitous and dense secondary growth, the ELP's soil health must be understood as a complex mosaic of human-environmental interactions which may include the abandonment of a deliberately intensified landscape (Pratt 2015:10).

Existing scholarship has identified the long-term pursuit of intensified sugarcane agriculture as the cause for soil degradation across the Caribbean but this study's findings contrast with this conventional wisdom, serving as a case study where the soils within an area kept in sugarcane agriculture for nearly 200 years appear to, today, be relatively organic carbon content and phosphate rich, and show signs of long-term stability and development *in situ* (Ragatz 1928, Sheridan 1960, Watts 1990, Fox 2016, Wells et al. 2017, Pratt 2015). As such, this research challenges archaeologists, historians, and environmental scientists to place additional emphasis on the study of specific and sudden changes in the types of human activities which take place on a given landscape. Rather than strictly pursuing a study of the *longue durée* of a given study

area, it might also be worth focusing on more narrow punctations which may be abrupt, (relatively) short-term, yet extensive instances of change which have the potential to cause dramatic and defining alterations in environmental systems and their future trajectories (Crumley 1987, 1994, Walsh 2004, Balée 1998, Dunne and Leopold 1978). In the case of the Caribbean in particular, this study shows that it may be worthwhile to focus on the environmental changes which came following the abandonment of sugar plantations, as these may have been among some of the most volatile periods in that area's history of land use.

Chapter 12. Conclusion: The Environmental Legacy of Sugar Planting in St. Croix, US Virgin Islands

What Investigations were Conducted?

This dissertation has explored the long-term impacts of sugarcane agriculture during the eighteenth, nineteenth, and twentieth centuries on the hydrological and soil systems of the island of St. Croix. Motivated by troubling scientific reports which lay bare the dire environmental circumstances which face the island, and the Caribbean region more broadly, this research looked for evidence that might support or refute the long held hypothesis that intensified sugar planting are to blame for the poor environmental conditions of today (USGCRP 2018, VIWRRI 2012, Craig 2018, Rawlins et al. 1998, Febles-González et al. 2012, Madramootoo et al. 1990, Madramootoo and Norville 1993, Metternicht et al. 2010, Ragatz 1928, Crosby 1986, Grove 1996, Mintz 1986, Watts 1990). Taking inspiration from recent works of Caribbean archaeology and history which have highlighted initial land clearing, water management, and various types of land uses associated with sugar planting as capable of having had significant and detrimental impacts to Caribbean environments, the present study examined ethnographic, ethnohistoric, archival, cartographic, topographic, archaeological, paleoenvironmental, and geological data to find evidence that might directly link the outcomes of centuries of intensified sugarcane agriculture and the region's current environmental conditions (Meniketti 2015, Fox 2016, Pratt 2015, Wells et al. 2017, Tricarico 2019, Siegel 2018, Wallman et al. 2018, Pulsipher 1977, Pulsipher and Goodwin 2001, Ezcurra and Rivera-Collazo 2018, Delle 1994).

Consisting of three distinct but interrelated lines of interdisciplinary research, the investigations presented within this dissertation include ethnographic and ethnohistoric investigations into colonial era sugar planting practices on the island and their potential for, and perceived relationship to, long-term environmental impacts (Chapters 1 through 5). It also involved the archaeological survey of colonial era water management features on plantations across the island, as well as a characterization of the different forms of water use which took place on active sugar plantations on St. Croix (Chapters 6 through 8). Incorporating the findings of these efforts, I then develop a water balance model for the Estate Little Princess (ELP) during its active use as a sugarcane plantation between the 1730s and the early-twentieth century to demonstrate the tremendous water deficit which plantations on St. Croix likely incurred over the span of nearly two-hundred years of sugar planting (Chapter 9). Lastly, I pursued a geoarchaeological investigation on the ELP to identify and interpret observable geochemical and geophysical attributes found in the soils across the ELP as clear links between present soil conditions and specific types of human activities which are known to have taken place in various locations across the plantation during its active use (Chapters 10 and 11).

What is the Environmental Legacy of Sugar Planting on the Island of St. Croix?

The results from the project's ethnographic interviews provided unexpected answers (Chapters 1, 2, 3, and 5). Ethnographic interviews were predominantly held in the Summer of 2022, at a time when St. Croix was experiencing an acute drought. While this drought may have played a role in the reasoning behind every interviewee identifying a lack of sufficient water to support their crops as their primary environmental concern. It was surprising to hear from the overwhelming majority of interviewees that they largely attributed this lack of water to an island wide lack of sufficient water catchments, water management, and water conservation efforts. Interviewees never mentioned the possibility that there was a connection between the centuries-long and

widespread adoption of intensified sugarcane agriculture on island and the current lack of water and did not vocalize making these connections even when prompted by the deliberate asking of questions suggesting the possibility of a connection between the two concepts. When asked instead, what they thought the current lack of water could be attributed to, interviewees readily made references to the inadequate maintenance of the island's series of water detention ponds which had been constructed by the Virgin Islands Department of Agriculture in the earlier part of the twentieth century. Almost every farmer interviewed also reported to have relied upon water contained and conveyed from these ponds at one point or another and suggested that the ponds' being allowed to fail was particularly damaging to local agricultural and pastoral pursuits during a drought. As a result, the biggest takeaway from this ethnographic research proved to not be about sugarcane's impact on the environment at all, but instead focused on the realization that while the information shared by project interviewees may not corroborate nor entirely refute conventionally understood connections between past sugarcane planting and current environmental conditions, the understandings being shared by Crucians represented, if not outright furtive understandings of local environmental conditions and their causes, then at the very least expressions of values and concerns regarding water resources and their management which run counter to those held by governmental agencies, developers, and contemporary scientific researchers (Hosbey and Roane 2021, Roane 2018, Roane and Hosbey 2019). As a result, what began as an ethnographic investigation into the sugarcane-based causes of present-day environmental conditions on St. Croix transformed into an exploration into the space between the narratives presented in prevailing historical literature and contemporary scientific studies, and local understandings of environmental conditions and their antecedents. In this way, the project's ethnographic results shed light on heretofore neglected perspectives on acutely felt water stresses, and demonstrate that from local perspectives increased funding of, and increased governmental oversight on, the maintenance of already extent water management infrastructure and retention ponds and water catchments is a readily applicable solution to at least part of the island's pressing water concerns.

The ethnographic investigation as well as the ethnohistoric research conducted also revealed a great deal about specific sugar planting practices on St. Croix and their potential to impact the environment. Project interviewees with firsthand knowledge of sugarcane planting suggested that the cane was grown in furrows and was strictly rain fed (not irrigated). It was also revealed that these furrows were placed along contour lines of local topography (a now commonly recommended soil conservation strategy). A proprietor of 300 acres of sugarcane in the 1940s, 50s, and 60s, also suggested that he left "cane trash" (or the trimmed/pruned leaves of sugarcane that are discarded during harvest) on the field deliberately to suppress weeds, and that sugarcane was allowed to ratoon (a form of runner-based procreation) between harvests for periods of five to seven years before it had to be freshly replanted with cuttings from harvested mature plants (Hans Lawaetz, personal communication, 2022). Both of these practices are understood to be potential conservation practices available to, and frequently recommended to, modern day farmers as "cane trash" is known cover and protect agricultural fields from rainsplash damage and the choice to ratoon plants prevents the fields from having to be tilled and loosened for replanting.

The ethnohistoric examination of the John Delano 1941 and 1942 US Farm Security Administration (FSA) photograph collection also yielded key details about cane planting traditions on the island, with images depicting the crop as universally planted in furrows

measuring between one and two feet (0.30 – 0.61 m) wide by 0.5 to two feet (0.15 – 0.61 m) in height (Chapter 4). "Cane trash" was notably absent within each of the Delano photographs which depicted cane fields in sufficient detail to reveal ground surface inclusions. Though seemingly running contrary to Mr. Lawaetz's description of the use of "cane trash," it is quite possible that the practice of leaving "cane trash" on the fields was either only for a duration, and thus absent from photographs of fields that had been harvested more than a few weeks or month ago, and, or not practiced by all cane planters on the island. Furthermore, the absence of large piles of ash or charcoal, and or soil discolorations in any of the Delano photographs which might suggest the presence of ash or charcoal, suggest that "cane trash" was neither burned off while still on the plant, nor burned in the field once removed from the cane stalks in the cane fields of St. Croix. These two details taken together strongly suggest that the local practice consisted of the physical removal of "cane trash" by field laborers during cane harvests. In this case the removal of leaves and other debris from the cane stock might have been completed *in situ* but cleaned up by hand during the harvest, or the separation of stock from leaves might have been deferred until the cane was either about to be loaded onto the cart, or once the cane had arrived at the location where it would be juiced. This absence of "cane trash" on the fields suggests that at least early to mid-twentieth century sugarcane planters on the island did not take advantage of this low tech but potent natural tool to help fight rainsplash damage to their cane field soils. Moreover, the absence of charcoal and ash from the depicted fields also suggests that fire was not a tool frequently used by cane planters on the island, and that local cane fields were not likely to be frequently replenished by nutrients commonly found in plant ashes including magnesium, calcium, potassium, and phosphorus.

The results from the project's archaeological survey of colonial era water management features on plantations across St. Croix revealed a great deal about water use on colonial era sugar plantation settings (Chapters 6 and 7). Taken as a whole the details collected from the ruins of 13 water management features identified on six former sugar plantations located across the island demonstrated how these features can be understood to "represent a colonial coming-to-terms with unfamiliar physical environments, the recognition of possibilities and limitations to settlement [and sugar planting], and the adaptation of technologies to local circumstances" (Lawrence and Davies 2012:47). Viewed through this lens, the recorded features' sizes, requirements of labor for construction, and universal utilization of ad-hoc and utilitarian construction materials (including locally cut and broken limestone, locally produced plaster, and Danish brick, once used as ballast on ships traveling to the island from the home country), reveal that plantation managers on the island would go to great lengths in order to obtain additional water access and storage capacity on a relatively dry island to support their agricultural efforts (Shaw 1933).

Through the investigation of the types of sugar planting related water management features found on St. Croix, which included stone-lined wells, wind driven water towers, plaster lined cisterns, a windmill converted to a cistern, a water driven sugarcane mill, a water "flume" (or aqueduct) a dripstone, and two coarse earthenware water carrying jugs, we were then well situated to characterize the different forms of water use on colonial era plantations in St. Croix. Ultimately four categories of sugar plantation water use were identified including water consumed by or otherwise used by humans, water consumed by draft animals and cattle, water used in sugar processing, and the water required for use in sugarcane agriculture (Chapter 8). Making use of these four categories of water use, and by identifying scientifically and

historically derived estimates for the quantity of water regularly required for each of the four identified categories of plantation water uses Chapter 9 developed a water balance model to estimate the quantities of water that sugar plantations would have required to sustain the ELP sugar plantation in the eighteenth, nineteenth, and early-twentieth centuries. This model incorporated historically recorded precipitation records for the island, details from the plantation's land use history (i.e. acres kept in sugarcane), and cotemporary scientific estimates of human, animal, and sugarcane water requirements, to reveal key components of the relationship between sugar planting in St. Croix and the water resources available on the island. Ultimately the outputs produced by the ELP water balance model revealed a great deal about historic water use on ELP. Importantly, they revealed the disproportionate amount of water demanded by sugarcane cultivation itself compared to the needs of humans and livestock on ELP. This was most apparent in the model years of 1772 to 1779. During these years the plantation was understood to have the highest number of humans and livestock on plantation, yet the amount of water required to sustain these populations still represented considerably less than 1% of the water needed to support the plantation's 133 acres of sugarcane kept during the same period.

Perhaps the most significant findings from the ELP water balance model, however, were its projected discrepancies between the amounts of water introduced into the plantation's water system annually through rainfall and the amounts of water estimated to be required for the successful cultivation of the acres kept in sugarcane on the plantation each year. Estimates of the annual deficit at which sugarcane was cultivated ranged from -46.71 to -854.97 million gallons (or -176.84 to -3,236.43 million liters) per annum (using the Davis 2003 estimate for sugarcane water needs) and -6.87 to -176.97 million gallons (-26.04 to -669.94 million liters) per annum (using Deerr's 1905 estimate for sugarcane water needs), even during years of above average rainfall. While the Kingshill Aquifer, which underlies the plantation, may have supplemented the estate's sugarcane related water needs, the aquifer's recharge rate, estimated at a maximum of 3% of annual rainfall, would be clearly insufficient to offset the plantation's annual water deficit (USGS 2016a, CADMUS 2011). These findings strongly suggest that prolonged drawdowns on the reserves of the Kingshill Aquifer have likely contributed to the long-term and irreparable degradation of freshwater resources in the area, including perhaps the aquifer's contamination by seawater (VIWRRI 2012).

Lastly, through the geoarchaeological investigation of the soils found across the ELP, this dissertation developed a nuanced understanding of how different sugarcane era land uses have impacted the area's soil systems (Chapters 10 and 11). Within an area of the plantation known to be used as an African laborer's village, we found relatively high phosphate concentrations, which reflect the area's extended history of human occupation (stemming from the repeated deposition of food and human waste) (Holliday and Gartner 2007). Furthermore, soils in this area showed clear geophysical signs of extended human induced disturbance including clearance, construction, and foot traffic. These anthropogenic activities resulted in erosion (as evinced by the absence of, or presence of only nascent, B horizons in the area) and soil compaction (which in turn encouraged further erosion). Despite these setbacks, secondary plant growth, which has taken root since the village's abandonment in the early to mid-twentieth century, is leading toward the formation of a more stable, and organic-rich A horizon, while slowly beginning to encourage the development of a B horizon.

In portions of the plantation where historic records show that the land was deliberately kept in timber and or bush, we found signs of stable and *in situ* development. Soils in this area were characterized by more well physically and geochemically defined and well-developed A, B, and C horizons, and evidence of sedimentary deposition caused by erosion which had taken place further upslope, and flooding events within a small ghut which runs through the northern portion of the plantation. Containing markedly lower phosphate levels than the African Village, it seems that this portion of the estate remained unoccupied during the plantation era, and that no deliberate manuring took place here. While perhaps subject to some timber harvesting and clearing efforts during the plantation's initial development, and on occasions of large construction projects and or African Village expansion, the evidence gleaned from soils analyses in this area suggest that it was left largely undisturbed during the colonial period enabling its soils to develop via natural pedogenic processes including chemical and physical weathering of parent material and regular inclusion of organic and inorganic matter that accretes at the ground surface within a sub-tropical woodland.

By far the biggest takeaway from the geoarchaeological investigation, however, were the results from the soils analyses of portions of the plantation that are thought to have been kept in sugarcane agriculture for nearly two centuries. While historians, archaeologist, and natural scientists have suggested that sugar planting is the cause of the poor environmental conditions currently seen throughout the Caribbean, soils in this area were among the most stable examined across the plantation (Ragatz 1928, Crosby 1972, Mintz 1986, Grove 1996, Watts 1990). Excavations in this portion of the plantation revealed deep strata, gradual transitions between strata, and heterogeneity between strata, all strong indicators of a history of long-term landscape stability and *in situ* soil development. Geochemically we also found signs of stability, including soils where organic carbon content increased between the A and B horizons, showing that organic materials (and likely minerals and other soil particles) have been moved by processes of translocation and the percolation of water down the intact soil profile, and phosphate levels which generally decreased with increases in depth down the soil column. Moreover, from a soil nutrient health perspective, phosphate concentrations in the sugarcane growing area's B horizons, were found to be greater than those from the B horizons examined in any other portion of the plantation. Despite the extensive agricultural activities conducted in the area from the early-eighteenth to the early-twentieth centuries, including clearing, ploughing, furrow construction, sugarcane planting, maintenance, harvesting, tilling, and replanting, the soils on the plantation used for sugarcane planting appear to have been relatively stable, and are in relatively good condition for future agricultural use.

In light of these results, we are left to strongly consider Chelsea Fischer's "abandoning the garden" hypothesis, which states that the fashion in which an agricultural pursuit is abandoned may be more so responsible for the cause of localized environmental degradation than the agricultural pursuit itself (Fischer 2005:89). Geoarchaeological study at the ELP supports the notion that post-plantation era abandonment, rather than sugar planting practices themselves, might have contributed to the observed soil degradation now observed across the Caribbean. During their operation, plantations like ELP actively invested in soil stability and fertility. From the ethnographic and ethnohistoric research detailed in Chapters 1 through 5 we know that Crucian sugar planters had access to and likely made use of several low tech but effective soil conservation techniques including contour farming, the development and maintenance of furrows (which could channelize and detain excess water), the use of "cane trash" as a line of defense for

loose soils against rainsplash damage, and the practice of ratooning sugarcane plants, rather than total plant removal and replanting after harvests, sparing the soils of sugarcane fields from undue tilling and exposure to damage from wind and rain. Furthermore, it should be recalled that during the overwhelming majority of the sugarcane plant's lifecycle, mid-growth stage and mature sugarcane provide a robust level of protection to an area's ground surface against rainsplash damage and erosion, rivaling that provided by natural hardwood growth that would have been found elsewhere on the island (Renard et al. 1991).

The premise that soil retention and soil health were prioritized and deliberately maintained by plantation owners is corroborated by available historical records of sugarcane production on ELP. Rates of sugar production on a per acre per year basis remained stable if not sometimes improved on ELP throughout the late eighteenth and early nineteenth centuries, increasing from an average 0.86 hogshead (258 liters) per acre between 1862 to 1889 to an average of 1.06 hogsheads (318 liters) per acre between 1880 and 1890, and an average 0.94 hogsheads (224 liters) per acre between 1890 and 1902 (GDWII 1892, 1905). While this is not to say that the ELP's sugarcane fields experienced no erosion at all during initial clearing, planting, tilling, and severe rainstorm events, these archival findings, combined with the geoarchaeological data found through this study suggest that there were relatively stable soil conditions and the development of soils *in situ* within ELP's sugarcane fields during the plantation era.

Unfortunately, available records pertaining to the ELP do not specify when or how the sugarcane fields were decommissioned. Presumably they were abandoned after a final harvest in the late 1920s or early 1930s. Following the abandonment, but prior to the full takeover of secondary growth, the soils would have been exposed for an extended period of time, likely ranging from several months to years, making them vulnerable to solar radiation, and rainsplash damage which could result in soil degradation, such as cracking, dehydration, and erosion until secondary growth reclaimed the area. Although no direct geoarchaeological evidence of this abandonment event was found during the present geoarchaeological investigation, it is possible that the modern A horizon rich in organic carbon, phosphates, and root matter, now covering this portion of the plantation, masks the impacts of this abandonment period disturbance. As this A horizon possesses extremely high organic carbon content, as well as considerable root matter, it is clear that it has been heavily influenced by the now present secondary growth which consists of brush, bushes, smaller hardwoods, and sansevieria. As a result, it is important to appreciate that the plantation's landscape today is characterized by both the land use practices of the sugar planting era as well as the area's more recent environmental history. While there is evidence of soil degradation from plantation-era activities, especially within the African Village area, the current soil conditions found across ELP reflect a complex interaction of human-environmental factors, including the abandonment of an intensely cultivated landscape (Pratt 2015:10).

Future Directions and Opportunities for Further Investigation

Given the unanticipated results from this study's ethnographic investigation, future researchers and policy advocates could further the goals of Crucian agriculturalists, pastoralists, and environmental activists by continuing to shed light on their neglected perspectives on water stressors and their historical antecedents, as well as their overlooked and ignored suggestions for solutions and requests for more regular and substantial government assistance (Atalay 2006, Marshall 2002, Little and Shackel 2007, Flewellen et al. 2021). More direct investigations into the lack of funding for water related public works, and the current state of insufficient

governmental oversight for the maintenance of existing water management infrastructure may also be warranted to call further attention to the root causes of these issues and to identify possible remedies to these systemic issues (Agbe-Davies 2010:172). Simultaneously, future ethnographers may also seek to continue to explore the complex disconnect between local perceptions and understandings of environmental stressors and those held by government agencies and research scientists (Rivera-Collazo et al. 2018, Hosbey and Roane 2021, Roane and Hosbey 2019). Comparative ethnographic studies across other Caribbean islands that have experienced similar agricultural intensification in the more distant past could potentially highlight regional differences in how local populations perceive environmental challenges like water scarcity and their root causes. These studies could also examine how local knowledge informs contemporary water management strategies, offering a more integrated view of the intersection between community practices and environmental governance (Roane 2018, Roane and Hosbey 2019).

Future research could also build on the findings of this dissertation by exploring the broader regional impacts of sugarcane agriculture on the hydrological systems of Caribbean islands. While this study focused specifically on St. Croix and demonstrated the tremendous capacity for sugarcane agriculture to negatively impact freshwater resources it may be worth exploring the hydrological consequences of sugar planting on other Caribbean islands with either similar or quite different climatic and geological conditions. Comparative studies could develop water balance models similar to the one developed for the ELP and apply them to plantations on other islands where sugarcane agriculture and historical precipitation records are well documented. Such works could help refine our understanding of the water management challenges faced by specific sugar plantations and the long-term ecological consequences of sugarcane planting practices, providing a more comprehensive picture of how colonial agricultural practices shaped the Caribbean's environmental history and present (Sheridan 1960, Fox 2016, Delle 1994, Meniketti 2015, Pulsipher 1977).

Lastly, I would suggest that future research be dedicated to the examination of the "abandoning the garden hypothesis" as it may apply to the abandonment of sugarcane plantations (Fischer 2005). While much of the existing scholarship suggests that the long-term pursuit of intensified sugarcane agriculture is the cause for the soil degradation presently observed across much of the Caribbean the current study contrasts with this conventional wisdom, and provides a case where the soils within an area kept in sugarcane agriculture for nearly 200 years appear to, today, be comparatively rich in organic carbon content and phosphate, and show signs of long-term stability and development *in situ* (Ragatz 1928, Sheridan 1960, Watts 1990, Fox 2016, Wells et al. 2017, Pratt 2015). As such, this research challenges future environmentally minded archaeologists, historians, and scientists to place additional emphasis on the study of specific and sudden changes in the types of human activities which take place on a given landscape. Rather than pursuing works focused on the *longue durée* of a given study area, focus on narrower punctations, which may be abrupt, yet significant, instances of change, may be warranted (Crumley 1987, 1994, Walsh 2004, Balée 1998, Dunne and Leopold 1978). In the case of the Caribbean in particular, this study shows that the period of sugar plantation abandonment may be particularly worthy of geoarchaeological study, as this fairly brief time frame may have the potential to be among the most volatile periods in the history of a plantation's soil development.

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Appendix A. Annual Water Balance Model for Estate Little Princess

Table A-1. ELP Water Balance Model

Year (yr)	Average Annual Rainfall (inch/yr)	Acres Kept in Sugar at ELP	Total Gallons of Rain per Year Falling on All Acres Kept in Sugar (rate of 1 inch/acre= 27,154 gallons)	Number of White Occupants or Laborers on ELP	Number of Enslaved or Free African Laborers on ELP	Total Gallons of Water Used by Humans on Property Per Year	Number of Livestock on Property (Based on ratios presented in Table 4)			Total Gallons of Water Used by Livestock on Property per Year	Water Required for Acres Kept in Sugarcane per Year in Gallons using Davis 2003 Estimate (13,997 gallons/acre/ day)	Water Required for Acres Kept in Sugarcane per Year in Gallons using Deerr 1905 Estimate (4,901 gallons/acre/ day)	Total Water lost to Evapotranspiration per acre per Year based on Vincente et al. 2013 Estimate (67 gallons per acre per day)	Modeled Annual Water Balance for ELP Using Davis 2003 Estimate in Gallons	Modeled Annual Water Balance for ELP Using Deerr 1905 Estimate in Gallons
							Cows/Oxen	Horses/Donkeys	Sheep/Goats/Pigs						
1739	46	0	0	3	10	2,256	14	5	9	101,642	0	0	0	-103,897	-103,897
1740	46	0	0	3	10	2,256	14	5	9	101,642	0	0	0	-103,897	-103,897
1741	46	0	0	3	10	2,256	14	5	9	101,642	0	0	0	-103,897	-103,897
1742	46	0	0	3	10	2,256	14	5	9	101,642	0	0	0	-103,897	-103,897
1743	46	0	0	13	50	10,738	56	21	42	419,480	0	0	0	-430,218	-430,218
1744	46	12	14,881,763	13	50	10,738	56	21	42	419,480	61,306,860	21,466,380	293,460	-47,148,775	-7,308,295
1745	46	25	31,003,673	20	78	16,676	104	33	65	729,507	127,722,625	44,721,625	611,375	-98,076,511	-15,075,511
1746	46	25	31,003,673	20	78	16,676	104	33	65	729,507	127,722,625	44,721,625	611,375	-98,076,511	-15,075,511
1747	46	25	31,003,673	20	78	16,676	104	33	65	729,507	127,722,625	44,721,625	611,375	-98,076,511	-15,075,511
1748	46	25	31,003,673	20	78	16,676	104	33	65	729,507	127,722,625	44,721,625	611,375	-98,076,511	-15,075,511
1749	46	25	31,003,673	20	78	16,676	104	33	65	729,507	127,722,625	44,721,625	611,375	-98,076,511	-15,075,511
1750	46	50	62,007,345	28	110	23,462	147	46	92	1,027,661	255,445,250	89,443,250	1,222,750	-195,711,778	-29,709,778
1751	46	50	62,007,345	28	110	23,462	147	46	92	1,027,661	255,445,250	89,443,250	1,222,750	-195,711,778	-29,709,778
1752	46	50	62,007,345	28	110	23,462	147	46	92	1,027,661	255,445,250	89,443,250	1,222,750	-195,711,778	-29,709,778
1753	46	50	62,007,345	28	110	23,462	147	46	92	1,027,661	255,445,250	89,443,250	1,222,750	-195,711,778	-29,709,778
1754	46	50	62,007,345	28	110	23,462	147	46	92	1,027,661	255,445,250	89,443,250	1,222,750	-195,711,778	-29,709,778
1755	46	75	93,011,018	28	110	23,462	147	46	92	1,027,661	383,167,875	134,164,875	1,834,125	-293,042,105	-44,039,105
1756	46	75	93,011,018	20	77	16,532	103	33	65	725,036	383,167,875	134,164,875	1,834,125	-292,732,549	-43,729,549
1757	46	75	93,011,018	20	77	16,532	103	33	65	725,036	383,167,875	134,164,875	1,834,125	-292,732,549	-43,729,549
1758	46	75	93,011,018	20	77	16,532	103	33	65	725,036	383,167,875	134,164,875	1,834,125	-292,732,549	-43,729,549
1759	46	75	93,011,018	20	77	16,532	103	33	65	725,036	383,167,875	134,164,875	1,834,125	-292,732,549	-43,729,549
1760	46	100	124,014,691	26	101	21,621	135	43	85	948,635	510,890,500	178,886,500	2,445,500	-390,291,565	-58,287,565
1761	46	100	124,014,691	26	101	21,621	135	43	85	948,635	510,890,500	178,886,500	2,445,500	-390,291,565	-58,287,565
1762	46	100	124,014,691	26	101	21,621	135	43	85	948,635	510,890,500	178,886,500	2,445,500	-390,291,565	-58,287,565
1763	46	100	124,014,691	26	101	21,621	135	43	85	948,635	510,890,500	178,886,500	2,445,500	-390,291,565	-58,287,565
1764	46	100	124,014,691	26	101	21,621	135	43	85	948,635	510,890,500	178,886,500	2,445,500	-390,291,565	-58,287,565

Year (yr)	Average Annual Rainfall (inch/yr)	Acres Kept in Sugar at ELP	Total Gallons of Rain per Year Falling on All Acres Kept in Sugar (rate of 1 inch/acre= 27,154 gallons)	Number of White Occupants or Laborers on ELP	Number of Enslaved or Free African Laborers on ELP	Total Gallons of Water Used by Humans on Property Per Year	Number of Livestock on Property (Based on ratios presented in Table 4)			Total Gallons of Water Used by Livestock on Property per Year	Water Required for Acres Kept in Sugarcane per Year in Gallons using Davis 2003 Estimate (13,997 gallons/acre/ day)	Water Required for Acres Kept in Sugarcane per Year in Gallons using Deerr 1905 Estimate (4,901 gallons/acre/ day)	Total Water lost to Evapotranspiration per acre per Year based on Vincente et al. 2013 Estimate (67 gallons per acre per day)	Modeled Annual Water Balance for ELP Using Davis 2003 Estimate in Gallons	Modeled Annual Water Balance for ELP Using Deerr 1905 Estimate in Gallons
							Cows/Oxen	Horses/Donkeys	Sheep/Goats/Pigs						
1766	46	130	161,219,098	29	114	24,310	152	48	95	1,064,906	664,157,650	232,552,450	3,179,150	-507,206,918	-75,601,718
1767	46	130	161,219,098	29	114	24,310	152	48	95	1,064,906	664,157,650	232,552,450	3,179,150	-507,206,918	-75,601,718
1768	46	130	161,219,098	29	114	24,310	152	48	95	1,064,906	664,157,650	232,552,450	3,179,150	-507,206,918	-75,601,718
1769	46	130	161,219,098	29	114	24,310	152	48	95	1,064,906	664,157,650	232,552,450	3,179,150	-507,206,918	-75,601,718
1770	46	130	161,219,098	29	114	24,310	152	48	95	1,064,906	664,157,650	232,552,450	3,179,150	-507,206,918	-75,601,718
1771	46	130	161,219,098	29	114	24,310	152	48	95	1,064,906	664,157,650	232,552,450	3,179,150	-507,206,918	-75,601,718
1772	46	133	164,939,539	36	141	30,104	188	59	118	1,315,657	679,484,365	237,919,045	3,252,515	-519,143,102	-77,577,782
1773	46	133	164,939,539	36	141	30,104	188	59	118	1,315,657	679,484,365	237,919,045	3,252,515	-519,143,102	-77,577,782
1774	46	133	164,939,539	36	141	30,104	188	59	118	1,315,657	679,484,365	237,919,045	3,252,515	-519,143,102	-77,577,782
1775	46	133	164,939,539	36	141	30,104	188	59	118	1,315,657	679,484,365	237,919,045	3,252,515	-519,143,102	-77,577,782
1776	46	133	164,939,539	36	141	30,104	188	59	118	1,315,657	679,484,365	237,919,045	3,252,515	-519,143,102	-77,577,782
1777	46	133	164,939,539	36	141	30,104	188	59	118	1,315,657	679,484,365	237,919,045	3,252,515	-519,143,102	-77,577,782
1778	46	133	164,939,539	36	141	30,104	188	59	118	1,315,657	679,484,365	237,919,045	3,252,515	-519,143,102	-77,577,782
1779	46	133	164,939,539	36	141	30,104	188	59	118	1,315,657	679,484,365	237,919,045	3,252,515	-519,143,102	-77,577,782
1780	46	133	164,939,539	33	131	27,848	175	55	110	1,225,323	679,484,365	237,919,045	3,252,515	-519,050,512	-77,485,192
1781	46	133	164,939,539	33	131	27,848	175	55	110	1,225,323	679,484,365	237,919,045	3,252,515	-519,050,512	-77,485,192
1782	46	133	164,939,539	33	131	27,848	175	55	110	1,225,323	679,484,365	237,919,045	3,252,515	-519,050,512	-77,485,192
1783	46	133	164,939,539	33	131	27,848	175	55	110	1,225,323	679,484,365	237,919,045	3,252,515	-519,050,512	-77,485,192
1784	46	133	164,939,539	33	131	27,848	175	55	110	1,225,323	679,484,365	237,919,045	3,252,515	-519,050,512	-77,485,192
1785	46	133	164,939,539	33	131	27,848	175	55	110	1,225,323	679,484,365	237,919,045	3,252,515	-519,050,512	-77,485,192
1786	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1787	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1788	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1789	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1790	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1791	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1792	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1793	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1794	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1795	46	138	171,140,274	26	102	21,766	136	43	85	953,106	705,028,890	246,863,370	3,374,790	-538,238,278	-80,072,758
1796	46	139	172,380,420	29	113	24,166	151	48	95	1,060,435	710,137,795	248,652,235	3,399,245	-542,241,220	-80,755,660
1797	46	139	172,380,420	29	113	24,166	151	48	95	1,060,435	710,137,795	248,652,235	3,399,245	-542,241,220	-80,755,660

Year (yr)	Average Annual Rainfall (inch/yr)	Acres Kept in Sugar at ELP	Total Gallons of Rain per Year Falling on All Acres Kept in Sugar (rate of 1 inch/acre= 27,154 gallons)	Number of White Occupants or Laborers on ELP	Number of Enslaved or Free African Laborers on ELP	Total Gallons of Water Used by Humans on Property Per Year	Number of Livestock on Property (Based on ratios presented in Table 4)			Total Gallons of Water Used by Livestock on Property per Year	Water Required for Acres Kept in Sugarcane per Year in Gallons using Davis 2003 Estimate (13,997 gallons/acre/ day)	Water Required for Acres Kept in Sugarcane per Year in Gallons using Deerr 1905 Estimate (4,901 gallons/acre/ day)	Total Water lost to Evapotranspiration per acre per Year based on Vincente et al. 2013 Estimate (67 gallons per acre per day)	Modeled Annual Water Balance for ELP Using Davis 2003 Estimate in Gallons	Modeled Annual Water Balance for ELP Using Deerr 1905 Estimate in Gallons
							Cows/Oxen	Horses/Donkeys	Sheep/Goats/Pigs						
1798	46	139	172,380,420	29	113	24,166	151	48	95	1,060,435	710,137,795	248,652,235	3,399,245	-542,241,220	-80,755,660
1799	46	139	172,380,420	29	113	24,166	151	48	95	1,060,435	710,137,795	248,652,235	3,399,245	-542,241,220	-80,755,660
1800	46	139	172,380,420	29	113	24,166	151	48	95	1,060,435	710,137,795	248,652,235	3,399,245	-542,241,220	-80,755,660
1801	46	139	172,380,420	29	113	24,166	151	48	95	1,060,435	710,137,795	248,652,235	3,399,245	-542,241,220	-80,755,660
1802	46	139	172,380,420	29	113	24,166	151	48	95	1,060,435	710,137,795	248,652,235	3,399,245	-542,241,220	-80,755,660
1803	46	139	172,380,420	29	113	24,166	151	48	95	1,060,435	710,137,795	248,652,235	3,399,245	-542,241,220	-80,755,660
1804	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1805	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1806	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1807	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1808	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1809	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1810	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1811	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1812	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1813	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1814	46	139	172,380,420	32	127	27,000	170	53	106	1,186,863	710,137,795	248,652,235	3,399,245	-542,370,483	-80,884,923
1815	46	106	131,455,572	21	82	17,524	110	35	69	772,439	541,543,930	189,619,690	2,592,230	-413,470,551	-61,546,311
1816	46	110	136,416,160	21	82	17,524	110	35	69	772,439	561,979,550	196,775,150	2,690,050	-429,043,403	-63,839,003
1817	46	110	136,416,160	21	82	17,524	110	35	69	772,439	561,979,550	196,775,150	2,690,050	-429,043,403	-63,839,003
1818	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1819	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1820	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1821	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1822	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1823	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1824	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1825	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1826	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1827	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1828	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1829	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945

Year (yr)	Average Annual Rainfall (inch/yr)	Acres Kept in Sugar at ELP	Total Gallons of Rain per Year Falling on All Acres Kept in Sugar (rate of 1 inch/acre= 27,154 gallons)	Number of White Occupants or Laborers on ELP	Number of Enslaved or Free African Laborers on ELP	Total Gallons of Water Used by Humans on Property Per Year	Number of Livestock on Property (Based on ratios presented in Table 4)			Total Gallons of Water Used by Livestock on Property per Year	Water Required for Acres Kept in Sugarcane per Year in Gallons using Davis 2003 Estimate (13,997 gallons/acre/ day)	Water Required for Acres Kept in Sugarcane per Year in Gallons using Deerr 1905 Estimate (4,901 gallons/acre/ day)	Total Water lost to Evapotranspiration per acre per Year based on Vincente et al. 2013 Estimate (67 gallons per acre per day)	Modeled Annual Water Balance for ELP Using Davis 2003 Estimate in Gallons	Modeled Annual Water Balance for ELP Using Deerr 1905 Estimate in Gallons
							Cows/Oxen	Horses/Donkeys	Sheep/Goats/Pigs						
1830	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1831	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1832	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1833	46	75	93,011,018	21	82	17,524	110	35	69	772,439	383,167,875	134,164,875	1,834,125	-292,780,945	-43,777,945
1834	46	90	111,613,222	17	68	14,420	91	29	57	639,173	459,801,450	160,997,850	2,200,950	-351,042,772	-52,239,172
1835	46	90	111,613,222	17	68	14,420	91	29	57	639,173	459,801,450	160,997,850	2,200,950	-351,042,772	-52,239,172
1836	46	90	111,613,222	17	68	14,420	91	29	57	639,173	459,801,450	160,997,850	2,200,950	-351,042,772	-52,239,172
1837	46	90	111,613,222	17	68	14,420	91	29	57	639,173	459,801,450	160,997,850	2,200,950	-351,042,772	-52,239,172
1838	46	90	111,613,222	17	68	14,420	91	29	57	639,173	459,801,450	160,997,850	2,200,950	-351,042,772	-52,239,172
1839	46	90	111,613,222	17	68	14,420	91	29	57	639,173	459,801,450	160,997,850	2,200,950	-351,042,772	-52,239,172
1840	46	88	109,132,928	18	70	14,980	94	30	59	660,639	449,583,640	157,420,120	2,152,040	-343,278,371	-51,114,851
1841	46	88	109,132,928	18	70	14,980	94	30	59	660,639	449,583,640	157,420,120	2,152,040	-343,929,852	-51,766,332
1842	46	88	109,132,928	18	70	14,980	94	30	59	660,639	449,583,640	157,420,120	2,152,040	-343,278,371	-51,114,851
1843	46	88	109,132,928	18	70	14,980	94	30	59	660,639	449,583,640	157,420,120	2,152,040	-343,278,371	-51,114,851
1844	46	88	109,132,928	18	70	14,980	94	30	59	660,639	449,583,640	157,420,120	2,152,040	-343,278,371	-51,114,851
1845	46	88	109,132,928	18	70	14,980	94	30	59	660,639	449,583,640	157,420,120	2,152,040	-343,278,371	-51,114,851
1846	46	90	111,613,222	14	56	11,876	75	24	47	527,374	459,801,450	160,997,850	2,200,950	-350,928,428	-52,124,828
1847	46	92	114,093,516	15	58	12,435	78	25	49	548,840	470,019,260	164,575,580	2,249,860	-358,736,879	-53,293,199
1848	46	92	114,093,516	15	58	12,435	78	25	49	548,840	470,019,260	164,575,580	2,249,860	-358,736,879	-53,293,199
1849	46	92	114,093,516	15	58	12,435	78	25	49	548,840	470,019,260	164,575,580	2,249,860	-358,736,879	-53,293,199
1850	46	92	114,093,516	15	58	12,435	78	25	49	548,840	470,019,260	164,575,580	2,249,860	-358,736,879	-53,293,199
1851	46	92	114,093,516	15	58	12,435	78	25	49	548,840	470,019,260	164,575,580	2,249,860	-358,736,879	-53,293,199
1852	47	92	118,563,053	15	58	12,435	78	25	49	548,840	470,019,260	164,575,580	2,249,860	-354,267,341	-48,823,661
1853	54	92	135,300,779	15	58	12,435	78	25	49	548,840	470,019,260	164,575,580	2,249,860	-337,529,615	-32,085,935
1854	53	92	133,548,939	15	58	12,435	78	25	49	548,840	470,019,260	164,575,580	2,249,860	-339,281,456	-33,837,776
1855	50	92	126,013,839	19	74	15,828	99	31	62	692,263	470,019,260	164,575,580	2,249,860	-346,963,371	-41,519,691
1856	37	92	93,440,851	19	74	15,828	99	31	62	692,263	470,019,260	164,575,580	2,249,860	-379,536,359	-74,092,679
1857	51	66	91,050,892	19	74	15,828	99	31	62	692,263	337,187,730	118,065,090	1,614,030	-248,458,958	-29,336,318
1858	45	66	80,483,845	19	74	15,828	99	31	62	692,263	337,187,730	118,065,090	1,614,030	-259,026,005	-39,903,365
1859	44	66	78,803,691	19	74	15,828	99	31	62	692,263	337,187,730	118,065,090	1,614,030	-260,706,159	-41,583,519
1860	43	100	115,971,340	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-398,361,287	-66,357,287
1861	59	100	159,295,547	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-355,037,080	-23,033,080

Year (yr)	Average Annual Rainfall (inch/yr)	Acres Kept in Sugar at ELP	Total Gallons of Rain per Year Falling on All Acres Kept in Sugar (rate of 1 inch/acre= 27,154 gallons)	Number of White Occupants or Laborers on ELP	Number of Enslaved or Free African Laborers on ELP	Total Gallons of Water Used by Humans on Property Per Year	Number of Livestock on Property (Based on ratios presented in Table 4)			Total Gallons of Water Used by Livestock on Property per Year	Water Required for Acres Kept in Sugarcane per Year in Gallons using Davis 2003 Estimate (13,997 gallons/acre/ day)	Water Required for Acres Kept in Sugarcane per Year in Gallons using Deerr 1905 Estimate (4,901 gallons/acre/ day)	Total Water lost to Evapotranspiration per acre per Year based on Vincente et al. 2013 Estimate (67 gallons per acre per day)	Modeled Annual Water Balance for ELP Using Davis 2003 Estimate in Gallons	Modeled Annual Water Balance for ELP Using Deerr 1905 Estimate in Gallons
							Cows/Oxen	Horses/Donkeys	Sheep/Goats/Pigs						
1862	41	100	111,837,143	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-402,495,483	-70,491,483
1863	34	100	92,177,647	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-422,154,979	-90,150,979
1864	39	100	107,180,232	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-407,152,394	-75,148,394
1865	49	100	134,167,914	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-380,164,713	-48,160,713
1866	46	100	125,648,347	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-388,684,280	-56,680,280
1867	47	100	126,388,293	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-387,944,334	-55,940,334
1868	38	100	102,333,243	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-411,999,383	-79,995,383
1869	48	100	129,378,627	26	104	22,055	139	44	87	974,572	510,890,500	178,886,500	2,445,500	-384,953,999	-52,949,999
1870	51	98	136,041,685	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-368,144,677	-42,780,757
1871	35	98	93,816,798	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-410,369,554	-85,005,634
1872	32	98	84,655,989	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-419,530,363	-94,166,443
1873	30	98	78,595,352	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-425,591,000	-100,227,080
1874	48	98	127,975,241	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-376,211,112	-50,847,192
1875	31	98	81,436,068	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-422,750,284	-97,386,364
1876	36	98	94,871,256	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-409,315,096	-83,951,176
1877	49	98	129,841,331	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-374,345,021	-48,981,101
1878	57	98	150,950,444	30	117	25,014	156	49	98	1,092,058	500,672,690	175,308,770	2,396,590	-353,235,909	-27,871,989
1879	68	97	177,879,710	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-320,432,720	1,611,160
1880	41	97	108,952,845	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-389,359,585	-67,315,705
1881	58	97	152,383,191	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-345,929,239	-23,885,359
1882	44	97	116,238,976	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-382,073,454	-60,029,574
1883	48	97	126,817,539	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-371,494,900	-49,451,020
1884	44	97	115,534,398	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-382,778,032	-60,734,152
1885	46	97	119,913,320	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-378,399,110	-56,355,230
1886	54	97	142,357,764	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-355,954,666	-33,910,786
1887	48	97	125,938,453	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-372,373,977	-50,330,097
1888	57	97	149,722,913	10	39	8,338	52	17	33	368,172	495,563,785	173,519,905	2,372,135	-348,589,517	-26,545,637
1889	55	130	192,478,753	10	73	13,252	98	31	61	686,576	664,157,650	232,552,450	3,179,150	-475,557,875	-43,952,675
1890	30	148	121,583,528	19	73	15,683	98	31	61	686,576	756,117,940	264,752,020	3,619,340	-638,856,011	-147,490,091
1891	50	195	266,406,197	19	73	15,683	98	31	61	686,576	996,236,475	348,828,675	4,768,725	-735,301,262	-87,893,462
1892	35	188	179,305,058	19	73	15,683	98	31	61	686,576	960,474,140	336,306,620	4,597,540	-786,468,881	-162,301,361
1893	56	229	347,756,526	19	73	15,683	98	31	61	686,576	1,169,939,245	409,650,085	5,600,195	-828,485,173	-68,196,013

Year (yr)	Average Annual Rainfall (inch/yr)	Acres Kept in Sugar at ELP	Total Gallons of Rain per Year Falling on All Acres Kept in Sugar (rate of 1 inch/acre= 27,154 gallons)	Number of White Occupants or Laborers on ELP	Number of Enslaved or Free African Laborers on ELP	Total Gallons of Water Used by Humans on Property Per Year	Number of Livestock on Property (Based on ratios presented in Table 4)			Total Gallons of Water Used by Livestock on Property per Year	Water Required for Acres Kept in Sugarcane per Year in Gallons using Davis 2003 Estimate (13,997 gallons/acre/ day)	Water Required for Acres Kept in Sugarcane per Year in Gallons using Deerr 1905 Estimate (4,901 gallons/acre/ day)	Total Water lost to Evapotranspiration per acre per Year based on Vincente et al. 2013 Estimate (67 gallons per acre per day)	Modeled Annual Water Balance for ELP Using Davis 2003 Estimate in Gallons	Modeled Annual Water Balance for ELP Using Deerr 1905 Estimate in Gallons
							Cows/Oxen	Horses/Donkeys	Sheep/Goats/Pigs						
1894	44	217	258,964,406	19	73	15,683	98	31	61	686,576	1,108,632,385	388,183,705	5,306,735	-855,676,974	-135,228,294
1895	56	204	308,593,941	19	73	15,683	98	31	61	686,576	1,042,216,620	364,928,460	4,988,820	-739,313,758	-62,025,598
1896	56	199	302,185,393	19	73	15,683	98	31	61	686,576	1,016,672,095	355,984,135	4,866,545	-720,055,506	-59,367,546
1897	55	199	295,950,937	19	73	15,683	98	31	61	686,576	1,016,672,095	355,984,135	4,866,545	-726,289,962	-65,602,002
1898	50	198	270,820,623	19	73	15,683	98	31	61	686,576	1,011,563,190	354,195,270	4,842,090	-746,286,917	-88,918,997
1899	34	199	183,872,564	19	73	15,683	98	31	61	686,576	1,016,672,095	355,984,135	4,866,545	-838,368,335	-177,680,375
1900	45	199	245,217,455	19	73	15,683	98	31	61	686,576	1,016,672,095	355,984,135	4,866,545	-777,023,444	-116,335,484
1901	67	86	156,081,871	24	92	19,780	123	39	77	862,772	439,365,830	153,842,390	2,103,130	-286,269,642	-746,202
1902	61	191	317,888,280	23	92	19,510	123	39	77	862,772	975,800,855	341,673,215	4,670,905	-663,465,762	-29,338,122
1903	45	191	234,374,049	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-746,625,509	-112,497,869
1904	37	191	193,453,242	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-787,546,315	-153,418,675
1905	53	191	275,398,583	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-705,600,974	-71,473,334
1906	56	191	290,905,961	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-690,093,596	-55,965,956
1907	38	191	198,069,151	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-782,930,407	-148,802,767
1908	46	191	237,797,082	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-743,202,475	-109,074,835
1909	52	191	267,878,283	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-713,121,274	-78,993,634
1910	43	191	222,912,074	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-758,087,484	-123,959,844
1911	45	191	235,774,380	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-745,225,177	-111,097,537
1912	37	191	192,415,959	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-788,583,598	-154,455,958
1913	39	191	202,425,738	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-778,573,819	-144,446,179
1914	37	191	194,438,661	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-786,560,896	-152,433,256
1915	62	191	322,906,136	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-658,093,422	-23,965,782
1916	57	191	296,092,375	14	55	11,731	74	23	46	516,066	975,800,855	341,673,215	4,670,905	-684,907,182	-50,779,542
1917	35	191	179,761,109	4	14	3,104	19	6	12	133,265	975,800,855	341,673,215	4,670,905	-800,847,020	-166,719,380
1918	42	191	215,651,094	4	14	3,104	19	6	12	133,265	975,800,855	341,673,215	4,670,905	-764,957,035	-130,829,395
1919	51	191	265,648,125	4	14	3,104	19	6	12	133,265	975,800,855	341,673,215	4,670,905	-714,960,004	-80,832,364
1920	36	50	48,619,237	4	14	3,104	19	6	12	133,265	255,445,250	89,443,250	1,222,750	-208,185,132	-42,183,132
1921	34	50	45,781,644	4	14	3,104	19	6	12	133,265	255,445,250	89,443,250	1,222,750	-211,022,725	-45,020,725
1922	32	50	42,876,166	4	14	3,104	19	6	12	133,265	255,445,250	89,443,250	1,222,750	-213,928,203	-47,926,203
1923	34	50	45,890,260	4	14	3,104	19	6	12	133,265	255,445,250	89,443,250	1,222,750	-210,914,109	-44,912,109
1924	56	50	75,786,814	4	14	3,104	19	6	12	133,265	255,445,250	89,443,250	1,222,750	-181,017,555	-15,015,555
1925	37	50	50,547,171	17	65	13,987	87	28	55	613,237	255,445,250	89,443,250	1,222,750	-206,748,052	-40,746,052

Appendix B. Lab Test Procedures

B-1. pH Testing

Potential of Hydrogen (pH) indicate the hydrogen potential of a soil which in turn can point towards past human and natural processes which have added or removed hydrogen ions (H+) and hydroxyl molecules (OH-) in soils (Holliday 2004, Pratt 2015, Tricarico 2019, Wells et al. 2018, Courty, Goldberg, and Macphail 1989). Digital testing of soil pH can be a fast and effective way to understand variances in pH across the horizontal or vertical extent of a test area.

Steps:

1. Gather materials:
    1. Calibrated portable digital pH meter
        1. Calibrate following calibration instructions for your particular pH meter, using known solutions of 7.0, 4.0, and 10.0 pH levels.
    2. Distilled water
    3. Glass beaker
    4. Stirring rod
2. Keep all specimen at 27 degrees Celsius during testing, to ensure consistent pH readings between samples.
3. Add 5 grams of the desired soil to the beaker.
4. Add 10 mL of distilled water to the beaker.
5. Stir the contents of the beaker for at least 1 minute, so that all particles of the soil are suspended in the water.
6. Wait approximately 5 minutes, then briefly re-agitate the sample.
7. Insert the digital pH meter electrode into the solution and read the display.
8. Take the reading a second time and record the average result.
9. Rinse all of your equipment using distilled water to prep it for the next soil sample to be tested.

B-2. Particle Size Analysis

Particle size analysis (PSA) quantifies the amount of sand, silt, and clay within each collected soil and reveals each soil's type (Gee and Or 2002, Wells et al. 2013, Pratt 2015). Determining soil particle size can help characterize soils and parent materials within fluvial, aeolian, or lacustrine depositional systems, It can also indicate the sediment type and or origin of a soil, can reveal soils as being compacted (potentially by human activity), and can reveal patterns of erosion that would affect site stratigraphy (Holliday 2004, Scudder et al. 1996, Timpson and Foss 1993, Courty et al. 1989, Goldberg and Macphail 2006, Waters 1992).

B-2.1. Shaker Screen Testing

Subsamples taken from bulk soil samples collected at ELP were passed through a series of geological sieves with screen sizes of 8 mm, 4 mm, 2 mm, 1 mm, .25 mm, .125 mm, .062 mm. Particles which passed through the smallest sieve fell into a pan placed at the bottom of the sieve set. The fraction of the sample captured by the pan would be later used in Gravitation particle size analysis (described in the next section of this Appendix).

Steps:

1. Gather materials:
    1. Geological sieve set
    2. Mechanical shaker
    3. Brush
    4. Clean weigh boats
    5. Digital scale
2. Leave desired bulk sample out to dry (in an open ziplock bag) for 2 days to dry out any excess moisture.
3. Mark down weight of weigh boat before adding soil onto it.
4. Using a digital scale and weigh boat, weigh out 50 g subsample of a given bulk sample.
5. Use a brush to move the 50 g subsample from the weigh boat into a mortar.
6. Using a pestle, gently break down any larger clods or aggregated soil grains until only single grains remain.
7. Stack the assorted geo-sieves with largest on top, in descending order, placing the pan at the bottom.
8. Using a brush pour the 50 g subsample from the mortar into the screen with the largest sieve.
9. Place the lid on stack of geo-sieves and then place the stack in the mechanical shaker, secure the stack of sieves in the device to ensure the lid will not fall off.
10. Set the shaker to ten minutes and press start.
11. Once the ten minutes expire, remove the stack of sieves from the mechanical shaker.
12. Using a set of weigh boats with already known weights, pour the soil contents of each geo-sieve into a separate weigh boat. Do this starting with the 8mm screen first, and work your way down, taking care to ensure that 100% of the soil grains within each screen make it into their respective weigh boat.
13. Using a digital scale, determine the weight of the amount of soil from each of the geo-sieves, and record these weights.

14. With the weight of the soil captured by each sieve now known, you can divide the weight of soil from each sieve by the original total weight of the subsample (50 g) and determine the percent of the subsample which was captured by each of the sieves.
15. Soil grains measuring between 2 mm and 0.063 mm were identified as sand. Soil Grains measuring 0.0629 mm and smaller were understood to represent a silt-clay fraction. This silt-clay fraction was then subjected to Gravitation particle size analysis to determine which fractions of the subsample are silt and clay.
16. Once these steps are completed, use a clean brush to clean off the weigh boats and geo-sieves to ensure that none of the materials from the previous test are still present. Then begin the steps again on the next desired bulk sample.

B-2.2. Gravitation Particle Size Analysis

Sample to be tested should be the fraction of a bulk soil sample which has fallen into the pan (last stage) during shaker screen analysis. This fraction represents particles measuring 0.063 mm or less, constituting medium grain of silt and grains of clay.

Steps:

1. Gather materials:
    1. Graduated test tubes at least 50 mL in size with caps
    2. Brush
    3. Clean weigh boats
    4. Digital scale
    5. Pipette with 1 mL mark
    6. Graduated syringe
    7. Clean sheets of paper
    8. Dispersing agent
2. Make sure you have test tubes clean and ready for each sample.
3. Grab plastic bag of desired sample (which consists of the silt and clay fraction from the shaker screen analysis).
4. Set up sheet of paper with a weigh boat on top.
    1. Mark down weight of the weigh boat before adding soil onto it.
5. Dump the soil sample into the weight boat (as much as possible).
    1. When you think you are done, turn plastic bag inside out and brush off all the soil that could be stuck on the bag.
    2. Any soil that falls on the sheets of paper will also be moved to the weight boat.
    3. Weigh the contents of the weigh boat to make sure you have gathered as much of the selected subsample as was listed as having been deposited into the pan in the previous shaker screen test.
    4. Weigh the weigh boat with soil, write down the weight.
        1. The difference between the weigh boat and the soil minus the weight of the weigh boat makes up the weight of the soil.
6. When all the soil is collected, create a paper funnel as thin as possible but not too thin to the point you will spill the soil everywhere.
    1. Paper funnel is created by rolling a sheet of paper and tightening it with fingers.
7. Have someone hold paper funnel inside a test tube, other person dumps the soil from weigh boat into the test tube vie the paper funnel and use of a brush.
    1. Person holding the funnel must make sure it is not touching the bottom nor the sides of the test tube.
    2. Unwrap the paper funnel and dump any soil it holds back onto weigh boat (make sure there is a sheet of paper underneath the weigh boat incase soil is misplaced).
    3. Redo step until all soil is inside test tube.
8. Measure how many mL are in the test tube, this is a dry reading.
9. Add 1 mL of dispersing agent into the test tube with soil using a small pipet with a 1 mL mark.
10. Fill the rest of the test tube with water (from the sink) until you hit the 45 mL line.
    1. DO NOT GO OVER LINE.
    2. Use a clean glass stirring rod to make sure the soil at the bottom of the beaker mixes in with the water and dispersing agent.

11. Cap the test tube, shake while holding down cap for 2 minutes.
    1. Make sure cap is held down as it will be pushing upwards.
    2. Shake it like a bartender shakes his cocktails.
    3. Make sure to time the shake for 2 minutes with a timer.
12. Stop shaking after 2 minutes, allow solution to settle for 30 minutes.
    1. Time out the 30 minutes with a timer.
13. At end of 30 minutes extract all the liquid with clay that's still suspended and place into a second beaker, record the mL of silt still remaining at the bottom of the first beaker.
    1. To extract the liquid and suspended clay, use a graduated syringe.
    2. Rinse syringe with water after each trial.
    3. DO NOT REMOVE ANY OF THE SILT AT THE BOTTOM WHEN REMOVING THE LIQUID AND SUSPENDED CLAY.
14. Record volume of silt that remains within graduated beaker.
15. Subtract volume of silt from the total silt/clay fraction that was taken from the pan to start the test. This will yield the silt and clay fractions from the larger soil sample.

B-3. Loss on Ignition Testing

Loss on ignition (LOI) testing is as an effective method for accurately estimating organic and inorganic carbon content in a soil (Dean 1974, Heiri et al. 2001, Garrison 2016). Soil organic carbon and inorganic carbon contents can provide a look into the organic inputs (such as waste deposited by flora, fauna, or decomposing organisms) that have been introduced into a soil being studied, and can also speak towards the measure of the carbonic influence of local parent materials on, or the level of weathering that has taken place on, materials within, a studied soil (Dean 1974, Goldberg and Macphail 2006, Heiri et al. 2001). Understanding these key aspects of a soil can speak toward the stability of current and past land surfaces.

Steps:

1. Gather materials:
    1. Ceramic crucibles (look like little cups)
        1. Should be 16 of them
        2. Make sure they are clean before use with no loose material inside
    2. Digital Scale accurate to thousandths place
    3. Mortar and pestle
    4. Scoop or spoon-like device
    5. Furnace capable of reaching and sustaining temperatures of 900 degrees Celsius
    6. Mitts and tongs for removing hot samples
    7. Excel file to record weights
2. Fill in excel file.
    1. Match each sample ID to a crucible ID.
    2. Set up column for initial weight, dried weight, organic carbon weight, and inorganic carbon weight.
3. Weigh the empty crucible.
    1. Make sure the scale is clean, then zero it out.
    2. Record the empty weight of the crucible in excel.
4. Add 2 g of desired sample into the crucible.
    1. Record combined weight.
    2. Set up the excel file to automatically subtract the empty crucible weight from the combined weight.
    3. Set the crucible in the furnace.
    4. Repeat recording empty weight then combined weight for each sample for the first batch of samples.
5. Set furnace to 100 degrees Celsius.
    1. Make sure the vent above the furnace is open.
    2. Turn the furnace on.
    3. Close door and leave samples inside for 12 hours.
6. Record dry weight.
    1. Take out samples (they'll be a little hot, so use mitts).
    2. Record combined weight, 10 min after the 100 degree burn.
    3. Set up the excel file to automatically calculate dry weight vs wet weight and percent water.

4. Don't let the samples sit out long before weighing or they will start to soak up water from the air and actually go up in weight on the scale while you're trying to record it.

7. Set furnace to 550 degrees Celsius.
    1. Put samples back in furnace.
    2. Set furnace to 550 degrees, it will take several hours to reach 550, once there leave samples in for at least 2 more hours.
8. Record percent of organic matter content.
    1. Take samples out.
        1. They'll be really hot now, so be careful, go slow, use tongs (the mitts will start to burn if you directly hold samples for more than about 10 seconds).
    2. Let the samples cool off for a few minutes.
    3. Record the combined weight of crucible and sample on the scale.
    4. Set up the excel file to calculate the percent of the sample that burned off at 550 degrees (the organic carbon content).
9. Set furnace to 900 degrees Celsius.
    1. Put samples back in furnace.
        1. The furnace will still be very hot so be careful putting them in; it's best to have long sleeves, lab coat, mitts, and tongs for this.
        2. The furnace should still be pretty hot from the last burn, but it will probably take at least 4 or 5 hours to reach 900.
    2. Once the furnace reaches 900 degrees, let samples sit in heated furnace for 2 hours.
10. Record percent of inorganic carbon content.
    1. Take samples out.
        1. Be extremely careful, samples with be very hot and dangerous!
        2. Crack the furnace door open and let the heat make its way out for about 15 minutes before trying to remove the samples; if it feels too hot, just wait until its safe to get close enough to take them out.
    2. Let samples cool for a while out of the furnace (but don't let them get actually cold cause they'll take on a little water if it's been too long).
    3. Record the combined weight on the digital scale.
    4. Set up the excel file to automatically calculate the percent of the sample that was burned off at 900 degrees (the inorganic carbon content).
11. Clean up
    1. Dump remaining sample in trash once they've cooled off.
    2. Rinse the crucibles and set in drying rack.
    3. Make sure the furnace is off and open vent all the way for it to cool.

B-4. Phosphate Testing

Phosphorous (P) in soil can be a strong indicator of past human activity and can potentially even suggest specific types of past human land uses in a given area (Goldberg and Macphail 2006:346). Human waste, food waste, and human burials all contain high levels of phosphates (Holliday and Gartner 2007:301, Garrison 2016:152, Courty et al. 1989, Wells 2006). Phosphates are produced by the decomposition of organic matter, including plant matter, and animal and human tissue and bone, as well as plant, animal, and human waste. Phosphorus is also a particularly powerful tool for the study of past land uses because it has a particularly long lifespan, potentially remaining in soils for thousands of years after their deposition. This lifespan makes phosphorus levels a relatively easy to detect and dependable signature of past human activities. The phosphorous testing methodology outlined below is a form of colorimetric analysis. It involves reacting soil extracts with a reagent to produce a color change, the intensity of which can then be measured through colorimetry to determine the soil's phosphate concertation in milligrams per liter (or parts per million).

Steps:

1. Gather materials:
    1. Hach dr/890 or equivalent colorimeter
    2. Phos Ver 3 powder pillow
    3. Hach sample cell with 10 mL line
    4. Glass beaker or jar
    5. Glass funnel
    6. Whatman Ashless Filter Paper
    7. Graduated eye dropper
    8. Test tubes with rubber cap
    9. Mehlich II acid
    10. Type II deionized water
    11. Safety gloves and eye protection (should be worn throughout phosphate testing)
    12. Large mixing beaker
    13. Stirring rod
2. Prepare a dilute solution consisting of Mehlich II acid and Type II deionized water.
    1. Prepare a clean beaker.
    2. Add 10 mL of concentrated Mehlich II acid using an eye dropper.
    3. Add 100 mL of type II deionized water to the beaker.
    4. Stir well.
3. Next take a clean test tube with a fitted rubber topper and add 2.00 g of the soil you wish to test to the test tube.
4. Add 20 mL of the acid extract to the test tube.
5. Cap the test tube and agitate the contents for 5 minutes by shaking.
    1. Occasionally you will want to "burp" the test tube by removing the cap, and allowing gases produced by chemical reactions between the acid solution and the soil. Failure to "burp" the test tubes intermittently may result in a large pressure build up, which will forcibly eject the top. This can be dangerous as the acid solution can be harmful.
6. After 5 minutes have expired take place a funnel in the jar in the glass beaker.

7. Place a sheet of Whatman ashless filter paper within the funnel and pour the mixed solution from the test tube into the funnel, using the paper to strain out the soil from the solution.
8. Once filtration is complete, pour 10 mL of the solution into the Hach dr/890 sample cell.
9. Optional step, once filtration is complete, take 1 mL from the solution and put it into a Hach dr/890 sample cell, and then add 9 mL of distilled water into the sample cell and stir until mixed. (this dilution step is optional so that you can test a wider range of potential phosphate values if the concentration of phosphates within your soils would otherwise be above the detectable limit of the Hach dr/890 colorimeter)
10. Add the contents of a Phos Ver 3 powder pillow (available from Hach, Inc.) to the solution and shake to dissolve. This takes approximately 2 minutes.
    1. The pillow contains ammonium molybdate, which produces a yellow phosphor-molybdate in the presence of phosphate.
    2. Through a reduction reaction with the acid, the Phos Ver 3 turns to blue molybdate compounds.
11. Once the Phos Ver 3 powder is fully dissolved, place the sample cell into the Hach dr/890 portable colorimeter, and run the phosphate test. The Hach dr/890 will provide you with the phosphate concentration of the solution in mg/l (or parts per million).
12. Record your results.
13. Between uses clean out the test tube and sample cell using acetone for quick and sterile drying.

Appendix C. Field Observations, Lab Results, Profile Wall Photographs, And Examined Geochemical and Geophysical Properties for the 14 Representative Shovel Tests

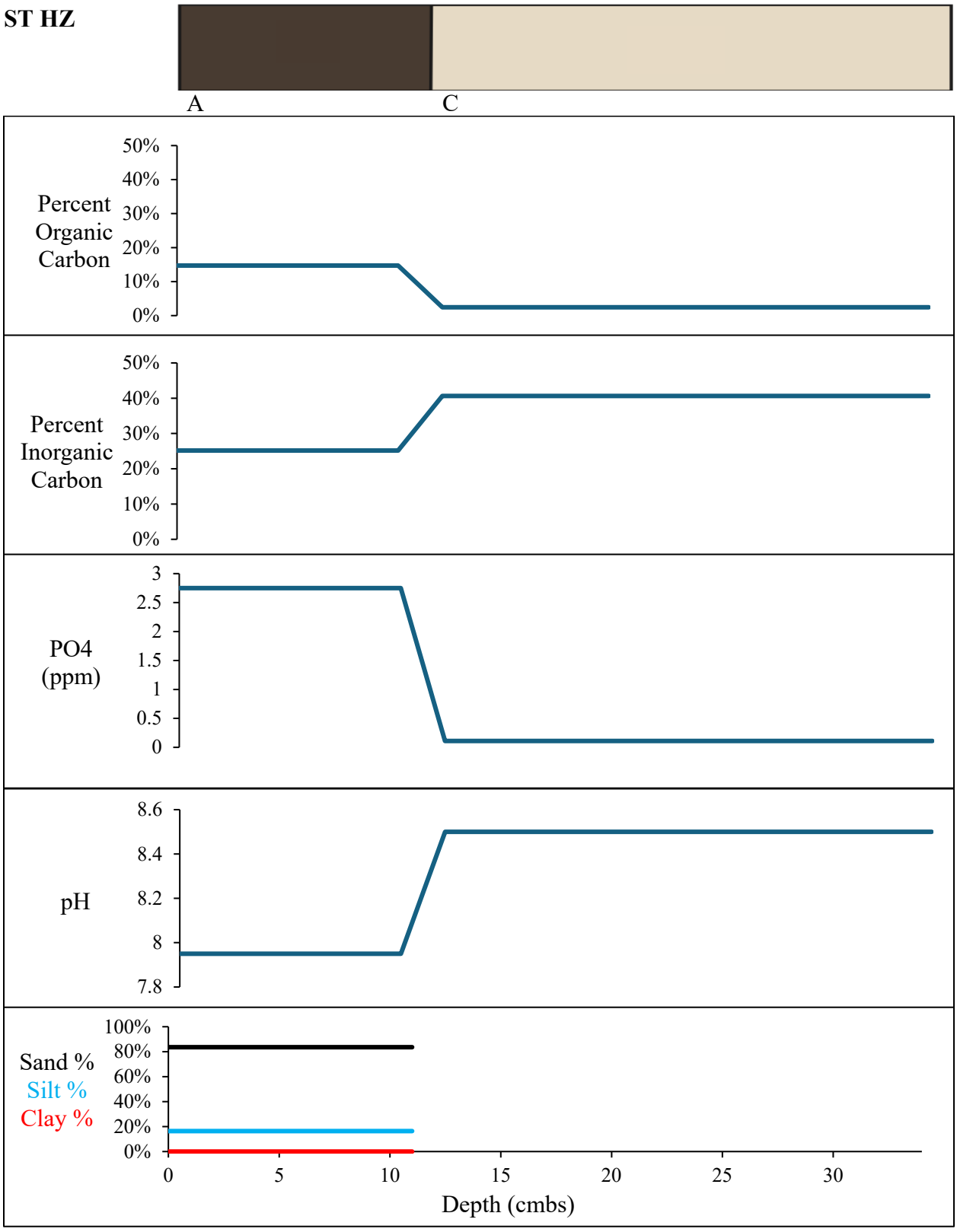
Appendix C-1: ST HZ

Table C-1.1. ST HZ field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	Soil at surface is very loose, rocky, with large chunks of limestone, plant debris present.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
0 to 11	I	A	10 YR 3/2 Very dark grayish brown	contains transition to B in last cm of depth, which consists of weathered bedrock, effectively no B horizon.	Entire strat is bulk sample	83.61/16.39/0	Sand	14.72	25.4656	25.16	2.06	2.75	0.9	7.95
11 to 34	II	C	10 YR 8/2 Very pale brown	Regolith/limestone parent material, Lowest root at 34 cmbs.	Entire strat is bulk sample	NT	NT	2.45	4.214	40.63	NT	NT	NT	8.5

Figure C-1.1. ST HZ west wall profile. Photograph by author, 6/27/22. Scale Bar is in 10 cm segments.

Figure C-1.2. ST HZ Examined Geochemical and Geophysical Properties



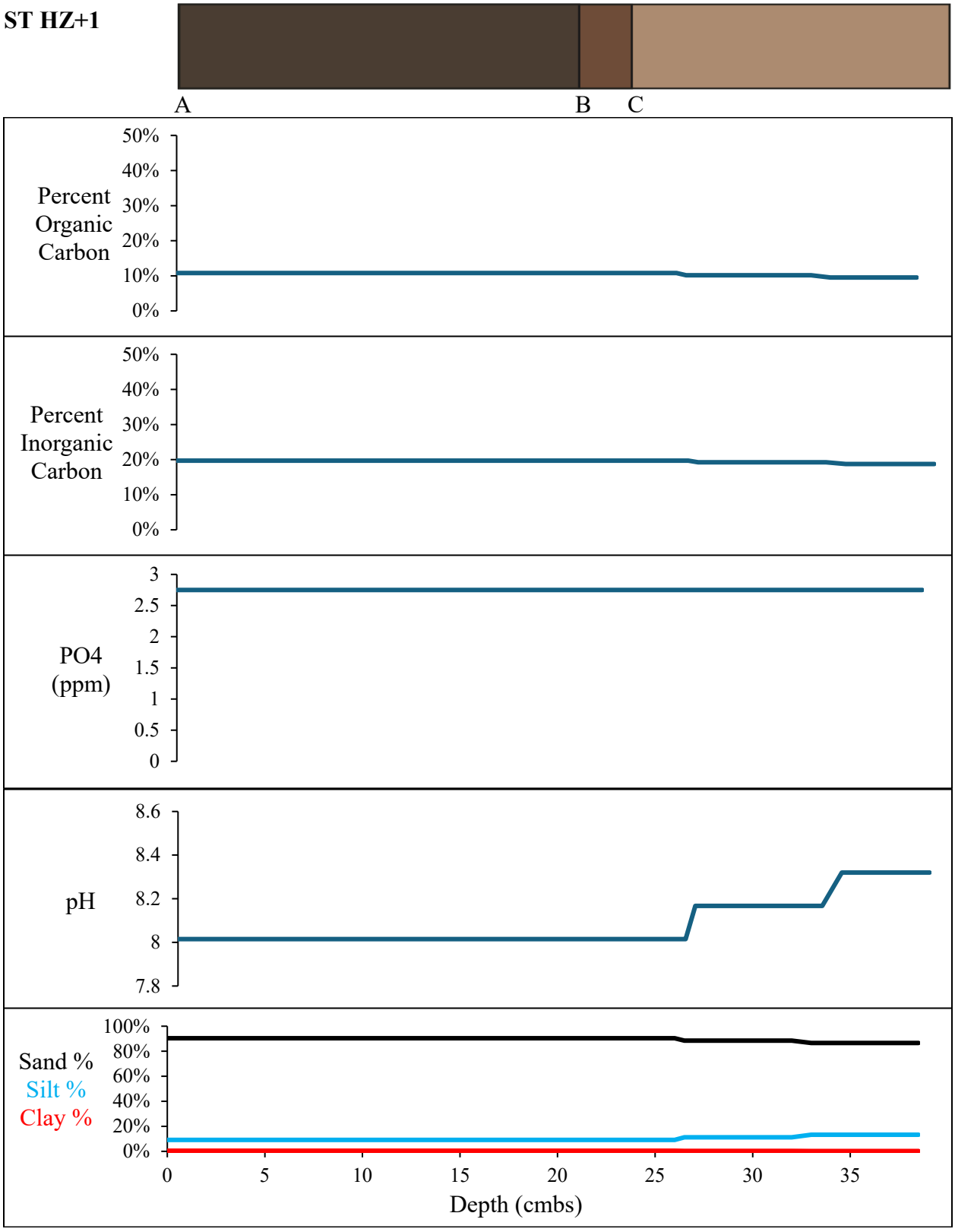
Appendix C-2: ST HZ+1

Table C-2.1. ST HZ field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	Surface vegetation consist of white manjack and stepmothers tongue, surface soil is loose (single grain) moderately rocky (less so than HZ Proper), smaller cobbles of limestone.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
0-32	I	A	10 YR 3/2 Very dark grayish brown	N/A	Entire strat is bulk sample	90.39/9.14/0.48	Sand	10.8	18.576	19.71	2.06	2.75	0.9	8.015
26.5-38.5	II	B	7.5 YR 4/4 Brown	In middle, B level has a feature, perhaps a rotted stop of an tree.	Entire strat is bulk sample	86.50/13.27/0.24	Sand	9.52	16.374	18.75	2.06	2.75	0.9	8.32
30-51	III	C	7.5 YR Pink	From NW corner, Lowest root at 51 cmbs.	Entire strat is bulk sample	NT	NT	NT	NT	NT	NT	NT	NT	NT

Figure C-2.1. ST HZ+1 west wall profile. Photograph by author, 6/27/22. Scale Bar is in 10 cm segments.

Figure C-2.2. ST HZ+1 Examined Geochemical and Geophysical Properties



Appendix C-3: ST HZ+5

Table C-3.1. ST HZ+5 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	Dense stepmother's tongue and white manjack to the north and south, tree canopy consists of taller trees than in HZ+4, cactus is also abundant here, 80% manjack branch litter, forming a mulch, sanseveria leaves present, 10% live roots, 5% majack leaves, 5% limestone inclusions, subangular, and < 1% terrestrial snail shell. Beneath leaft litter, 5% limestone linclusions less than 1 cm in diameter, sub angular. Lots of roots in mixture, as are seeds, grains are mostly single grain, very dry to touch	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
0-13	I	A	10 YR 2/2 Very dark brown	More moist than nearby soils, very small clasts, and single grain textures, sand with limestone	entire strat is sample	85.23/14.43/0.34	Sand	12.59	21.6548	15	2.06	2.75	0.9	8.025

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				inclusions but fewer 2-5%, .5 cm in diameter with subangular and rounded edges. Pipe stem found in strat I.										
13-26	II	B	10 YR 4/2 Dark grayish brown	Larger clasts up to 1.5 cm in diameter and smaller. Sand with limestone inclusions up to 0.5 cm in diameter and smaller, subangular. Also larger limestone cobbles present.	entire strat is sample	88.94/10.64/0.44	Sand	9.29	15.9788	10.56	2.06	2.75	0.9	8.34
26-40	III	Bk	7.5 YR 3/4 Dark brown	N/A	entire strat is sample	79.675/20.183/0.141	Loamy sand	8.11	13.9492	3.85	2.06	2.75	0.9	8.36
40-46	IV	C	7.5 YR Pink	Solid limestone	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Figure C-3.1. ST HZ+5 east wall profile. Photograph by author, 6/29/22. Scale bar is in 10 cm segments.

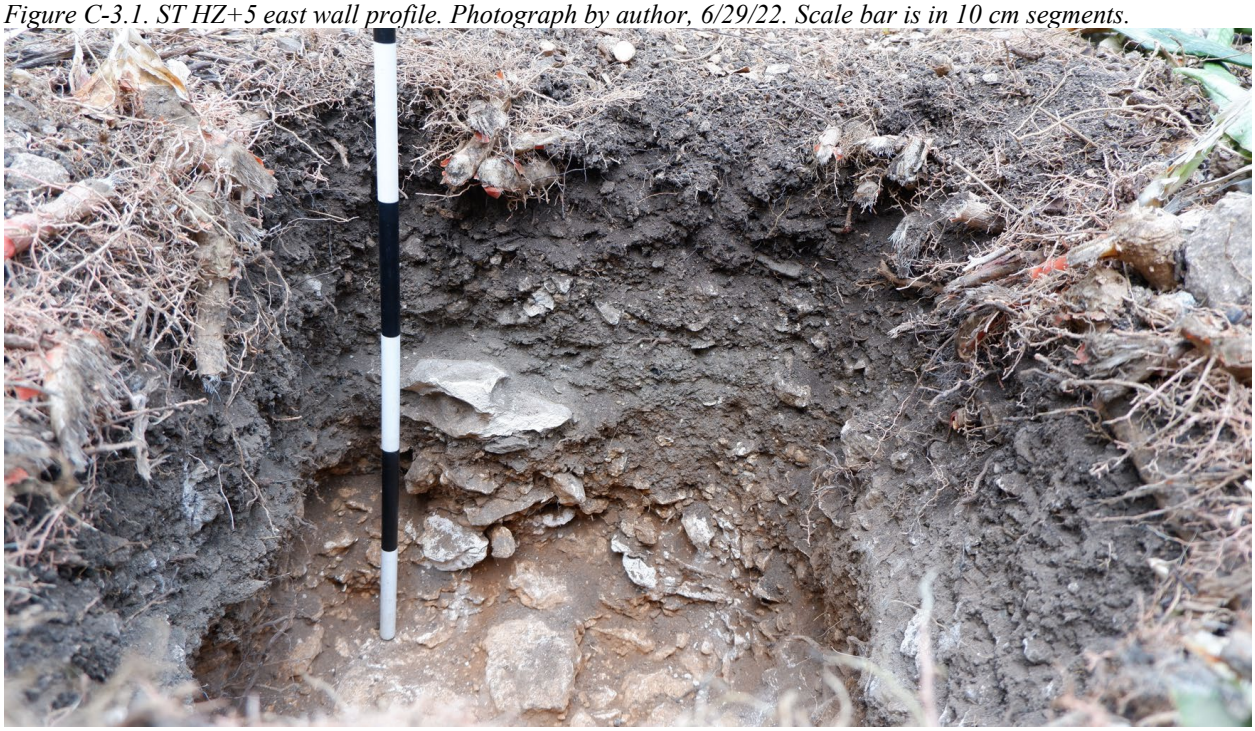
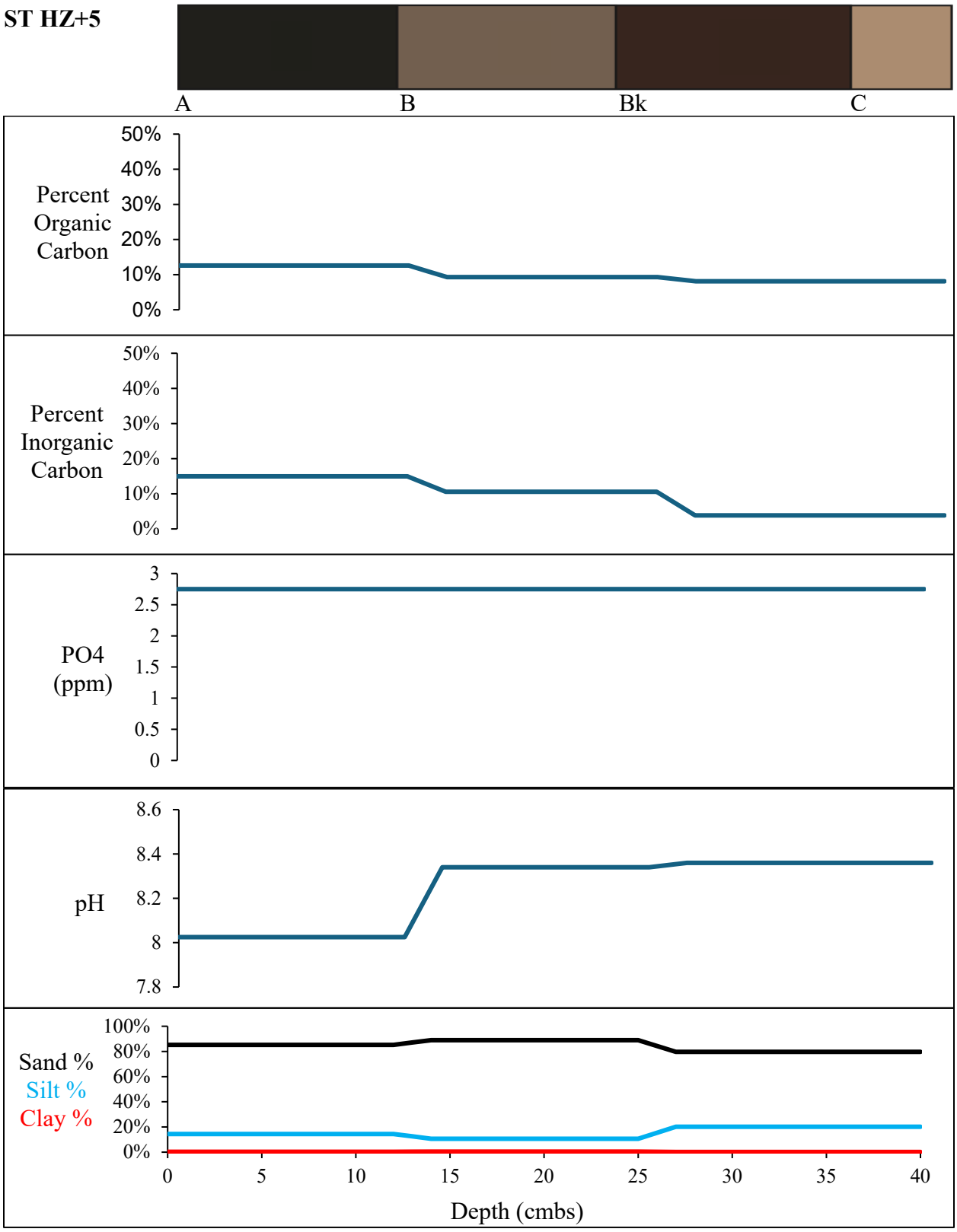


Figure C-3.2. ST HZ+5 Examined Geochemical and Geophysical Properties



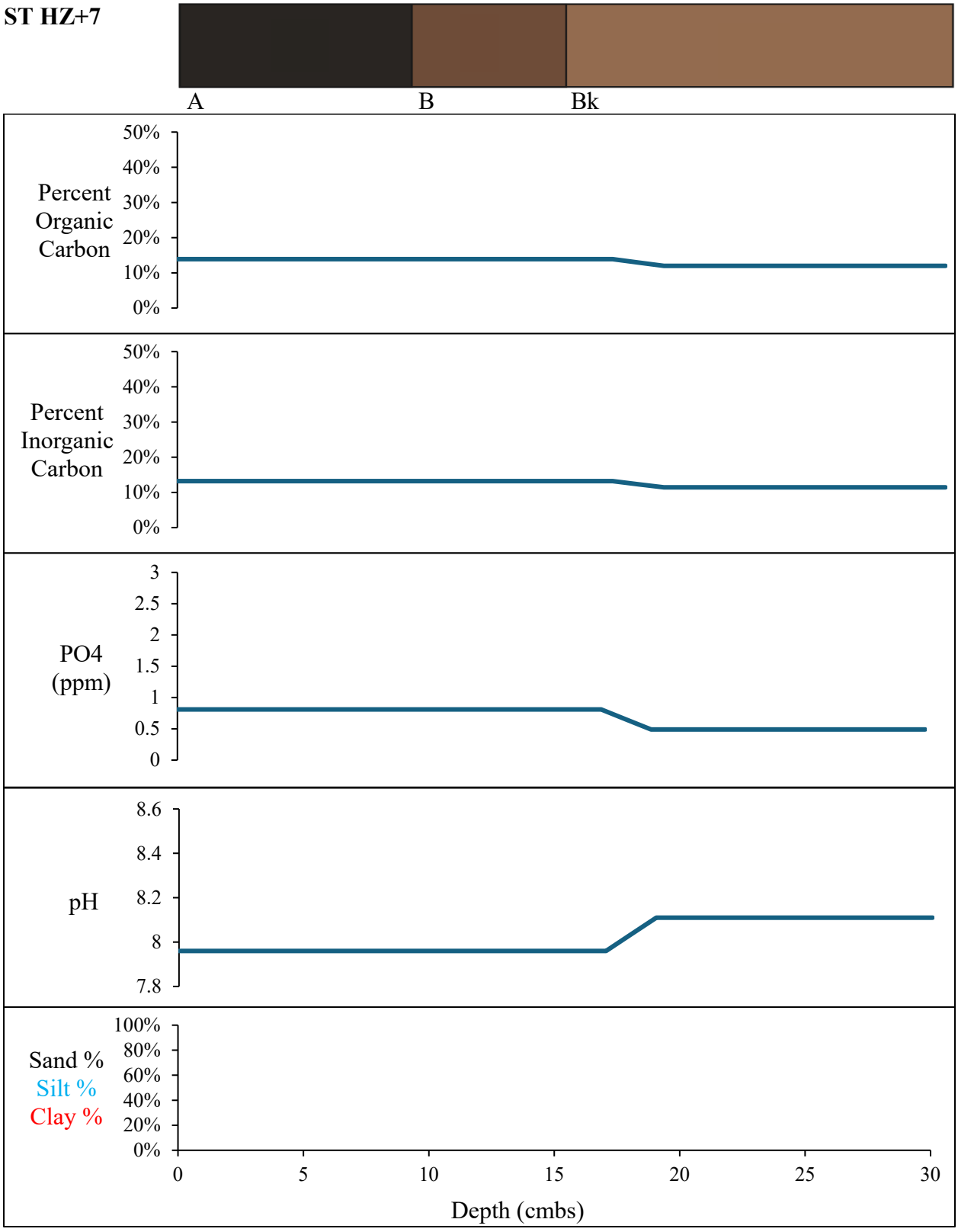
Appendix C-4: ST HZ+7

Table C-4.1. ST HZ+7 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	Located in a small clearing, with dense sanseveria and white manjack canopy to the south, 5+ cm of leaf litter .	NS	NS	NS	NS	NS	NS	NT	NT	NT	NT
0-18	I	A	7.5 YR 2.5/1 Black	Sand	entire strat is sample	NT	NT	13.89	23.8908	13.21	0.6	0.81	0.26	7.96
18-30	II	B	7.5 YR 4/4 Brown	Sand with clasts	entire strat is sample	NT	NT	11.99	20.6228	11.44	0.36	0.49	0.16	8.11
30-60	III	Bk	7.5 YR 5/4 Light brown	Small limestone inclusions no sample collected	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
60	IV	C	10 YR 5/4 Yellowish brown	Limestone parent material	NS	NS	NT	NS	NS	NS	NS	NS	NS	NS

Figure C-4.1. ST HZ+7 east wall profile. Photograph by author, 6/30/22, Scale bar is in 10 cm segments.

Figure C-4.2. ST HZ+7 Examined Geochemical and Geophysical Properties



Appendix C-5: ST 3

Table C-5.1. ST 3 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0-6	N/A	O	N/A	Discernable slope down to the north approximately 6%, ~5m to the north is dense sanseveria, but the ST is in a drier area, large termite nest in tree to northwest (~4m), accounts for lots of bark on the ground, Manjack to South and sansevera to West and Northwest also a large Tan Tan, canopy is moderate to light with tan tan trees, leaf litter is 50% bark and twigs, 45% leaves, 3% large rounded river cobbles 4.5 cm diameter and smaller, granite, smaller limestone, 1% snail shell, 1 % tan tan pods, 3x small palms (knee high) to north. Unit straddles the topo-line evident from sanseveria	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

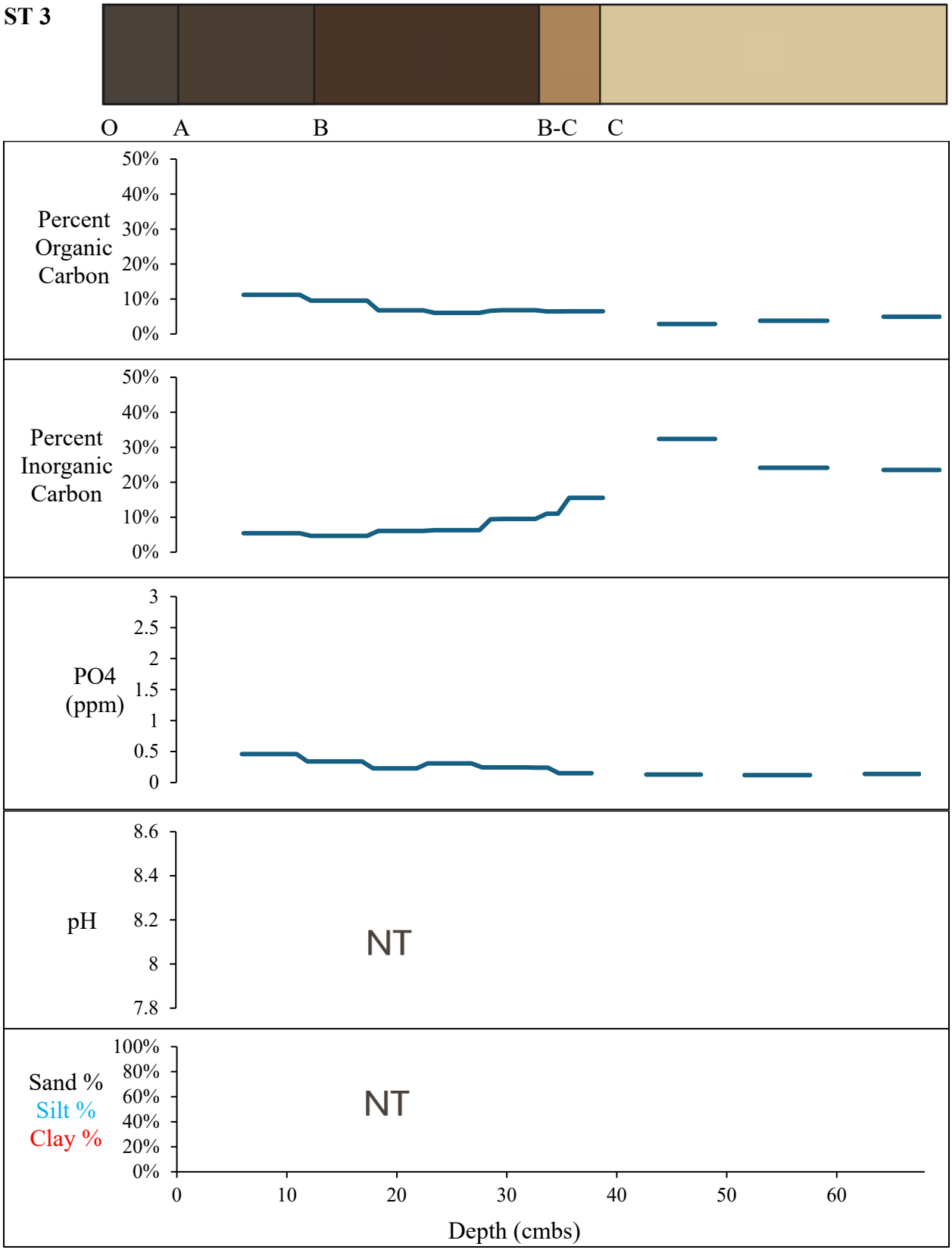
Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				to north/northwest and downslope), and just above the berm that characterizes STs 4, 5, and 6, though the presences of large rounded granite (and other) cobbles suggests that during major floods this area may have also seen water. 2 cm leaf litter, once removed reveals a 10yr 4/2 80% clasts .05 cm and smaller, 25% rounded small cobbles 3 cm in diameter and smaller granite river stones and limestone, 5% live roots (some very thin) rest is soil										
6 to 17	I	A Horizon	10 YR 3/2 Very dark grayish brown	70% clasts < .1 cm in diameter, 7% roots, 10% limestone inclusions, 1 cm diameter and smaller, angular granite pebbles accounting for 3%	6 - 12 12 -17	NT	NT	19.28 16.41	33.16 28.23	25.16 NT	0.34 0.25	0.46 0.34	0.150.11	NT
	Transition from I to II			Abrupt but very little color change, only		NS	NS	NS	NS	NS	NS	NS	NS	NS

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				slightly lighter. It's a change because rock inclusions are much larger and seemingly more numerous below										
17-35	II	B Horizon	10 YR ¾ Dark yellowish brown	60% clasts <.5 cm diameter, 5% roots, 3x2 cm limestone subangular to rounded and smaller, 10% 2 cm diameter granite inclusions, roots 3%	18-22 23-28 28-32 29-34	NT	NT	6.77 6.05 NT 6.41	11.64 10.41 NT 11.03	6.07 6.27 NT 6.48	0.17 0.23 NT 0.185	0.23 0.31 NT 0.25	0.07 0.10 NT 0.08	NT
	Transition from II to III			Abrupt, texture is mostly rocks below and much lighter gray in color		NS	NS	NS	NS	NS	NS	NS	NS	NS
35-40	III (this strat IS the transition from B to C)	B to C Transition	10 YR 5/4 Yellowish brown	mostly rocks, matrix is 50% rocks with limestone inclusions .5cm in diameter, granite as well, both subangular to rounded. Slate also potentially present. Larger granite cobbles also present, 3cm in diameter, consisting of 3-5% of strat.	33-38	NT	NT	6.48	11.15	15.52	0.12	0.15	0.05	NT
	Transition from III to IV			Abrupt, texture and color change to very light below, presumably marl	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
40-68	IV	C Horizon	10 YR 7/3 Very pale brown	Marl, comes off wall as very fine particle, roots 1% or less, large granite and sandstone cobbles 6x3 cm in diameter and smaller, rounded, 30% clasts, .5 cm in diameter	43-48 53-58 63-68	NT	NT	2.85 3.79 4.93	4.90 6.52 8.48	32.37 24.12 23.49	0.1 0.09 0.11	0.13 0.12 0.14	0.04 0.04 0.05	NT

Figure C-5.1. ST 3 northeast wall profile. Photograph by author, 7/14/22. Scale bar is in 10 cm segments.

Figure C-5.2. ST 3 Examined Geochemical and Geophysical Properties



Appendix C-6: ST 4

Table C-6.1. ST 4 field observations and lab test results.

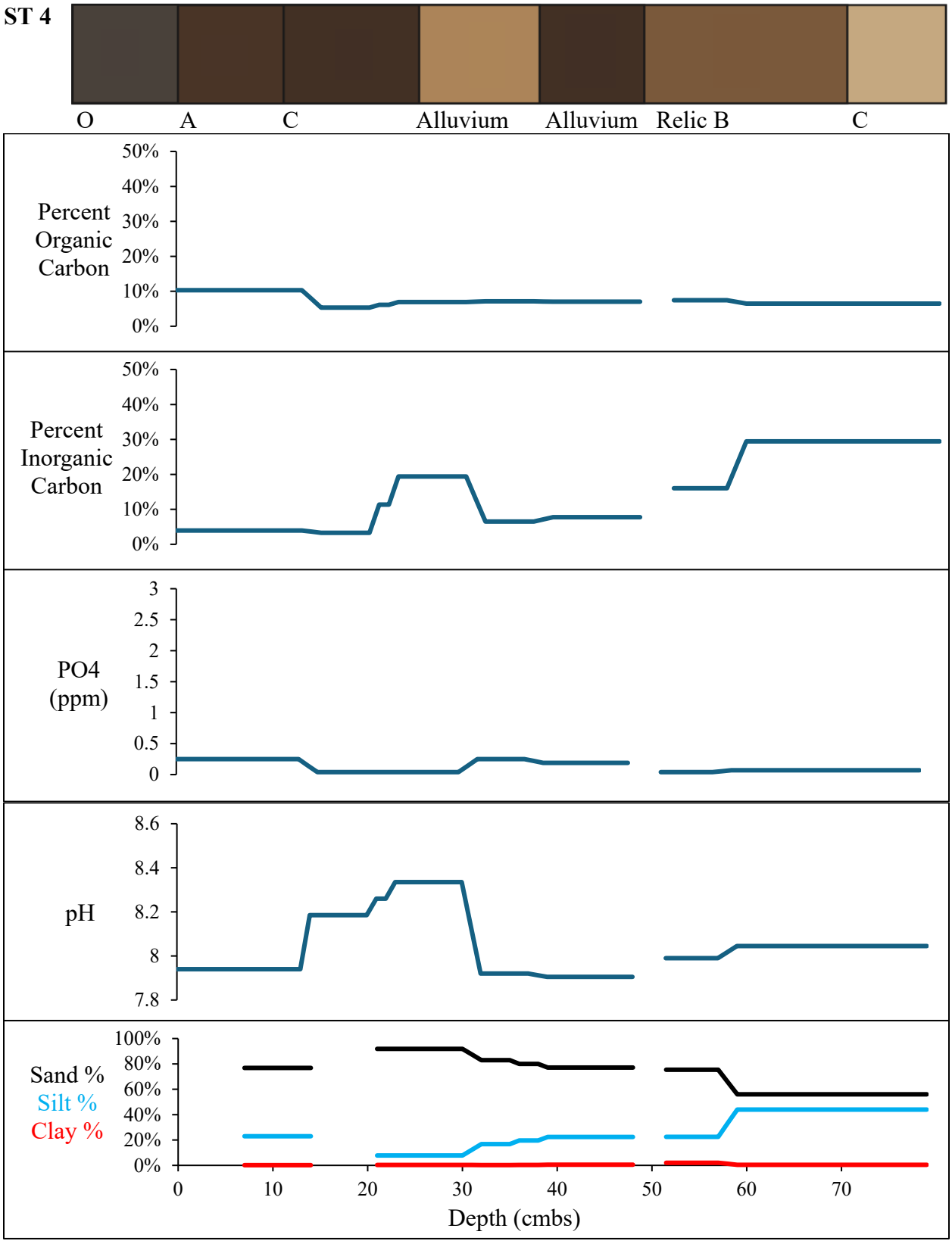
Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0-7	N/A	O	10 YR 3/1 Very dark gray	Dense sanseveria in all directions, discernable slope ~ 6 degrees to the north, and moderate canopy of white manjack. Leaf litter is dense sanseveria leaves, dead branches with no bark likely due to terminates, and mulch, under sansevera cover (75%), 20% of which is bark, 10% dead and living root clutter and leaves	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
7 to 14	I	A Horizon	10 YR 3/4 Dark yellowish brown	Loamy sand, entirely single grain, 20% root, inclusions of granite, subangular	entire strat is sample	76.87/22.95/0.18	Loamy sand	10.31	17.73332	3.04	0.19	0.25	0.08	7.94

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				largest 1 cm diameter										
14-23	II	C Horizon	10 YR 3/3 Dark brown	Soils in strat 2 likely to have trickled down into this strat which is almost entirely rock, largest is 11 cm width 5 cm tall. Rock is whole strat, and its not limestone, perhaps slate, soil inclusions 10%	14-22	NT	NT	5.33	9.1676	3.29	0.03	0.04	0.01	8.185
	Transition from II to III			Abrupt, stark change from rocks to gray alluvium	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
23-31	III	Alluvium Deposited cobbles	10 YR 5/4 Yellowish brown	Sand, likely alluvium *in situ*-blocky but coming from wall its single grain	23-31	91.85/7.80/0.35	Sand	6.92	11.9024	19.4	0.03	0.04	0.01	8.335
Transition from III to VII	Transition from III to VII			Abrupt, color change stark	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
31-38	VII	Alluvium	10 YR 6/2 Light brownish gray	n/a	31-38	82.96/16.79/0.25	Loamy Sand	7.13	12.26	6.5	0.19	0.25	0.08	7.92
38-51.5	IV	Alluvium Deposited cobbles	10 YR 2/2 Very dark brown	Loamy sand, rounded granite inclusions, largest is 7 cm wide by 5 cm tall	36-48	77.1/22.42/0.48	Loamy Sand	7.02	12.07	7.8	0.14	0.19	0.06	7.905

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				consisting of 20% of matrix, all in top 7 cm of this strat										
51.5-58	V	Relic B	10 YR 3/3 Dark brown	Clasts with single grain structure, roots less than 1% strat represents gradual change from IV to VI	51.5-58	75.45/22.50/2.04	Loamy Sand	7.45	12.81	16.03	0.03	0.04	0.01	7.99
		Transition from Relic B to C		Transition is captured within the bottom of strat V	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
58	VI	C Horizon	10 YR 6/3 Pale brown	Silt loam, no inclusions , roots 1% or less	58-79	56.02/43.98/0.46	Silt loam	6.47	11.13	29.45	0.05	0.07	0.02	8.045

Figure C-6.1. ST 4 west wall profile. Photograph by author, 7/13/22. Scale bar is in 10 cm segments

Figure C-6.2. ST 4 Examined Geochemical and Geophysical Properties



Appendix C-7: ST 8

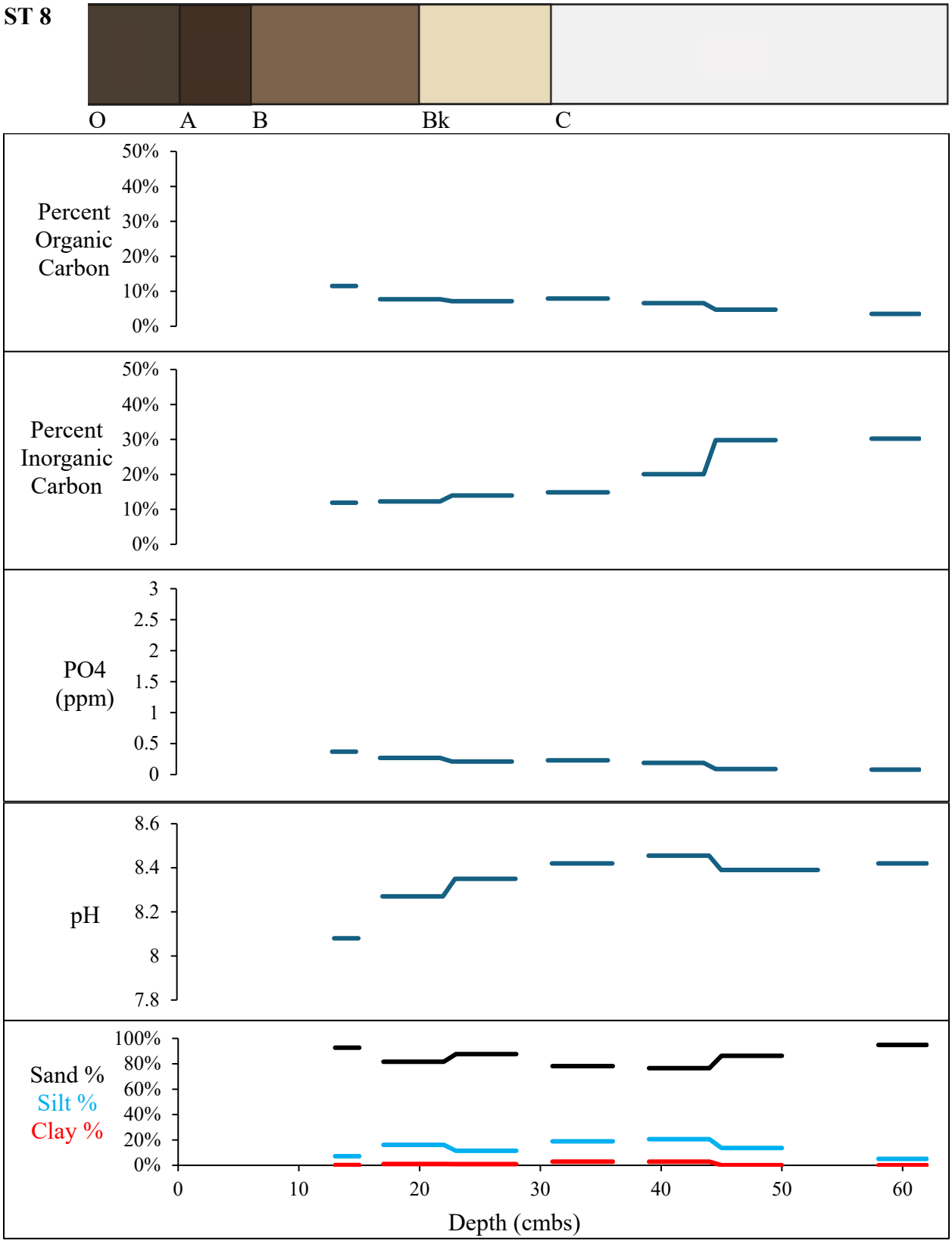
Table C-7.1. ST 8 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0-10	N/A	O	N/A	Hardwood trees to the east, south, and north, including a white manjack to the north east, very dense sanseveria to the west and northwest, leaf litter is 90% tree leaf, 10% twigs, 4 cm deep, the exposed surface soil is 50% small clasts .1 cm in diameter, 2-5% snail shell and fragments, matrix is almost springy and moist, and single grain	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10 to 16	I	A	10 YR 3/2 Very dark greyish brown	Sandy, clasts .5 cm and smaller and single grain, 20% roots 1/8 cm diameter, larger inclusions are 3 cm diameter limestone pebbles subangular, 1% inclusions .2 cm diameter limestones and smaller.	13-15	92.68/7.13/0.19	Sand	11.51	19.7972	11.9	0.28	0.37	0.12	8.08
16-30	II	B	10 YR 3/3 Dark brown	Loamy sand overwhelmingly .1 cm clasts, some single grain, inclusions of charcoal less than 1%, limestone	17-22 23-28	81.66/16.17/1.03 87.61/11.45/0.93	Loamy sand Sand	7.71 7.17	13.26 12.33	12.27 13.95	0.20 0.16	0.27 0.21	0.09 0.07	8.27 8.35

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				maybe 1.25 cm diameter and smaller sub angular limestone inclusions @ 1%, roots 5%.										
30-41	III	Bk	10 YR 4/3 Brown with white small inclusions which are 10 YR 8/2 very pale brown	Small white inclusions that are part of the clasts, predominantly clasts 70% roots 5%, strat break is gradual, the top of this start marks the beginning of white inclusions (flecking).	31-36	78.19/18.92/2.89	Loamy sand	7.9 6.61	13.59 11.37	14.86 20.07	0.18 0.14	0.23 0.19	0.08 0.06	8.42
41-74	IV	Transition from Bk to C	10 YR 8/3 Very pale brown-modeled with 10 YR 4/4 Yellowish Brown	Strat is the transition from III to V, roots less than 1%. 90% single grain, abrupt with strat 3, but gradual transition below.	41-44 45-50 58-62	76.58/20.60/2.82 86.33/13.62/0.05 94.88/5.08/0.04	Loamy sand Sand Sand	4.74 3.54 NT	8.15 6.09 NT	29.79 30.22 NT	0.07 0.06 NT	0.09 0.08 NT	0.03 0.03 NT	8.46 8.39 8.42
74	V	C	10 YR 8/4	root inclusion 1% limestone inclusions 3%, length 3 cm and smaller.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Figure C7.1. ST 8 west wall profile. Photograph by author, 7/8/22, Scale bar is in 10 cm segments.

Figure C-7.2. ST 8 Examined Geochemical and Geophysical Properties



Appendix C-8: ST 9

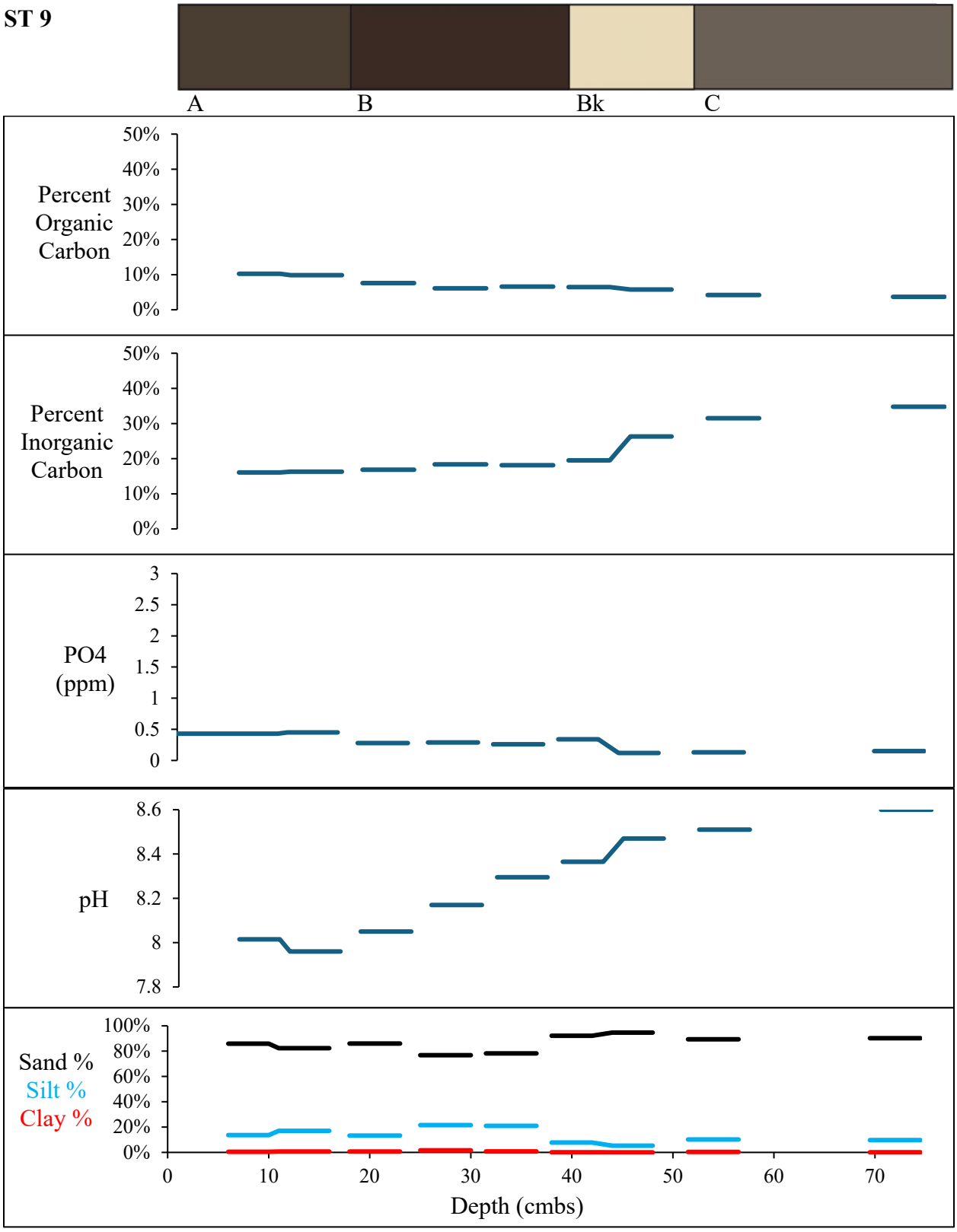
Table C-8.1. ST 9 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0-6	N/A	O	N/A	White manjack to the south, sansaveria to southwest and west, manjack to north and northeast, canopy moderate to dense with leaves still on manjack, 2.5 m to north and north east is occupied by tall grass and young palms (1m tall) and other young plants 33 cm tall, leef litter is very thin 1 cm tall with lots of exposed soil which consists of 40% leaves, 15% manjack branches/much snail shells present 7%, limestone cobbles present 10 cm length and smaller, remaining percent is exposed soil with half cm clasts and smaller and single grain, with leaf litter gone, slope is discernable to the east by north east (slight), root is 1-3%, with clasts	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	Inorganic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				and single grain, limestone inclusions .5 cm and less and at 1-3%. Snail shell also present at less than 1%, limestone inclusions subangular up to 1 cm in diameter										
6-16.5	I	A	10 YR 3/2 Very dark grayish brown	sand, clasts 1 cm and smaller 30%, single grain, limesotone cobbles 1 cm length and smaller sub angular 10%, roots 3%.	6 -10 11-16	85.96/13.63/0.43 82.34/17.02/0.65	Sand Loamy sand	10.25 9.86	17.63 16.96	16.07 16.29	0.32 0.34	0.43 0.45	0.14 0.15	8.02 7.96
16.5-37.5	II	B	10 YR 3/3 Dark brown	Sand/ sandy loam, clasts up to .5 cm 70% and single grain, limestone cobbles of up to 2.5 cm diameter 5%, roots 2%.	18-23 25-30 31.5-36.5	86.02/13.31/0.68 76.81/21.56/1.63 78.20/21.00/0.80	Sand Sandy loam Sandy loam	7.60 6.12 6.59	13.07 10.53 11.33	16.85 18.37 18.13	0.21 0.22 0.19	0.28 0.29 0.26	0.09 0.09 0.08	8.05 8.17 8.30
37.5-49.5	III	Bk	10 YR 8/3 Very pale brown	sand, transition from II to IV, clasts .5 cm and smaller 60%,sand, limestone inclusions 3.5 cm length and smaller, 5% subangular, roots 1%.	38-43 43-48	92.14/7.75/0.11 94.67/5.30/0.03	Sand Sand	6.45 5.76	11.09 9.91	19.51 26.32	0.26 0.09	0.34 0.12	0.11 0.04	8.37 8.47
49.5-74.5	IV	C	10 YR 3/3 Very pale brown	clasts .5 cm and smaller, clasts off wall, floor is comprised of large limestone cobbles.	51.5-56.5 69.5-74.5	89.41/10.24/0.35 90.27/9.69/0.05	Sand Sand	4.21 3.68	7.24 6.33	31.51 34.78	0.09 0.12	0.13 0.15	0.04 0.05	8.51 8.6

Figure C-8.1. ST 9 west wall profile. Photograph by author, 7/9/22. Scale bar is in 10 cm segments.

Figure C-8.2. ST 9 Examined Geochemical and Geophysical Properties



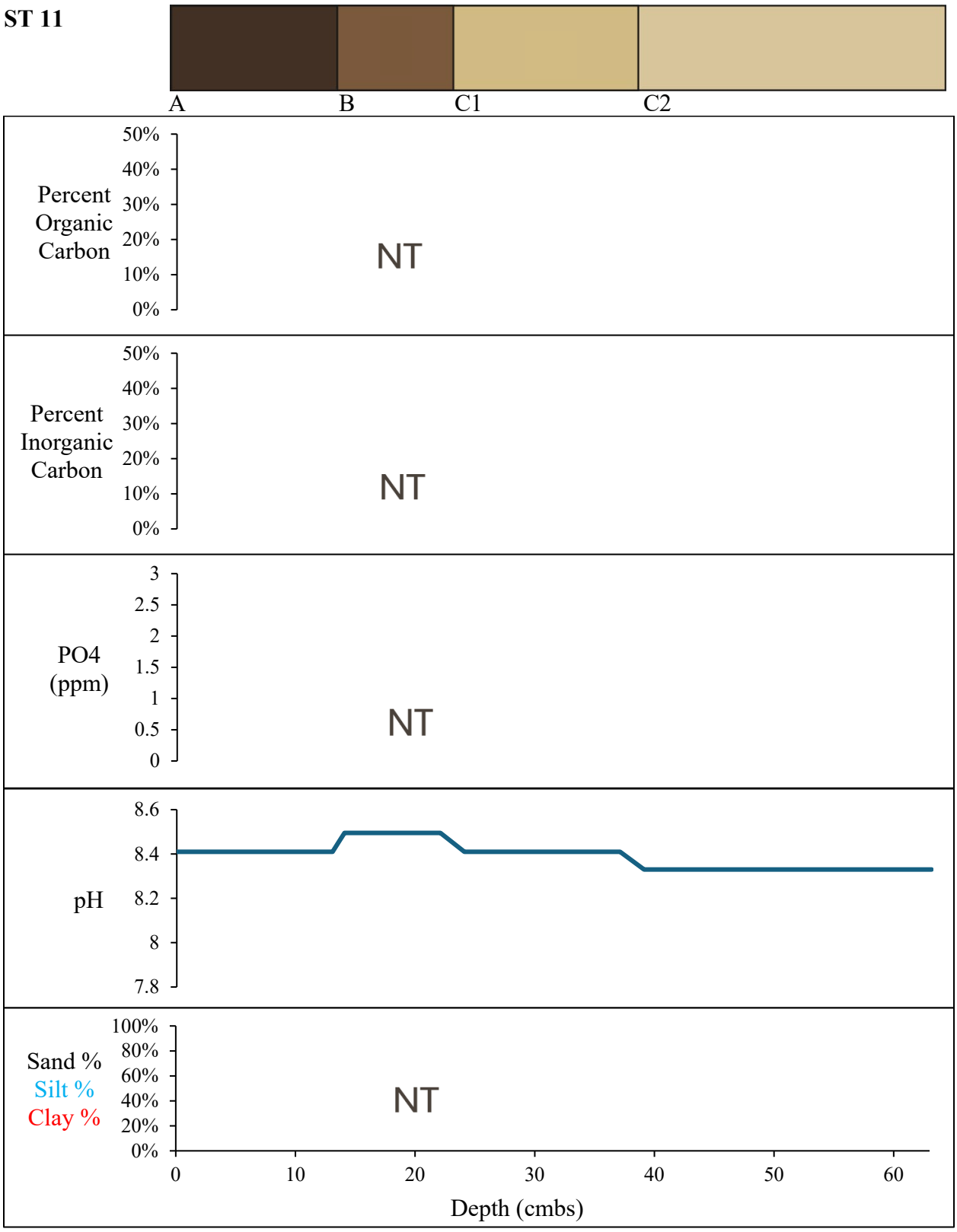
Appendix C-9: ST 11

Table C-9.1. ST 11 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
0-13.5	I	A	10 YR 3/3 Dark brown	Sand, rooty, lots of clasts lots of little roots, small and subangular pebbles as well.	entire strat is sample	NT	NT	NT	NT	NT	NT	NT	NT	8.41
13.5-23	II	B	10 YR 4/4 Dark yellowish brown	Sand, single grain	entire strat is sample	NT	NT	NT	NT	NT	NT	NT	NT	8.50
23-38	III	C1	10 YR 7/4 Very pale brown	Limestone, transition strat, darker at top, some stone inclusion but mostly limestone or caliche, stone visible is caliche.	entire strat is sample	NT	NT	NT	NT	NT	NT	NT	NT	8.41
38-63	IV	C2	10 YR 7/3 Very pale brown	Limestone soft enough to sample, Lowest root at 62 cm.	entire strat is sample	NT	NT	NT	NT	NT	NT	NT	NT	8.33

Figure C-9.1. ST 11 south wall profile. Photograph by author, 6/24/22. Scale bar is in 10 cm segments.

Figure C-9.2. ST 11 Geochemical and Geophysical Tested Properties



Appendix C-10: ST Uphill Pond 2

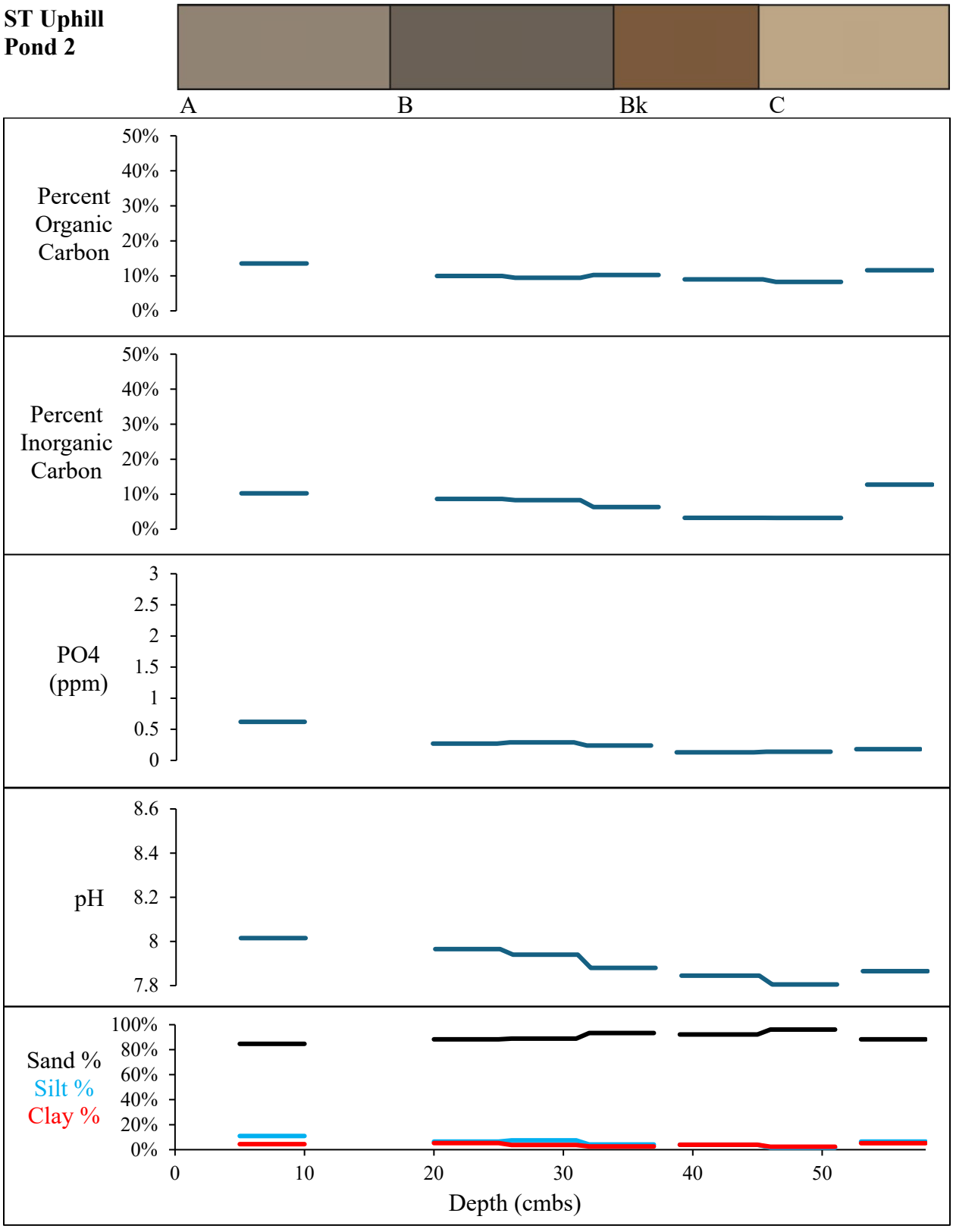
Table C-10.1. ST Uphill Pond 2 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	Large white manjack trees to east, southeast, and west. Vines very prevalent in all directions, but test unit is in clearing likely caused by very large manjack to the east which dominates area's canopy. Canopy dense with leaves of manjack and vines, to south is lighter secondary growth and a culvert to the west which drains towards southwest. Vines very dense in all directions. leaf litter over the test unit is 80% leaves (manjack) 20% twigs and bark. 3 cm of leaf litter. 30% of matrix is 1 cm and smaller pieces of bark, 1% large limestone cobbles, and the rest is very loose 95% of which is .5 cm clasts and smaller, and 5% single grain.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
0-19	I	A	10 YR 5/1 Gray	Top soil	5 to 10	84.68/10.94/4.38	Sa/Cl loam	13.53	23.27	10.24	0.46	0.62	0.2	8.015

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
19-39	II	B	10 YR 4/1 Dark gray	Subsoil	20-25 26-31 32-37	88.24/6.47/5.29 88.84/7.44/3.72 93.29/4.13/2.58	Sa/Cl loam Loamy sand Sa/Cl loam	9.98 9.44 10.25	17.17 16.24 17.63	8.64 8.31 6.35	0.20 0.22 0.18	0.27 0.29 0.24	0.09 0.08 0.09	7.96 57.94 7.88
39-52	III	Bk	!0 YR 5/4 Yellow brown	Bk	Top of Transition from II to III (B to C) 39-45 Part of Transition from II to III (B to C) 46-51 cmbs	92.18/3.91/3.91 96.11/1.56/2.33	Sandy loam Sand	9.01 8.27	15.50 14.22	3.24 3.22	0.1 0.1	0.13 0.14	0.04 0.05	7.85 7.805
52-69	IV	C	10 YR 6/2 Light brownish gray	C horizon	53-58	88.31/6.50/5.20	Sa/Cl loam	11.61	19.97	12.74	0.14	0.18	0.06	7.865

Figure C-10.1. ST Uphill Pond 2 north wall profile. Photograph by author, 7/23/22. Scale bar is in 10 cm segments.

Figure C-10.2. ST Uphill Pond 2 Geochemical and Geophysical Tested Properties



Appendix C-11: ST Uphill Pond 1

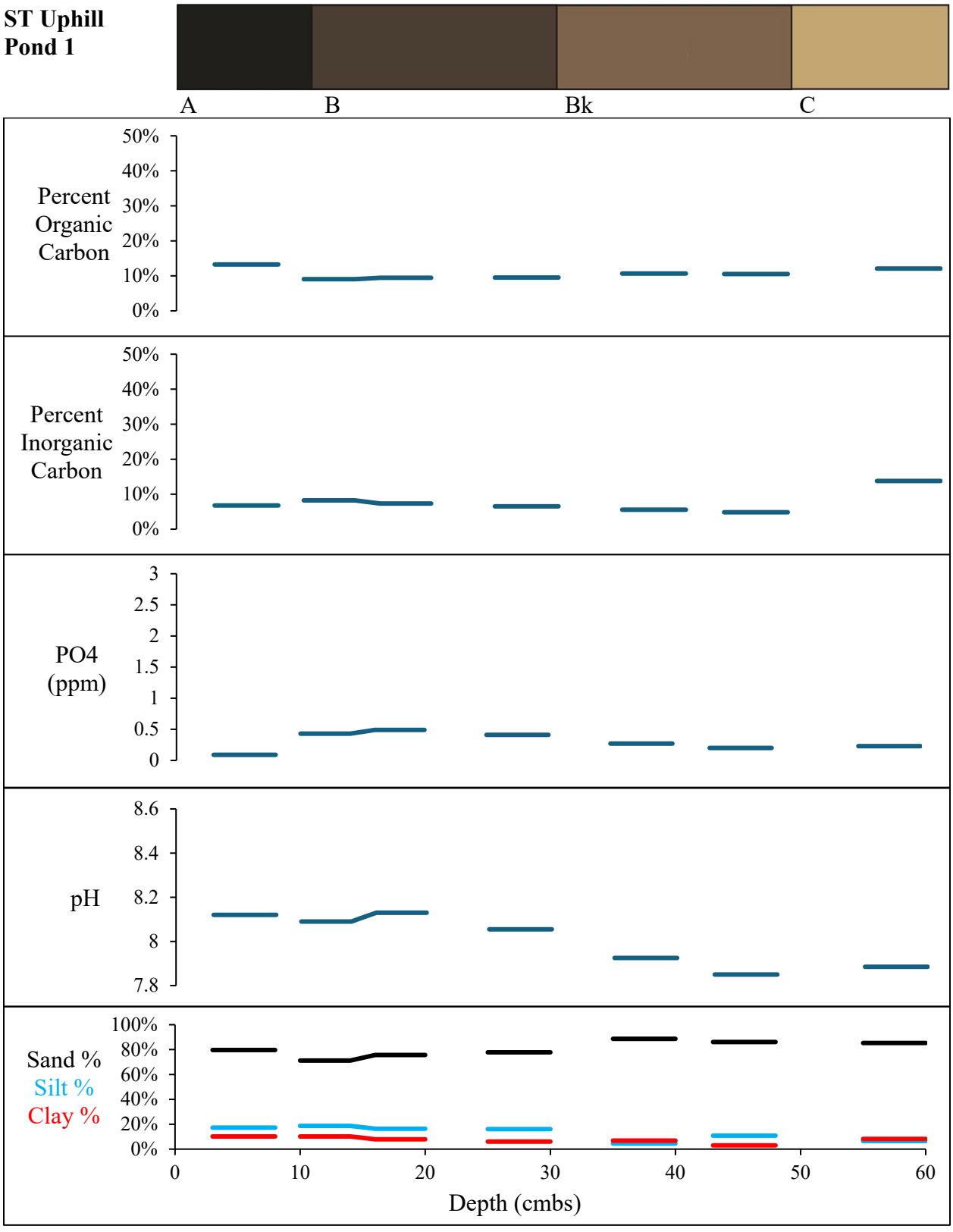
Table C-11.1. ST Uphill Pond 1 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	Environs consist of white manjacks to northwest, north, southwest, south, east, and northeast 3 meters away. Surrounding the test pit is a dense canopy of manjacks. Leaf litter is a bit more than 8% leaves, 15% bark twigs, 5% exposed soil and 2% is live roots and plants. Leaf litter is 2 cm deep. When removed ground surface with 15% live roots, 2% snail shell pieces, and 2% subangular limestone .5" in diameter, 50% clasts .1 cm in diameter while the rest was single grain.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
0-12	I	A	10 YR 2/2 Very	Sandy clay with 5% roots, clasts .5 cm in	3 - 8	79.64/17.30/3.05	Sa/Cl loam	13.25	22.79	6.77	0.07	0.09	0.03	8.12

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
			dark brown	diameter and smaller, less than 1% limestone inclusions .1 cm in diameter angular.										
12 to 34	II	B	10 YR 3/2 Very dark grayish brown	Sandy/clay Color change and presence of 2.25" x 2" limestone, subangular in nature, roots 3% or less, 50% of matrix is clasts. Charcoal piece found at 47 cmbs.	10 - 15 15 - 20 25 - 30	71.18/18.65/10.17 75.67/16.43/7.91 77.82//16.13/6.05	Sa/Cl loam Sa/Cl loam Sa/Cl loam	9.05 9.46 9.52	15.57 16.27 16.37	8.24 7.34 6.55	0.32 0.37 0.31	0.43 0.49 0.41	0.14 0.16 0.13	8.09 8.13 8.07
34-55	III	Bk	10 YR 4/3 Brown	Top of regolith denoted by slight color change, white specking, more dense and presence of larger limestone boulders 3.5" diameter and smaller that are subangular.	35-40 43-48	88.64/4.54/6.82 86.11/10.87/3.02	Sa/Cl loam Loamy sand	10.66 10.54	18.34 18.13	5.56 4.84	0.2 0.15	0.27 0.2	0.09 0.07	7.925 7.85
55-69	IV	C	10 YR 6/4 Light yellowish brown	very weathered parent material small limestone inclusions 1 cm and smaller, 30-40% of soil matrix, no other inclusions.	55-60	85.30/6.49/8.22	Sa/Cl loam	12.09	20.79	13.78	0.17	0.23	0.08	7.885

Figure C-11.1. ST Uphill Pond 1 northeast wall profile. Photograph by author, 7/22/22. Scale bar is in 10 cm segments.

Figure C-11.2. ST Uphill Pond 1 Examined Geochemical and Geophysical Properties



Appendix C-12: ST Downhill Pond 1

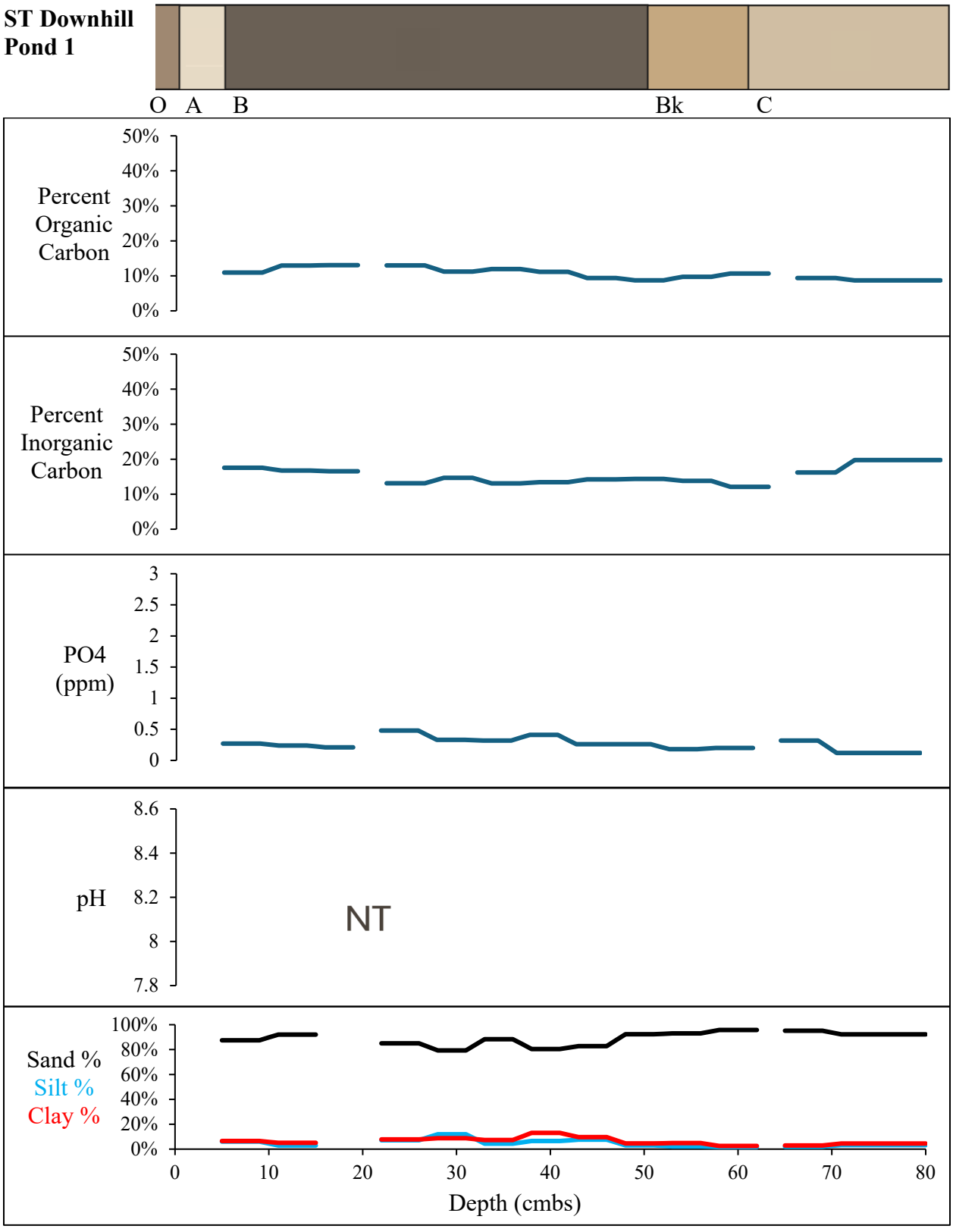
Table C-12.1. ST Downhill Pond 1 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0-4	N/A	O	N/A	Located 45m south of watermill, assumed to be in cane during the svitzer era as per the photos. Here area slopes to 66 degrees (northeast), 5% or so. Unit surrounded by white manjack on all sides, similar to ST Swamp 1. The ghut is to the northwest (bearing of 300 degrees) Measurements taken from middle of western wall, where there is a large bump up to just 4 cmbs	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
4 to 15	I	A	10 YR 5/2 Grayish brown	N/A	5-10 10-15	87.50/6.00/6.50 92.00/2.91/5.09	Sa/Cl loam Loamy sand	10.94 12.95	18.82 22.27	17.54 16.76	0.2 0.18	0.27 0.24	0.09 0.08	NT
15-19	II	B	10 YR 8/2 Very pale brown	N/A	15-19	NT	NT	13.06	22.46	16.54	0.16	0.21	0.07	NT
19-57	III	Bk	10 YR 4/1 Dark gray	N/A	22-27 27-32 32-37 37-42 42-47	85.02/7.13/7.85 79.32/11.93/8.75 88.37/4.36/7.27 80.41/6.53/13.06 82.75/7.59/9.66	Sa/Cl loam Sa/Cl loam Sa/Cl loam Sa/Cl loam Sa/Cl loam	12.99 11.21 11.95 11.16 9.39	22.34 19.28 20.38 19.20 16.15	13.11 14.68 13.09 13.45 14.22	0.36 0.25 0.24 0.31 0.19	0.48 0.33 0.32 0.41 0.26	0.16 0.11 0.1 0.13 0.08	NT

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
					47-52 52-57	92.34/3.06/4.60 92.98/2.16/4.86	Loamy sand Loamy sand	8.73 9.72	15.02 16.72	14.35 13.82	0.18 0.14	0.26 0.18	0.08 0.06	
57-70	IV	C1	10 YR 6/3 Pale brown	Sand with some iron splotches.	57-62 65-70	95.75/1.70/2.55 95.11/1.96/2.94	Sand Sand	10.68 9.39	18.37 16.15	12.10 16.20	0.15 0.24	0.2 0.32	0.06 0.11	NT
66-84	V	C2	10 YR 7/2 Light gray	Transition turns to marl.	70-80	92.24/3.23/4.53	Loamy sand	8.71	14.98	19.75	0.09	0.12	0.04	NT

Figure C-12.1. ST Downhill Pond 1 west wall profile. Photograph by author, 7/25/22, Scale bar is in 10 cm segments.

Figure C-12.2. ST Downhill Pond 1 Examined Geochemical and Geophysical Properties



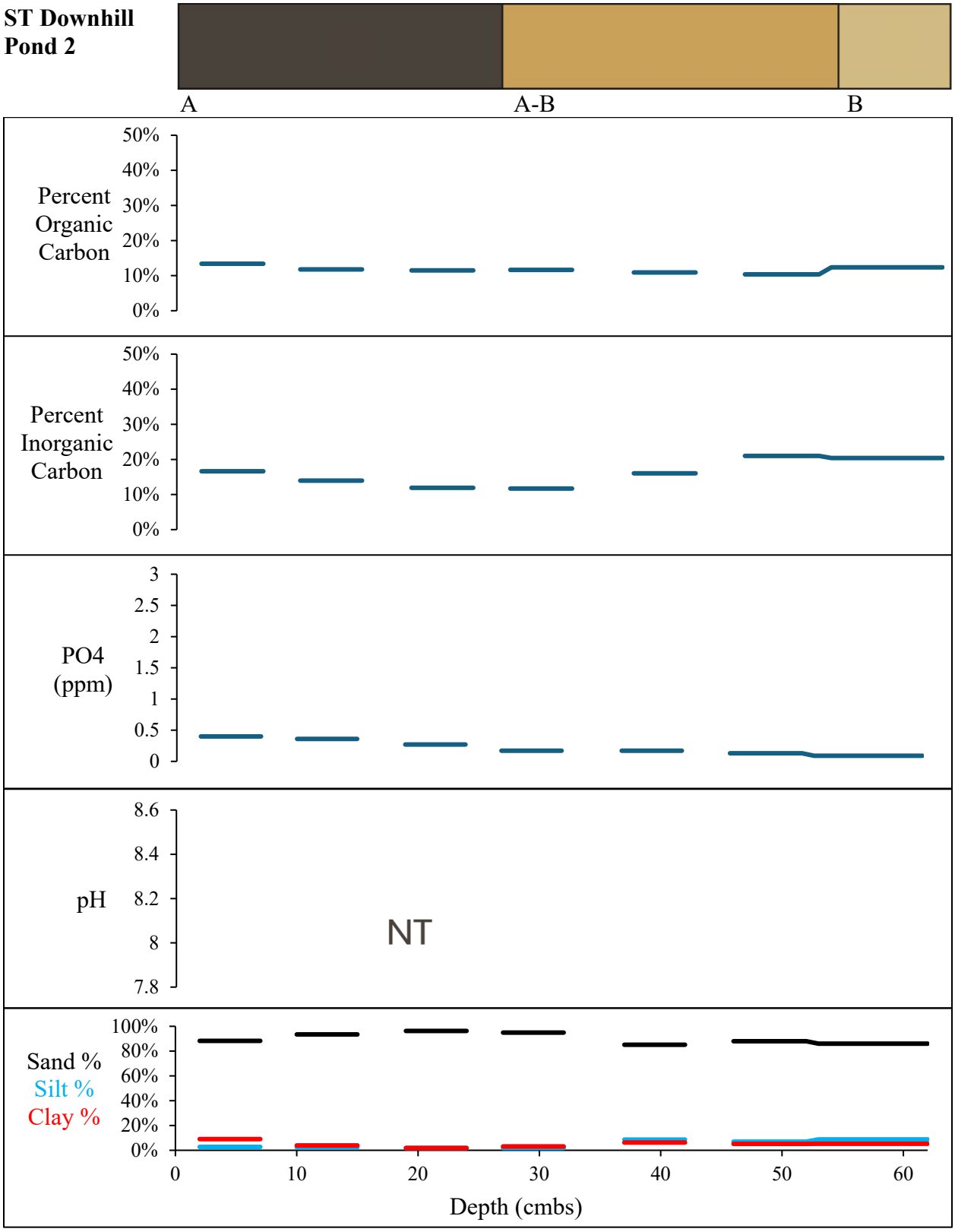
Appendix C-13: ST Downhill Pond 2

Table C-13.1. ST Downhill Pond 2 field observations and lab test results.

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	11m north of the test unit is the ELP's ghut. Manjack line both sides of the ghut. Tantan lies to the south. Manjack canopy on north and tantan to the south.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
0-26	I	A Horizon	10 YR 3/1 Very dark gray	80% peds 2 cm in diameter and smaller	2-7 10-15 19-24	88.25/2.71/9.04 93.41/2.4/3.95 96.27/1.86/1.86	Sa/Cl loam Loamy sand Sand	13.38 11.78 11.48	23.01 20.26 19.75	16.63 13.94 11.91	0.3 0.27 0.2	0.4 0.36 0.27	0.13 0.12 0.09	NT
26-53	II	A-B Transition Horizon	10 YR 6/6 Brownish yellow, mottled 10 YR 3/1 Very dark gray	N/A	27-32 37-42 46-52	94.95/1.89/3.16 85.13/8.58/6.29 87.92/6.91/5.18	Sand Sa/Cl loam Sa/Cl loam	11.63 10.89 10.36	20.00 18.73 17.82	11.70 16.04 21.00	0.13 0.12 0.12	0.17 0.17 0.17	0.06 0.05 0.05	NT
53-62	III	B Horizon	10 YR 7/4 Very pale brown	1% or less Limestone pebble less than half a cm in diameter, round, shell, 70% peds 2 cm and small in diameter, no inclusions, transition is extensive and patchy.	53-62	85.96/8.77/5.26	Sa/Cl loam	12.37	21.28	20.41	0.07	0.09	0.03	NT

Figure C-13.1. ST Downhill Pond 2 east wall profile. Photograph by author, 7/28/22. Scale bar is in 10 cm segments.

Figure C-13.2. ST Downhill Pond 2 Examined Geochemical and Geophysical Properties



Appendix C-14: ST Swamp 1

Table C-13.1. ST Swamp 1 field observations and lab test results.

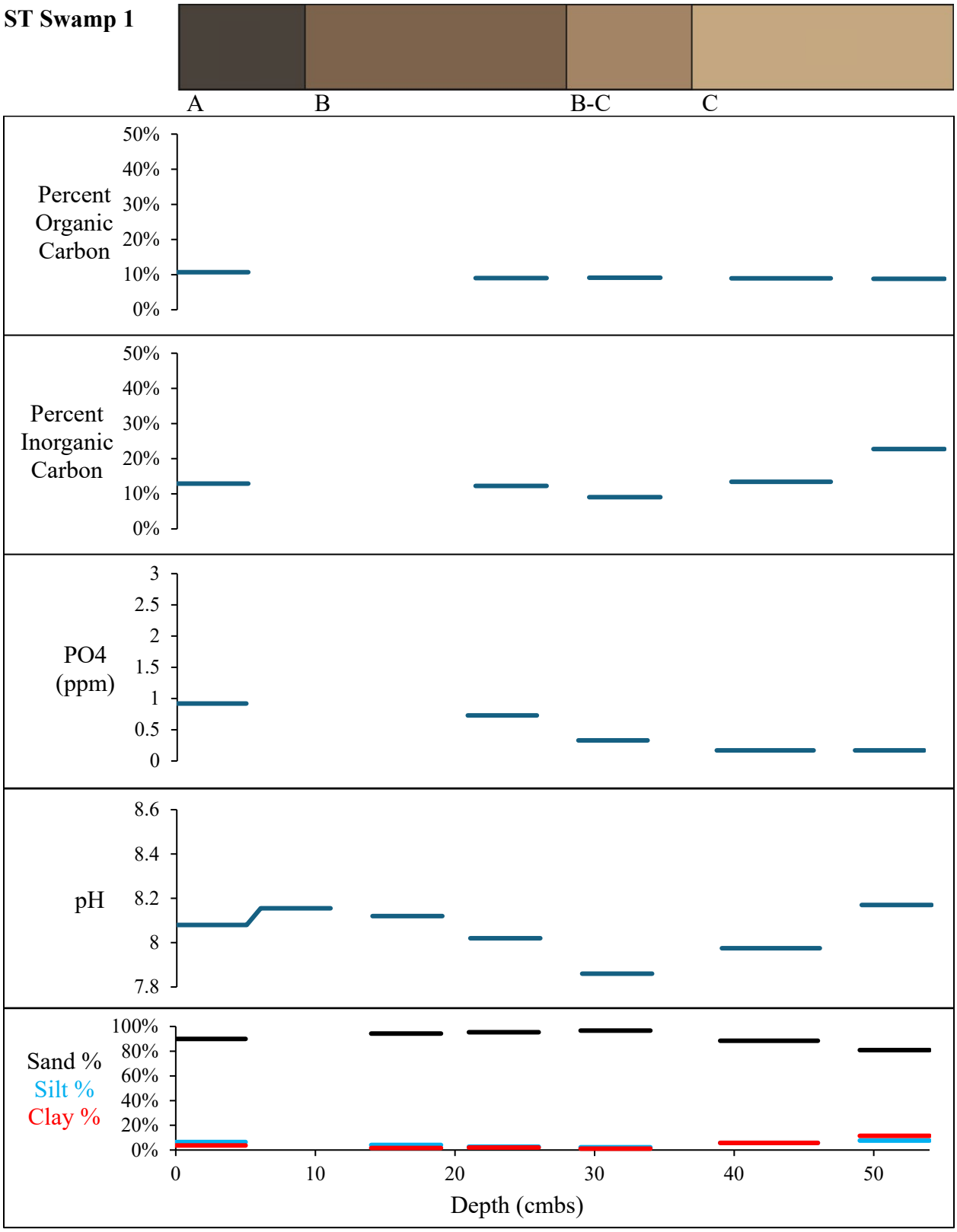
Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
0	N/A	O	N/A	~9m north of the ELP ghut, and located in a white manjack swamp. ST is located ~11m south of a line of sanseveria. The past high level of the ghut is clearly demarcated with moss or algae growing on the rocks on the banks. The plantation's bridge is just to the east and downstream of this location.	NS	NS	NS	NS	NS	NS	NS	NS	NS	
0-12	I	A	10 YR 3/1 Very dark gray	Canopy here is dense with manjacks all with lots of leaves. Ground cover is 70% leaves, 28% broken twigs and bark, 1% shell and 1% small plants. Once the leaf litter is removed, 80% clasts 1 cm in diameter and smaller, most less than .5 cm diameter, also	0-5	89.91/6.43/3.66	Sandy Loam	10.69	18.39	12.92	0.69	0.92	0.3	8.08

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				present subangular limestones 3.5 cm long by 1.5 cm wide, rounded 7.5 cm x 4.5 cm limestone, 1% rocks, 1% shell, and 1 % crab skeleton. Structure is mostly single grain.										
12 to 37	II	B	10 YR 4/3 Brown	roots occupying approximately 8%, less than .1 cm limestone inclusions and smaller 1% and oolite clasts .2 cm and smaller 30%, remainder is single grain.	14-19 21-26 29-34	94.28/4.06/1.65 95.31/2.68/2.01 96.65/2.23/1.12	Sand Sa/Cl loam Sa/Cl loam	NT 9.01 9.13	NT 15.50 15.70	NT 12.24 9.04	NT 0.54 0.25	NT 0.73 0.33	NT 0.24 0.11	8.12 8.02 7.86
37-49	III	Transition from B to C	10 YR 5/3 Brown	Transition from A to B is abrupt in color, B is far lighter, roots count is down to 5% though same size clasts as above. Cut off at solid color.	39-46	88.43/5.78/5.78	Sa/Cl loam	8.93	15.36	13.42	0.13	0.17	0.06	7.975
49-74	IV	C	10 YR 6/3 Pale brown	Is the transition from II to IV, and is gradual in nature, slowly changing to a lighter color at the bottom.	49-54	80.87/7.65/11.48	Sa/Cl loam	8.81	15.15	22.74	0.13	0.17	0.06	8.17

Depth of Stratum in cmbs	Strat #	USDA Horizon	Munsell Color	Excavation Notes	Bulk Sample Depths	Sand/Silt/Clay	USDA Soil Classification	Organic Carbon %	Estimated Soil Organic Matter (SOM) %	In-Organic Carbon %	P2O5 (mg/L)	PO4 (mg/L)	P (mg/L)	pH
				Roots 2%, clasts appear the same. There is also little white specking, thought to be calcium or calcification, beneath this stratum is pure marl much lighter than III or II										

Figure C-14.1. ST Swamp 1 west wall profile. Photograph by author, 7/18/22. Scale bar is in 10 cm segments.

Figure C-13.2. ST Downhill Pond 2 Examined Geochemical and Geophysical Properties



Appendix D. Radiocarbon Date Results

Radiocarbon Date Results Note: calibrated using OxCal v 4.4.4. which follows Ramsey 2001 and Atmospheric data from Reimer et al 2020. All years calculated were rounded up to the nearest 1 year. Radiocarbon date probability charts demonstrating this calibration, and the dates selected for use in the analysis within this dissertation are presented below, in order of RCD number as delivered to the lab in which they were tested.

Table D-1. ST 4 Radiocarbon dates – Specimen name ELP-RCD#1 ST4-Shell 1

from Strat IV, exact cmbs unknown (a Relic B horizon underneath an alluvial deposit)
95.4% probability 577 cal AD ± 26 years

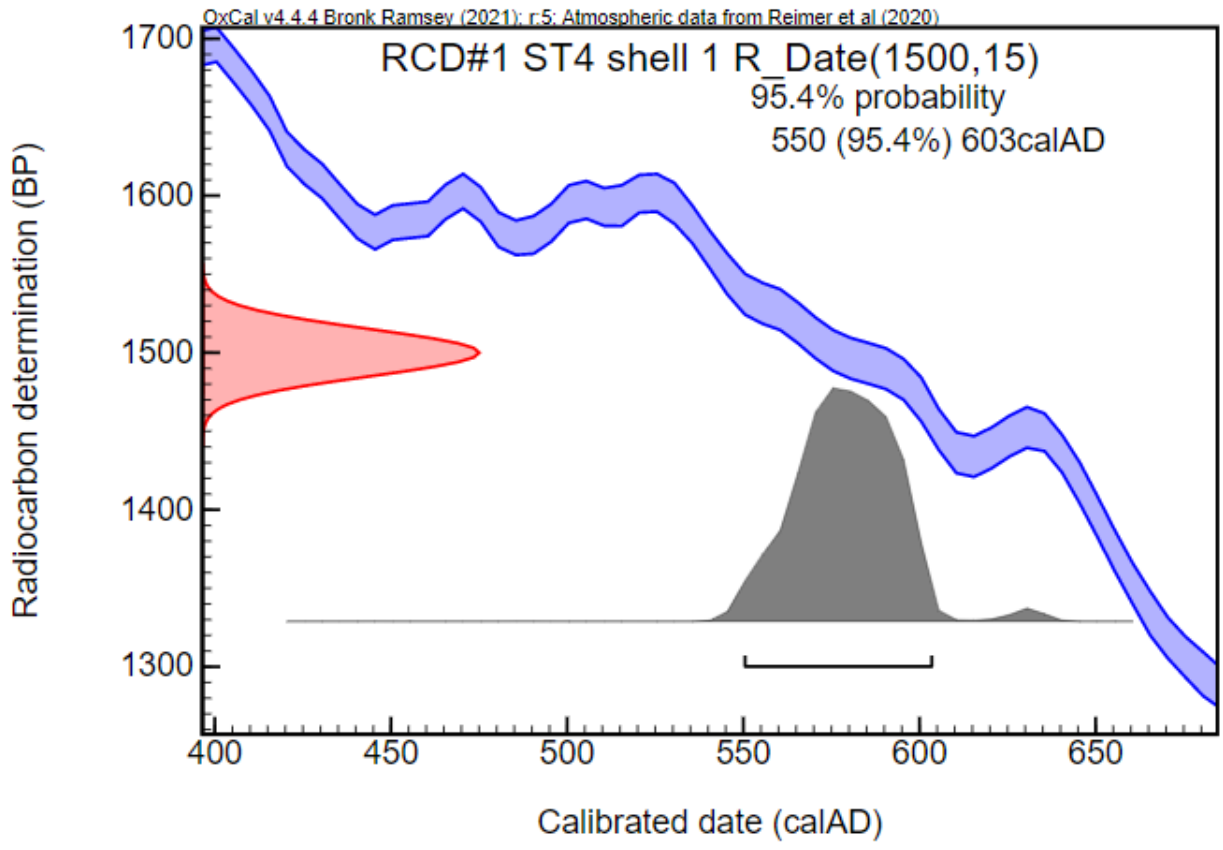


Table D-2. ST 8 Radiocarbon dates – Specimen name ELP-RCD #11 ST 8–Shell 1

From Top of Strat II, B horizon, Exact cmbs unknown
5.5% probability 5,603 calBC ± 6 years
90% probability 5,519 calBC ± 41 years

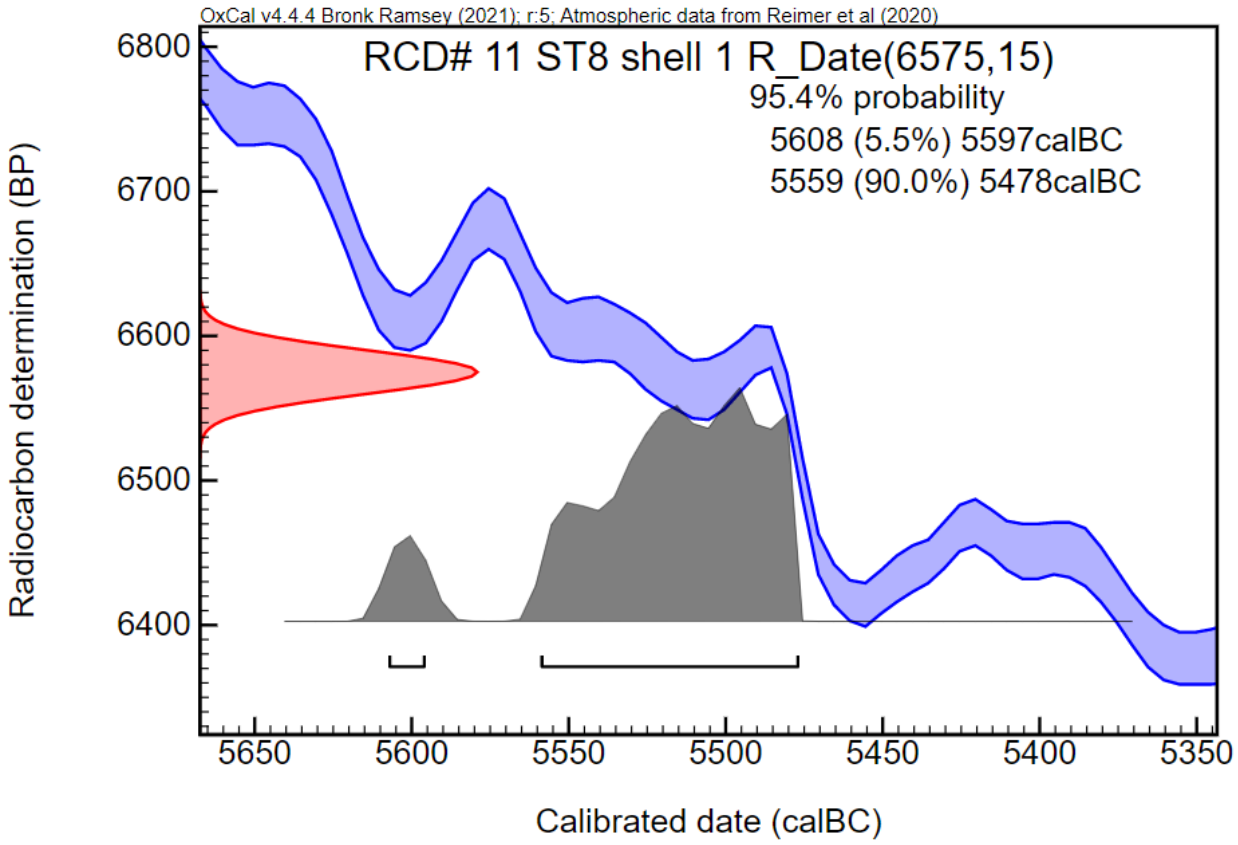


Table D-3. ST 9 Radiocarbon dates – Specimen name ELP-RCD # 4 ST 9-Shell 1

38 – 43 cmbs, Strat III, B horizon (from above start of transition from B to C)
95.4% probability 5,785 calBC ± 57 years

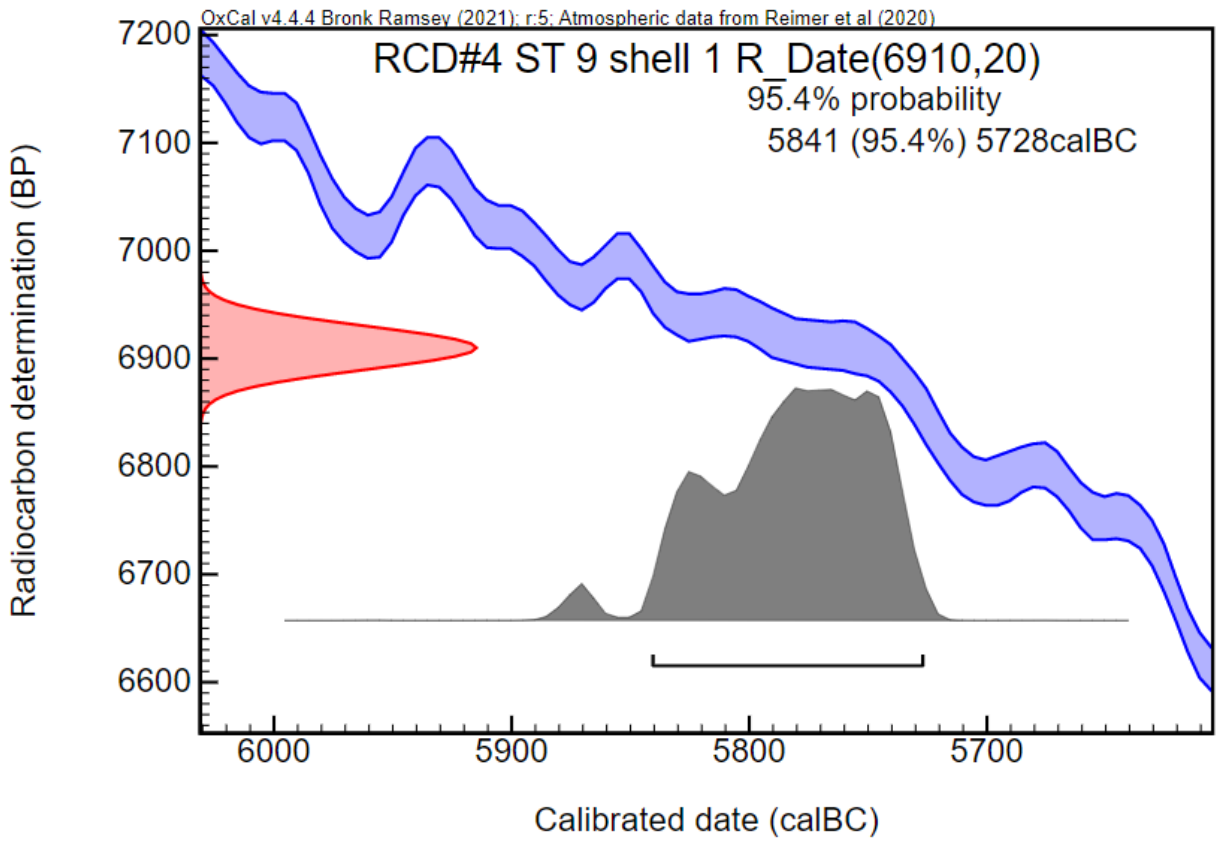


Table D-4. ST 11 Radiocarbon dates – Specimen name ELP-RCD # 7 ST 11-Shell 1

13.5 – 23 cmbs homogenized sample, several shell bits kept with the generic bulk, Strat II/ B horizon
95.4% probability 10,624 calBC ± 42 years
19.6% probability 10,530 calBC ± 46 years
6.9% probability 10,390 calBC ± 13 years
7.4% probability 10,337 calBC ± 32 years
6.3% probability 10,263 calBC ± 31 years

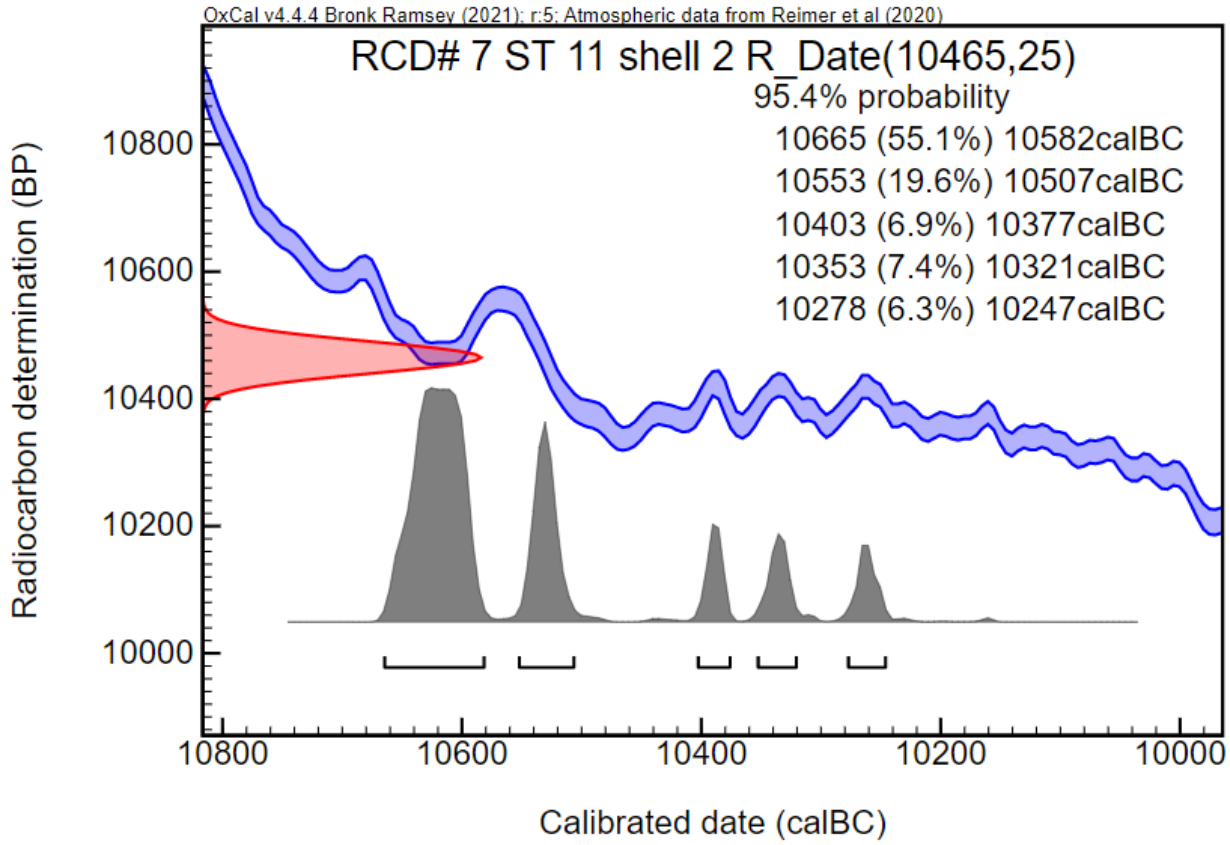


Table D-5. ST Uphill Pond 2 Radiocarbon dates – Specimen name ELP-RCD # 13 ST Uphill Pond 2-Shell 1

20 cmbs Strat II from the top of B horizon
95.4% probability 1,285 calAD ± 24 years

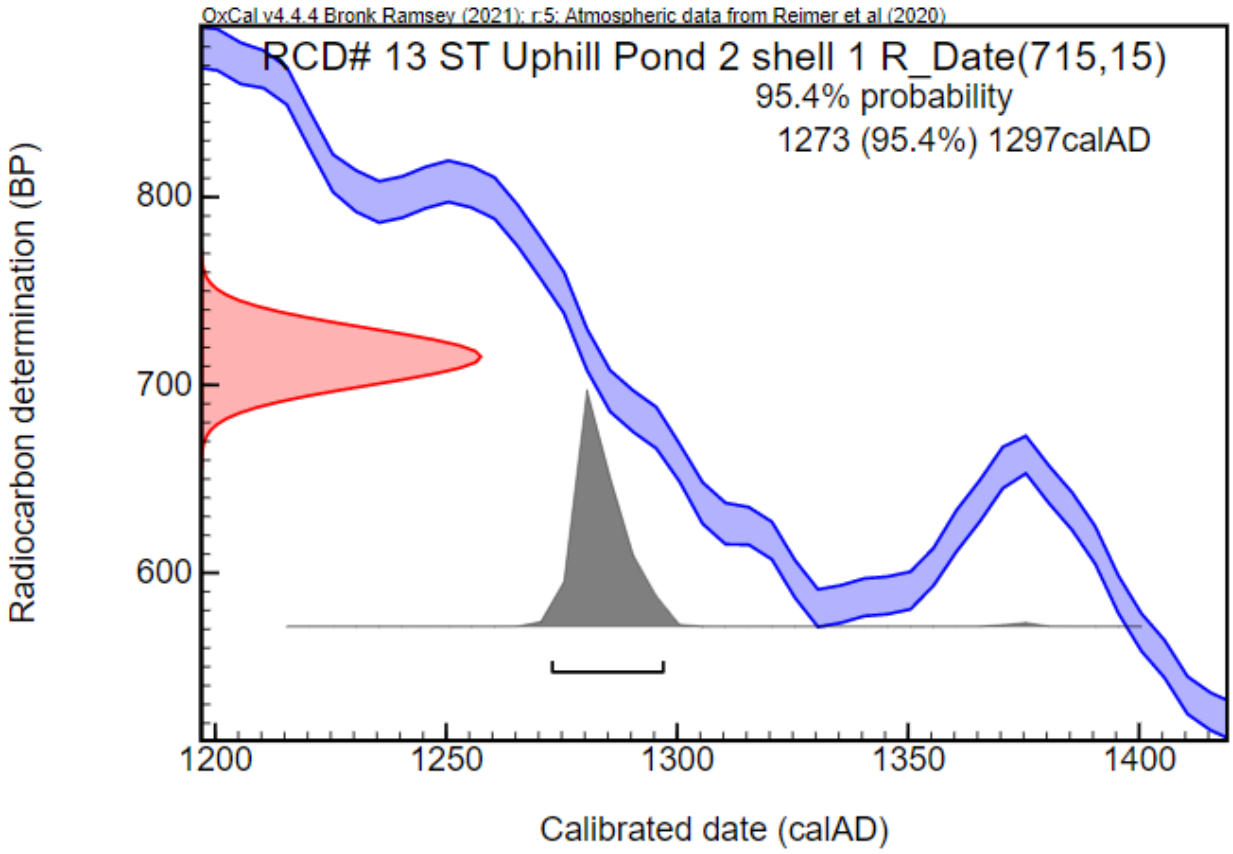


Table D-6. ST Uphill Pond 2 Radiocarbon dates – Specimen name ELP-RCD # 14 ST Uphill Pond 2-Shell 2

28 cmbs Strat II, middle of B horizon
95.4% probability 74 calAD ± 48.5 years

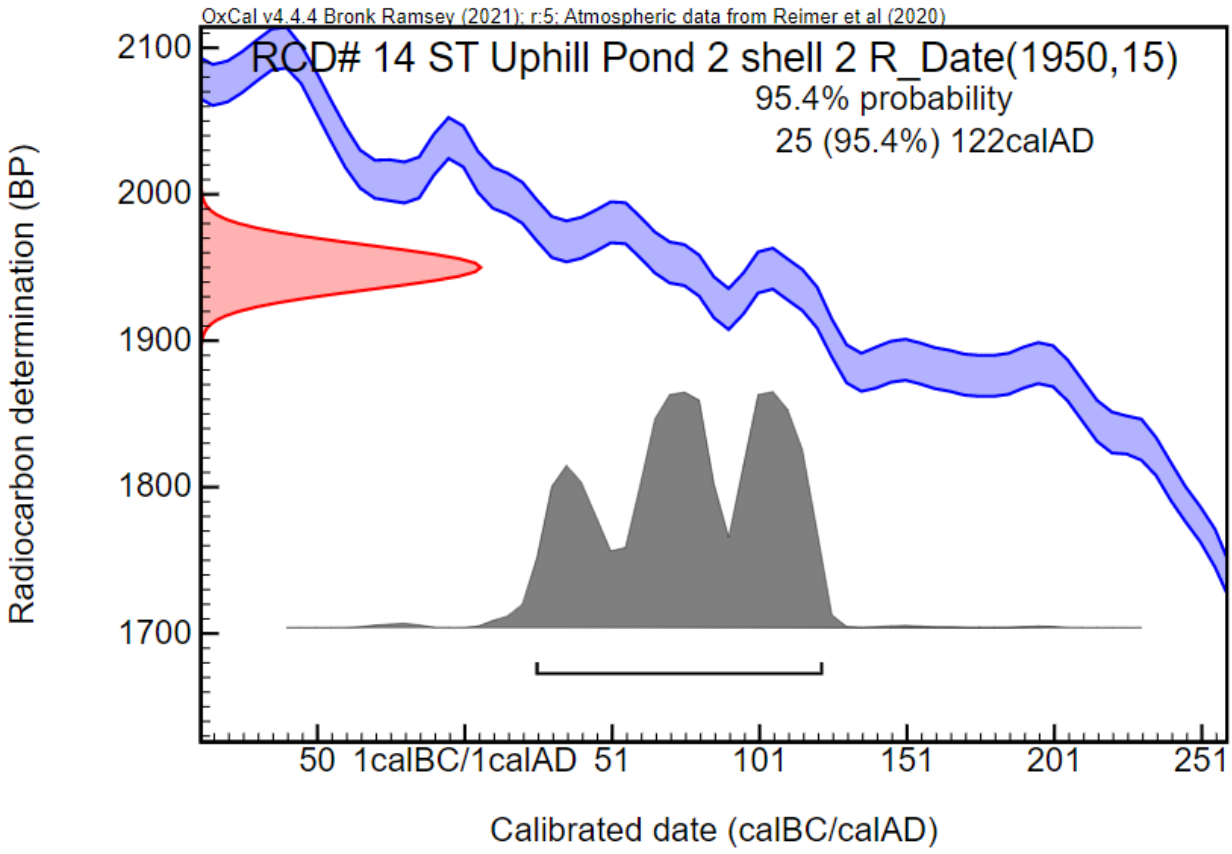


Table D-7. ST Uphill Pond 1 Radiocarbon dates – Specimen name ELP-RCD # 16 ST Uphill Pond 1-Charcoal 2

15 cmbs Strat II top of B horizon
71.9% probability 1870 calAD ± 68 years (as recent as 1938, as early as 1802)
23.6% probability 1710 calAD ± 28 years (as recent as 1838, as early as 1682)

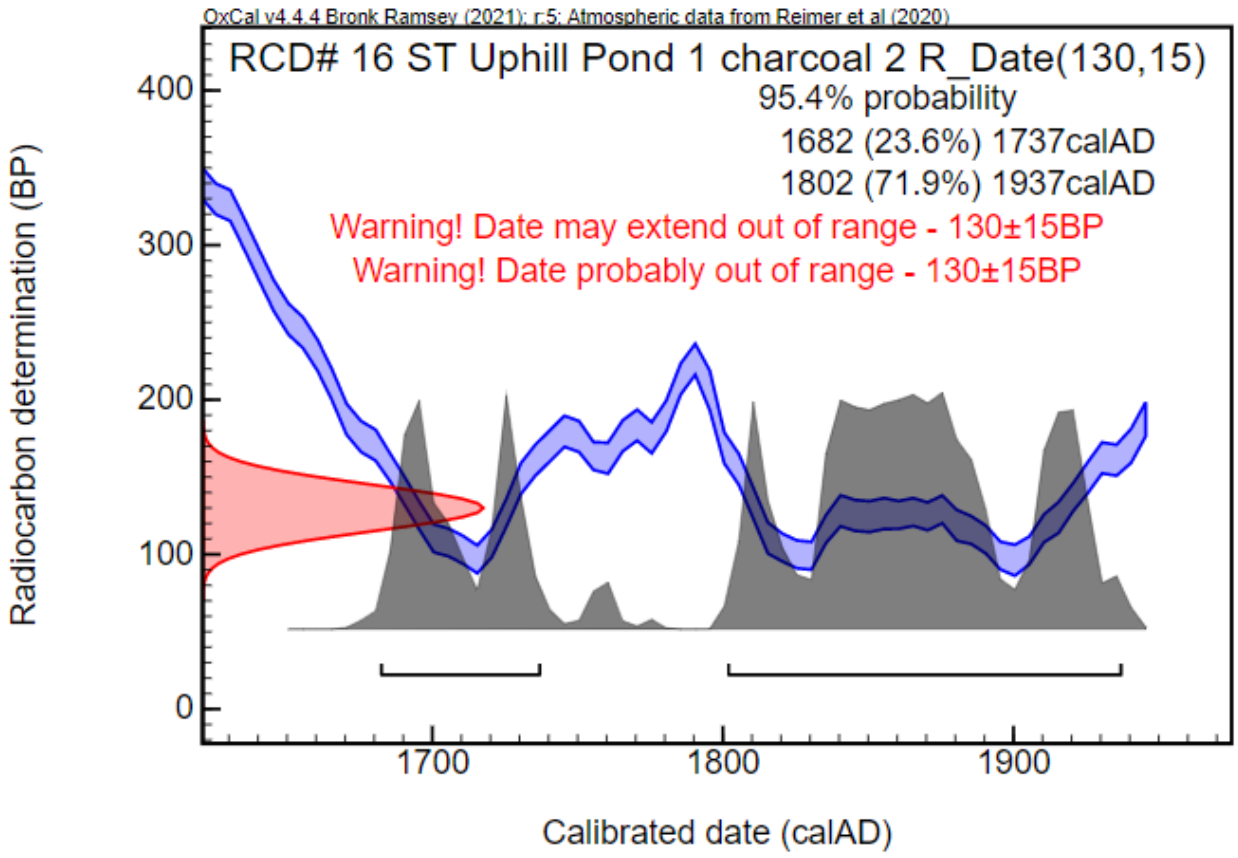
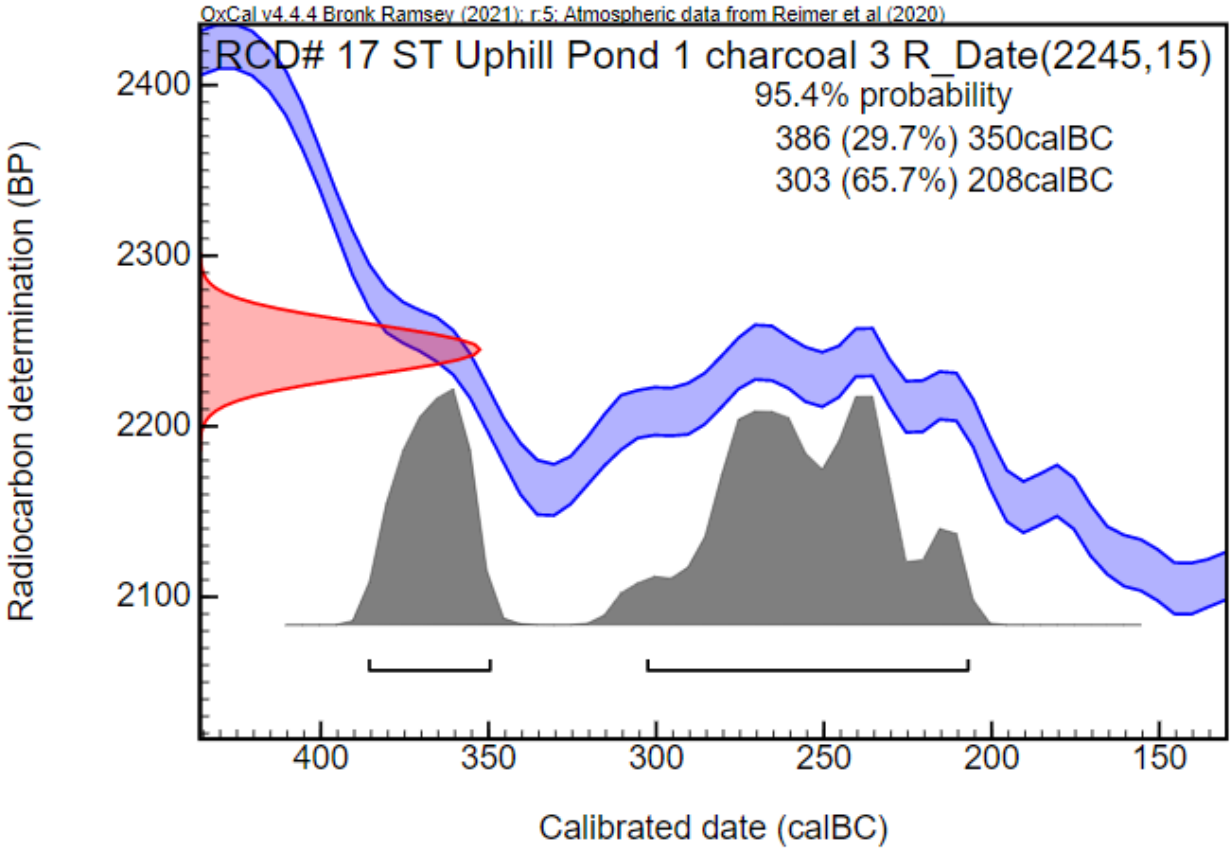


Table D-8. ST Uphill Pond 1 Radiocarbon dates – Specimen name ELP-RCD # 17 ST Uphill Pond 1-Charcoal 3

47 cmbs Strat II bottom of B horizon
65.7% probability 256 calBC ± 48 years
29.7% probability 368 calBC ± 36 years



Appendix E. Comparative Table with Results from All Lab Tests Conducted for 14 Representative Shovel Tests

Table E-1. Summary table for all laboratory testing results

ST	Depth of Stratum in cmbs	Strat #	USDA Horizon	Bulk Sample Depths	Munsell Color	pH	Sand/Silt/Clay %	USDA Soil Type	Organic Carbon %	Inorganic Carbon %	PO4 (mg/L)
ST HZ	0	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS
ST HZ	0-11	I	A	0-11	10 YR 3/2 Very dark grayish brown	7.95	83.61/16.39/0	Sand	14.72	25.16	2.75
ST HZ	11-34	II	C	11-34	10 YR 8/2 Very pale brown	8.5	NT	NT	2.45	40.63	NT
ST HZ+1	0	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS
ST HZ+1	0-32	I	A	0-32	10 YR 3/2 Very dark grayish brown	8.015	90.39/9.14/0.48	Sand	10.8	19.71	2.75
ST HZ+1	26.5-38.5	II	B	26.5-38.5	7.5 YR 4/4 Brown	8.32	86.50/13.27/0.24	Sand	9.52	18.75	2.75
ST HZ+1	30-51	III	C	30-51	7.5 YR Pink	NT	NT	NT	NT	NT	NT
ST HZ+5	0	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS
ST HZ+5	0-13	I	A	0-13	10 YR 2/2 Very dark brown	8.025	85.23/14.43/0.34	Sand	12.59	15	2.75
ST HZ+5	13-26	II	B	13-26	10 YR 4/2 Dark grayish brown	8.34	88.94/10.64/0.44	Sand	9.29	10.56	2.75
ST HZ+5	26-40	III	Bk	26-40	7.5 YR 3/4 Dark brown	8.36	79.675/20.183/0.141	Loamy sand	8.11	3.85	2.75
ST HZ+5	40-46	IV	C	40-46	7.5 YR pink	NS	NS	NS	NS	NS	NS
ST HZ+7	0	N/A	O	NS	N/A	NT	NS	NS	NS	NS	NT
ST HZ+7	0-18	I	A	0-18	7.5 YR 2.5/1 Black	7.96	NT	NT	13.89	13.21	0.81
ST HZ+7	18-30	II	B	18-30	7.5 YR 4/4 Brown	8.11	NT	NT	11.99	11.44	0.49
ST HZ+7	30-60	III	Bk	30-60	7.5 YR 5/4 Light brown	NS	NS	NS	NS	NS	NS
ST HZ+7	60	IV	C	NS	10 YR 5/4 yellowish brown	NS	NS	NT	NS	NS	NS
ST 3	0-6	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS
ST 3	6-17	I	A	6 - 12	10 YR 3/2 Very dark grayish brown	NT	NT	NT	19.28	25.16	0.46
ST 3				12 -17					16.41	NT	0.34
ST 3	17-35	II	B	18-22	10 YR 3/4 Dark yellowish brown	NT	NT	NT	6.77	6.07	0.23
ST 3				23-28					6.05	6.27	0.31
ST 3				28-32					NT	NT	NT
ST 3				29-34					6.41	6.48	0.25
ST 3	35-40	III	B to C Transition	33-38	10 YR 5/4 Yellowish brown	NT	NT	NT	6.48	15.52	0.15
ST 3	40-68	IV	C	43-48	10 YR 7/3 Very pale brown	NT	NT	NT	2.85	32.37	0.13
ST 3				53-58					3.79	24.12	0.12
ST 3				63-68					4.93	23.49	0.14
ST 4	0-7	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS

ST	Depth of Stratum in cmbs	Strat #	USDA Horizon	Bulk Sample Depths	Munsell Color	pH	Sand/Silt/Clay %	USDA Soil Type	Organic Carbon %	Inorganic Carbon %	PO4 (mg/L)
ST 4	7-14	I	A	7-14	10 YR 3/4 Dark yellowish brown	7.94	76.87/22.95/0.18	Loamy sand	10.31	3.04	0.25
ST 4	14-23	II	C	14-23	10 YR 3/3 Dark brown	8.185	NT	NT	5.33	3.29	0.04
ST 4	23-31	III	Alluvium deposited cobbles	23-31	10 YR 5/4 Yellowish brown	8.335	91.85/7.80/0.35	Sand	6.92	19.4	0.04
ST 4	31-38	VII	Alluvium	31-38	10 YR 6/2 Light brownish gray	7.92	82.96/16.79/0.25	Loamy Sand	7.13	6.5	0.25
ST 4	38-51.5	IV	Alluvium deposited cobbles	36-48	10 YR 2/2 Very dark brown	7.905	77.1/22.42/0.48	Loamy Sand	7.02	7.8	0.19
ST 4	51.5-58	V	Relic B	51.5-58	10 YR 3/3 Dark brown	7.99	75.45/22.50/2.04	Loamy Sand	7.45	16.03	0.04
ST 4	58	VI	C	58-79	10 YR 6/3 Pale brown	8.045	56.02/43.98/0.46	Silt loam	6.47	29.45	0.07
ST 8	0-10	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS
ST 8	10-16	I	A	13-15	10 YR 3/2 Very dark greyish brown	8.08	92.68/7.13/0.19	Sand	11.51	11.9	0.37
ST 8	16-30	II	B	17-22	10 YR 3/3 Dark brown	8.27	81.66/16.17/1.03	Loamy sand	7.71	12.27	0.27
ST 8				23-28		8.35	87.61/11.45/0.93	Sand	7.17	13.95	0.21
ST 8	30-41	III	Bk	31-36	10 YR 4/3 Brown with white small inclusions which are 10 YR 8/2 Very pale brown	8.42	78.19/18.92/2.89	Loamy sand	7.9	14.86	0.23
ST 8									6.61	20.07	0.19
ST 8	41-74	IV	Bk to C Transition	41-44 45-50	10 YR 8/3 Very pale brown- modeled with 10 YR 4/4 Yellowish brown	8.46	76.58/20.60/2.82	Loamy sand	4.74	29.79	0.09
ST 8				58-62		8.39	86.33/13.62/0.05	Sand	3.54	30.22	0.08
ST 8				68-74		8.42	94.88/5.08/0.04	Sand	NT	NT	NT
ST 8	74	V	C	NS	10 YR 8/4	NS	NS	NS	NS	NS	NS
ST 9	0-6	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS
ST 9	6-16.5	I	A	45453	10 YR 3/2 Very dark grayish brown	8.02	85.96/13.63/0.43	Sand	10.25	16.07	0.43
ST 9				45612		7.96	82.34/17.02/0.65	Loamy sand	9.86	16.29	0.45
ST 9	16.5-37.5	II	B	18-23	10 YR 3/3 Dark brown	8.05	86.02/13.31/0.68	Sand	7.6	16.85	0.28
ST 9				25-30		8.17	76.81/21.56/1.63	Sandy loam	6.12	18.37	0.29
ST 9				31.5-36.5		8.3	78.20/21.00/0.80	Sandy loam	6.59	18.13	0.26
ST 9	37.5-49.5	III	Bk	38-43	10 YR 8/3 Very pale brown	8.37	92.14/7.75/0.11	Sand	6.45	19.51	0.34
ST 9				43-48		8.47	94.67/5.30/0.03	Sand	5.76	26.32	0.12
ST 9	49.5-74.5	IV	C	51.5-56.5	10 YR 3/3 Very pale brown	8.51	89.41/10.24/0.35	Sand	4.21	31.51	0.13
ST 9				69.5-74.5		8.6	90.27/9.69/0.05	Sand	3.68	34.78	0.15
ST 11	0	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS

ST	Depth of Stratum in cmbs	Strat #	USDA Horizon	Bulk Sample Depths	Munsell Color	pH	Sand/Silt/Clay %	USDA Soil Type	Organic Carbon %	Inorganic Carbon %	PO4 (mg/L)
ST 11	0-13.5	I	A	0-13.5	10 YR 3/3 Dark brown	8.41	NT	NT	NT	NT	NT
ST 11	13.5-23	II	B	13.5-23	10 YR 4/4 Dark yellowish brown	8.5	NT	NT	NT	NT	NT
ST 11	23-38	III	C1	23-38	10 YR 7/4 Very pale Brown	8.41	NT	NT	NT	NT	NT
ST 11	38-63	IV	C2	38-63	10 YR 7/3 Very pale brown	8.33	NT	NT	NT	NT	NT
ST Uphill Pond 2	0	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS
ST Uphill Pond 2	0-19	I	A	5-10	1O YR 5/1 Gray	8.015	84.68/10.94/4.38	Sa/Cl loam	13.53	10.24	0.62
ST Uphill Pond 2	19-39	II	B	20-25	10 YR 4/1 Dark gray	7.965	88.24/6.47/5.29	Sa/Cl loam	9.98	8.64	0.27
ST Uphill Pond 2				26-31		7.947	88.84/7.44/3.72	Loamy sand	9.44	8.31	0.29
ST Uphill Pond 2				32-37		7.88	93.29/4.13/2.58	Sa/Cl loam	10.25	6.35	0.24
ST Uphill Pond 2	39-52	III	Bk	Top of Transition from II to III (B to C) 39-45	!0 YR 5/4 Yellowish brown	7.85	92.18/3.91/3.91	Sandy loam	9.01	3.24	0.13
ST Uphill Pond 2				Part of Transition from II to III (B to C) 46-51		7.805	96.11/1.56/2.33	Sand	8.27	3.22	0.14
ST Uphill Pond 2	52-69	IV	C	53-58	10 YR 6/2 Light brownish gray	7.865	88.31/6.50/5.20	Sa/Cl loam	11.61	12.74	0.18
ST Uphill Pond 1	0	N/A	O	NS	N/A	NS	NS	NS	NS		NS
ST Uphill Pond 1	0-12	I	A	3-8	10 YR 2/2 Very dark brown	8.12	79.64/17.30/3.05	Sa/Cl loam	13.25	6.77	0.09
ST Uphill Pond 1	12-34	II	B	10-15	10 YR 3/2 Very dark grayish brown	8.09	71.18/18.65/10.17	Sa/Cl loam	9.05	8.24	0.43
ST Uphill Pond 1				15-20		8.13	75.67/16.43/7.91	Sa/Cl loam	9.46	7.34	0.49
ST Uphill Pond 1				25-30		8.07	77.82//16.13/6.05	Sa/Cl loam	9.52	6.55	0.41
ST Uphill Pond 1	34-55	III	Bk	35-40	10 YR 4/3 Brown	7.925	88.64/4.54/6.82	Sa/Cl loam	10.66	5.56	0.27
ST Uphill Pond 1				43-48		7.85	86.11/10.87/3.02	Loamy sand	10.54	4.84	0.2
ST Uphill Pond 1	55-69	IV	C	55-60	10 YR 6/4 Light yellowish brown	7.885	85.30/6.49/8.22	Sa/Cl loam	12.09	13.78	0.23
ST Downhill Pond 1	0-4	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS

ST	Depth of Stratum in cmbs	Strat #	USDA Horizon	Bulk Sample Depths	Munsell Color	pH	Sand/Silt/Clay %	USDA Soil Type	Organic Carbon %	Inorganic Carbon %	PO4 (mg/L)
ST Downhill Pond 1	4 to 15	I	A	5-10	10 YR 5/2 Grayish brown	NT	87.50/6.00/6.50	Sa/Cl loam	10.94	17.54	0.27
ST Downhill Pond 1				10-15			92.00/2.91/5.09	Loamy sand	12.95	16.76	0.24
ST Downhill Pond 1	15-19	II	B	15-19	10 YR 8/2 Very pale brown	NT	NT	NT	13.06	16.54	0.21
ST Downhill Pond 1	19-57	III	Bk	22-27	10 YR 4/1 Dark gray	NT	85.02/7.13/7.85	Sa/Cl loam	12.99	13.11	0.48
ST Downhill Pond 1				27-32			79.32/11.93/8.75	Sa/Cl loam	11.21	14.68	0.33
ST Downhill Pond 1				32-37			88.37/4.36/7.27	Sa/Cl loam	11.95	13.09	0.32
ST Downhill Pond 1				37-42			80.41/6.53/13.06	Sa/Cl loam	11.16	13.45	0.41
ST Downhill Pond 1				42-47			82.75/7.59/9.66	Sa/Cl loam	9.39	14.22	0.26
ST Downhill Pond 1				47-52			92.34/3.06/4.60	Loamy sand	8.73	14.35	0.26
ST Downhill Pond 1				52-57			92.98/2.16/4.86	Loamy sand	9.72	13.82	0.18
ST Downhill Pond 1	57-70	IV	C1	57-62	10 YR 6/3 Pale brown	NT	95.75/1.70/2.55	Sand	10.68	12.1	0.2
ST Downhill Pond 1				65-70			95.11/1.96/2.94	Sand	9.39	16.2	0.32
ST Downhill Pond 1	66-84	V	C2	70-80	10 YR 7/2 Light gray	NT	92.24/3.23/4.53	Loamy sand	8.71	19.75	0.12
ST Downhill Pond 2	0	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS
ST Downhill Pond 2	0-26	I	A	2-7	10 YR 3/1 very dark gray	NT	88.25/2.71/9.04	Sa/Cl loam	13.38	16.63	0.4
ST Downhill Pond 2				10-15			93.41/2.4/3.95	Loamy sand	11.78	13.94	0.36
ST Downhill Pond 2				19-24			96.27/1.86/1.86	Sand	11.48	11.91	0.27
ST Downhill Pond 2	26-53	II	A to B Transition	27-32	10 YR 6/6 Brownish Yellow, mottled 10 YR 3/1 Very dark gray	NT	94.95/1.89/3.16	Sand	11.63	11.7	0.17
ST Downhill Pond 2				37-42			85.13/8.58/6.29	Sa/Cl loam	10.89	16.04	0.17
ST Downhill Pond 2				46-52			87.92/6.91/5.18	Sa/Cl loam	10.36	21	0.17
ST Downhill Pond 2	53-62	III	B	53-62	10 YR 7/4 Very pale brown	NT	85.96/8.77/5.26	Sa/Cl loam	12.37	20.41	0.09
Swamp 1	0	N/A	O	NS	N/A	NS	NS	NS	NS	NS	NS

ST	Depth of Stratum in cmbs	Strat #	USDA Horizon	Bulk Sample Depths	Munsell Color	pH	Sand/Silt/Clay %	USDA Soil Type	Organic Carbon %	Inorganic Carbon %	PO4 (mg/L)
Swamp 1	0-12	I	A	0-5	10 YR 3/1 Very dark gray	8.08	89.91/6.43/3.66	Sandy Loam	10.69	12.92	0.92
Swamp 1	12-37	II	B	14-19	10 YR 4/3 Brown	8.12	94.28/4.06/1.65	Sand	NT	NT	NT
Swamp 1				21-26		8.02	95.31/2.68/2.01	Sa/Cl loam	9.01	12.24	0.73
Swamp 1				29-34		7.86	96.65/2.23/1.12	Sa/Cl loam	9.13	9.04	0.33
Swamp 1	37-49	III	B to C Transition	39-46	10 YR 5/3 Brown	7.975	88.43/5.78/5.78	Sa/Cl loam	8.93	13.42	0.17
Swamp 1	49-74	IV	C	49-54	10 YR 6/3 Pale brown	8.17	80.87/7.65/11.48	Sa/Cl loam	8.81	22.74	0.17